The time loss effect in gaming: An exploration of gamers' time perception from a dual-process perspective

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Thesis submitted in fulfilment of the requirements of Nottingham Trent University for the degree of Doctor of Philosophy

November 2019

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Declaration of originality

The author declares that this thesis content has not been submitted in any other university for a degree. All the work produced within this thesis (i.e., theoretical review, experimental work) have been created solely by the author and is his own work.

Financial Support

The main financial support for this thesis was a three-year fully funded scholarship awarded from the Nottingham Trent University.

Furthermore, the author was also awarded two other grants for the attendance of the 6th edition of the International Conference on Behavioral Addiction (ICBA) which served to disseminate the research produced during this thesis. The first grant (£500) was the Santander's Postgraduate Travel Scholarship and the second one (£300) was the PsyPAG International Conference Bursary.

Dedication

I would like to dedicate this thesis to my older sister **Anne-France Nuyens**. As long as I can remember, she has always been there for me, pushing me forward. When I was only four years old, she started going to high school, and she was so excited about what she just learned that she started teaching me about anything she could. Of course, I could not understand as I was barely learning to read, but her words resounded with such passion that it did not matter that I was too young to understand, I would listen to her happily.

She is now one of the best teachers I know – if not the best – and I can say without any hesitation that I would be proud being half the lecturer she is one day. She has always been, and will always be, my role model in term of success, fighting spirit, and care. She has always been there for me, even during that awkward teenage phase, and I know she will always be there for me.

For all these reasons, and for many more, I am dedicating this journey, this thesis, and my all my past and future achievements to her.

Thank you big sister.

Acknowledgments

In the same way they started this journey of mine, I would like to start by showing my gratitude to my parents **Marion De Landsheer** and **Philippe Nuyens**. For as long as I can remember, they always pushed me forward, made me surpass myself and aim for the best I could achieve. Without their constant care, love, and support, I would never have reached such heights.

Second, I would like to thank my supervisors. First, **Daria Kuss** who contacted me as soon as she knew that two Ph.D. positions just opened in Nottingham Trent University. Without that first email, without her interest and constant support, I would not be writing these lines right now. Second, I would like to thank **Mark Griffiths**, my Director of Studies, who was systematically there for me whenever I needed – even if it was a 10pm panicked email. I also want to thank his eternal patience when it came to my English which has progressed drastically through the hours he spent working on my papers! Finally, even if it was only for one year, I would like to thank **Olatz Fernandez Lopez**, who was extremely caring and supporting. Whenever I saw her, she would take some time to check if I was alright and to cheer me up when I was not.

Another person close to my heart I would like to thank is my partner, **Ashley Leong**. For the past three years, she has always been there for me, listening to me, taking care of me, and supporting my thesis by any mean she could. During these three years in a country I did not know, she has been my pillar, my anchor, and I always knew that no matter how bad a day was, I would go home and be welcomed in her open arms.

I also want to show my gratitude to a multitude of friends who have been there for me, no matter the distance. These friends never gave up on me, even when I left to the United Kingdom, even when I was too busy to reply their messages as fast as I wished. Some of them kept advising me, answering short questions, especially **Jory Deleuze** and **Joël Billieux**. Some of them were simply there to cheer me up when I was feeling down, or play with me when I was alone, such as **Sylvain Toisoul**. But from all of these people, the one I would like to thank the most for her presence, her care, and all the help she provided me from the moment I met her is **Tieu Mi Vo** without who none of this would have been possible.

Finally, I would like to thank all my colleagues here in NTU who have been really helpful and supporting from my first day as a Ph.D. student to this very moment as a newly appointed lecturer. I especially want to thank **Melina Throuvala** who started her Ph.D. at the same time than me – our coffee and conversation really helped me going through this whole thesis!

Last but not least, I want to thank every single participant who came to my experiments. Especially some who came with a smile, happiness, and shared their good mood with me; they probably have no idea, but they really kept me going during the testing phases of this thesis. Also, there are many colleagues, friends, and loved ones that I could not possibly mention who have been there at different point of this journey. Around a coffee, during a Skype, or simply with some small messages, these people helped me, maybe without knowing, to keep going and push trough.

Now, as I start a new step of my life as a lecturer, bringing me closer to achieving my dream of becoming a Professor, I can only say that I did not achieve it by myself, but with the strength and support of all these persons. To everyone who ever helped me achieving this dream of mine, thank you.

List of publications

Peer-reviewed journal papers

Nuyens, F. M., Kuss, D. J., Lopez-Fernandez, O., & Griffiths, M. D. (2017). The experimental analysis of problematic video gaming and cognitive skills: A systematic review. *Journal de Thérapie Comportementale et Cognitive,* 27(3), 110–117. https://doi.org/10.1016/j.jtcc.2017.05.001

Nuyens, F. M., Kuss, D. J., Lopez-Fernandez, O., & Griffiths, M. D. (2018). The empirical analysis of non-problematic video gaming and cognitive Skills: A systematic review. *International Journal of Mental Health and Addiction. 17,* 389-414.https://doi.org/10.1007/s11469-018-9946-0

Nuyens, F. M, Kuss, D. J., Lopez Fernandez, O., & Griffiths, M. D. (2019). The arousing and attentional effects of facial expressions on time perception: A systematic review. *BPS Cognitive Section Bulletin*, 5, in press

Nuyens, F. M., Kuss, D. J., Lopez-Fernandez, O., & Griffiths, M. D. (2019). The potential interaction between time perception and gaming: A narrative review. *International Journal of Mental Health and Addiction.* Epub ahead of print. https://doi.org/10.1007/s11469-019-00121-1

Published abstracts

Nuyens, F. M., Griffiths, M. D., Kuss, D. J., & Lopez-Fernandez, O. (2018). The experimental analysis of problematic video gaming and cognitive skills: A systematic review. *Journal of Behavioral Addictions, 7*(Suppl. 1), 123. https://doi.org/10.1556/JBA.7.2018.Suppl.1

Nuyens, F. M., Kuss, D. J., Lopez Fernandez, O., & Griffiths, M. D. (2019a). Time perception, a potential underlying of time loss effect among gaming disorder. *Journal of Behavioral Addictions, 8*(suppl.1), 138. https://doi.org/10.1556/JBA.8.2019.Suppl.1

Nuyens, F. M., Kuss, D. J., Lopez Fernandez, O., & Griffiths, M. D. (2019b). Time loss: An impaired time perception amongst gamers? *Journal of*

Behavioral Addictions, 8(Suppl.1), 138–139. https://doi.org/10.1556/JBA.8.2019.Suppl.1

Conference papers presented

Nuyens, F. M., Kuss, D. J., Lopez-Fernandez, O., & Griffiths, M. D. (2017, March). *A systematic review on positive and negative cognitive outcomes of videogame play in experiments*. Paper presented at the School of Social Sciences Research Conference: Contemporary Responses to Social Science Issues, Nottingham, United Kingdom.

Nuyens, F. M., Kuss, D. J., Lopez-Fernandez, O., & Griffiths, M. D. (2018, February). *The empirical analysis of non-problematic video gaming and cognitive skills: A systematic review*. Paper presented at the School of Social Sciences Research Conference: Social Sciences Research Cross Disciplinary Perspectives, Nottingham United Kingdom.

Nuyens, F. M., Griffiths, M. D., Kuss, D. J., & Lopez-Fernandez, O. (2018, April). *The experimental analysis of problematic video gaming and cognitive skills: A systematic review*. Paper presented at the fifth International Conference on Behavioral Addiction, Cologne, Germany.

Nuyens, F. M., Kuss, D. J., Lopez-Fernandez, O., & Griffiths, M. D. (2019, February). *The potential interaction between time perception and gaming*. Paper presented at the School of Social Sciences Research Conference: Grappling with theory and practice, Nottingham, United Kingdom.

Nuyens, F. M., Kuss, D. J., Lopez Fernandez, O., & Griffiths, M. D. (2019a, June). *Time perception, a potential underlying of time loss effect among gaming disorder*. Paper presented at the sixth International Conference on Behavioral Addiction: Globally growing issues - need for innovation in prevention and research, Yokohama, Japan.

Nuyens, F. M., Kuss, D. J., Lopez Fernandez, O., & Griffiths, M. D. (2019a, June). *Time loss: An impaired time perception amongst gamers?* Paper presented at the sixth International Conference on Behavioral Addiction: Globally growing issues - need for innovation in prevention and research, Yokohama, Japan.

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Abstract

Gaming Disorder has been included in the 11th revision of the World Health Organization's International Classification of Diseases as a recurrent gaming behaviour with a lack of control from the gamer. One important aspect of gaming disorder, and gaming in general, is the time loss effect which can be defined as the underestimation of the time spent on an activity (i.e., gaming in this case). Since this process may lead the gamers to experience multiple negative consequences (e.g., conflicts with education and occupation, relationship problems, etc.) due to the increased time spent on videogames, the main objective of this thesis was to explore a potential underlying mechanism of time loss: time perception. This thesis contributed to knowledge by (i) systematically reviewing the variables commonly associated with both gaming (i.e., healthy and disordered) and time perception, allowing a deeper understanding of these two variables' interaction; (ii) testing the Dual-Process Contingency Model of time perception within durations above one minute; (iii) testing both the prospective and retrospective time perception of the gamers in comparison to non-gamers in a neutral setting; and (iv) testing how emotion and cognition affect the gamers' retrospective time perception.

The new primary data from this thesis were collected using quantitative approaches, utilizing both experimental (i.e., computer tasks) and psychometric (i.e., online survey) data collection. These data from three experimental studies and one psychometric study were analysed through multiple types of analysis such as ANOVAs, regressions, or general linear models. The results first indicated that the Dual-Process Contingency Model of time perception, unifying RTP and PTP, was not valid for longer time durations. Second, the results showed that the gamers exhibited a better PTP (but a similar RTP) than non-gamers when estimating time in a neutral setting. However, the gamers underestimated time when processing gaming pictures, this effect being stronger when the task to complete was more complicated. In conclusion, it appears from the studies carried out that the reason underlying the observed time loss effect experienced by gamers was impaired retrospective time perception occurring when aroused by gaming stimuli.

Chapter 1: Time perception

1.1. Chapter overview

This thesis aims to explore gamers' time perception to understand time loss (i.e., the underestimation of time spent on an activity) within Gaming Disorder. Before exploring time perception within this population, it is crucial to understand its underlying mechanisms and how it can be impaired/affected. Numerous variables have been demonstrated to interfere with time perception (e.g., drugs, fatigue level, and age), from which two main factors emerged: emotion and cognition.

Therefore, the aim of this chapter is to describe and define time perception, as well as how both cognition and emotion interfere with it. This chapter will be divided into the following sections: (i) models of time perception (i.e., defining the concept of time perception and the dominating models), (ii) measures of time perception (i.e., explaining the main measures), (iii) method (i.e., explaining how the databases have been searched), (iv) results (i.e., divided in emotional interference and cognition), and (v) discussion.

1.2. Models of time perception

Despite its importance in any sentient life form, scholars currently have limited knowledge on time perception, especially on time itself. Indeed, time is an intricate and indefinable concept, as it cannot be explained without resorting to a word belonging to semantic field of time itself (e.g., minute, instant, and period). Regardless of this obstacle, time perception has been studied for centuries, from the Greek philosophers of the antiquity such as Aristotle, to the most recent neuropsychological studies exploring its neural basis. Relentless research and reflection have led to numerous theories which constitute the basis of current knowledge, such as the distinction between retrospective and prospective time perception (Levin & Zakay, 1989). In prospective time perception (PTP), individuals are aware that they have to measure a duration. In an experimental design, the investigator tells the participant the aim of the experimental study beforehand, so that the participant can focus on time itself. Consequently, their perception is ad hoc. In retrospective time perception (RTP), individuals are unaware of the duration assessment until the very end of the experimental trial to be measured, which makes it more ecologically valid, as in real life individuals rarely use PTP. In the RTP experimental setting, the participants' temporal evaluation is post-hoc.

In the first modern studies attempting to explain how time is perceived, a physicochemical model of time perception was introduced, a type of biological mechanism determining how durations are estimated. These models postulated that temperature would affect the time perception of individuals (François, 1927; Piéron, 1923). For example, Hoagland (1933) tested the effect of influenza – and thus of fever – on his wife's time perception. The author replicated the previous results and postulated the existence of a chemical clock located in the nervous system, a clock which would become the basis of numerous models of time perception later (i.e., timer models), even though its form and behaviour vary substantially. For example, the counting model (Creelman, 1962) postulates the existence of a mechanism emitting pulses, these being recorded by a mechanism in order to allow a time estimation. The number of pulses would be a direct function of the duration to be evaluated. These types of models will be described as 'timer's models' from this point onwards.

As neuropsychological studies failed to find an organ or a neural system which could account for the pulsing mechanism, it was suggested that time perception should instead be explained by cognitive mechanisms (Ornstein, 1969). According to Ornstein's 'Storage Size' metaphor, the perceived duration is a function of the information processed during an interval. Consequently, it can vary by both the number of the stimuli and their complexity. And, according to the same hypothesis, the way the stimuli are coded into storage impacts the perceived duration too. For instance, a logical number series (e.g., 2468) would take less 'space' than an illogical random one (e.g., 2864). The following experiments performed by Ornstein all took place in an RTP design, and thus are not generalisable to PTP. Through two first experiments, Ornstein (1969) established the basis of his theory, the number of items presented to the participant, and their complexity – to a certain extent – lengthened the perceived duration. Moreover, a third and fourth experiment (respectively including auditory and visual stimuli) explored the complexity of the coding and not of the stimuli themselves. These showed that when the stimuli were more easily processed and analysed, the duration appeared to be shorter than when it was more complicated. This meets Ornstein's hypothesis, as the ‘easily codable’ items would use less storage space than the complicated ones. These results’ explanations were confirmed in a fifth experiment, where he explored the effect of habit on RTP. In this experiment, participants could either receive related or unrelated training before performing a task, the hypothesis being that if the participant was used to the task, it would be more easily codable, and as a result perceived as shorter. The hypothesis was confirmed, since the trained participants perceived the task as shorter than the participants who performed unrelated training.

Moreover, Ornstein (1969) explored the importance of different coding in several other experiments. A sixth experiment examined the segmentation effect on duration evaluation. This study showed that when a participant was first exposed to a video split in several core parts (i.e., important sections of a dance movement), the duration of the actual video was perceived as longer when viewed as a whole (meaning that the ability to observe more details of a video would lengthen the perceived duration of an interval). Two final studies explored how the arrangement of a figure affecting its coding in memory could change its perceived duration. For this purpose, participants were presented a series of curves which could either form the shape of an insect, spell the word ‘man’, form a coherent figure, or be placed randomly and not form any shape or word. The study showed that the more easily codable the curves were, the shorter the perceived duration, the easiest being the word, followed by the insect shape. All these studies tend to confirm Ornstein’s ‘Storage Size’ metaphor of time perception. However, even if he implied that this explanation was true for all kinds of time perception, the findings only relate to RTP.

PTP better fits timer’s models such Creelman’s (1962). The first complete model including a timing processer was developed by Treisman (i.e., 'Internal Clock' Model, 1963). In this model, a pacemaker emits a regular pulse through a pathway, these pulses being recorded by a counter which transfers these to a ‘store’. The last timer component is the comparator which will allow the contrasting of two measures of time to allow an appropriate response. Treisman, Faulkner, Naish, and Brogan (1990) improved the model by including an oscillator into his model. This improvement came from an attempt to understand how the pacemaker should be composed to account for its functioning. The authors first state that there should be multiple pacemakers to permit flexible time perception and motor action. There should also be a unified functioning of these pacemakers when they are required to work at the same pace, and there is a need for a hierarchical distribution overseen by a controller. This controller would be the aforementioned oscillator which would be coupled with a calibration unit receiving this pulse, and emitting a function of it (i.e., either increasing or decreasing the pulse rate). Such a configuration would allow different body parts to move at different paces (i.e., two different functions of the calibration unit) or at the same pace (i.e., one unique function, allowing a global acceleration of the pace). For this complex ‘Internal Clock’ model to work, a series of assumptions were made by the authors. First, the oscillator would be constituted of a small network of units (i.e., conceptual neurons) exerting either an excitatory or inhibitory effect on one another (i.e., allowing a slowing or an acceleration of the pulse). Second, the calibration unit would vary depending on the arousal level that can be induced from a sensory input (i.e., a high level leading to an increase of the calibration factor and the opposite for a low level). Finally, the main oscillator would be protected from such input. Nonetheless, Treisman and colleague’s experiments (1990) only partially supported their oscillator model, indicating that this model is not entirely reliable. Still, according to the authors, this type of model remains appropriate to explain PTP.

These two models (i.e., the ‘Storage Size’ Metaphor and the ‘Internal Clock’ model) were competing when they were first developed, but it is now known that they are not exclusive, as they both define RTP and PTP, respectively. Based on Ornstein’s (1969) work, a new model was developed to describe RTP – the Contextual-Change Model (CCM; Block & Reed, 1978). To develop the model, Block (1974) conducted two experiments exploring how both the number of stimuli and the complexity of their sequences affected RTP. These experiments replicated Ornstein’s (1969) results (i.e., a lengthened perceived time duration when the number of stimuli rose) with a simpler complexity of the sequence associated with a longer perceived duration (i.e., probably due to a higher number of stimuli retained in memory due to the simplicity of the coding). Later, Block (1978) explored the complexity of the sequence in more depth, showing that while the complexity of a pattern does not affect time estimation, its predictability does (i.e., less predictable figure leading to an overestimation). These results still adhered to several pre-existing theories and hypotheses on top of Ornstein's (1969), leading Block and Reed (1978) to run several experiments to find out which theory was the most capable of explaining RTP. Four main hypotheses were constructed to account for RTP comprising event-memory (i.e., duration as a function of the retrievable data in memory), attentional (i.e., lengthening of duration estimation with an increased attention to the passage of time), informational (i.e., the amount of information lengthens the duration only if there is no response required for that information), and contextual-change (i.e., duration is a function of the number of changes observed, or of which the observer is aware). The first experiment demonstrated that the level of processing in the task performed by the participants did not influence their perception of time, thus ruling out both the event-memory and attentional hypotheses. In the second experiment, participants were confronted with either a mixed level of processing or a constant level of processing when performing several tasks. Participants estimated the mixed processing level as longer than the constant one. In conclusion, the authors concluded that the Contextual-Change Model (CCM) was the most likely model to explain RTP.

PTP, on the other hand, is more appropriately described by the timer's models. The current leading model in this field is the 'Scalar Expectancy Theory' Model of time perception (SET, Church, 1984). Performing three experiments on rats, Roberts and Church (1978) defined six main properties of the internal clock of the rats, and compared these properties to a man-made clock: (i) it can be stopped temporarily; (ii) the duration before and after the break can be added to achieve a total duration; (iii) it can measure different durations; (iv) it can time different modalities (e.g., visual vs. auditory); (v) timing is absolute because it can measure different lengths with the same rate; and (vi) it can be reset quickly. Later, Church (1984) described a model of time perception by reviewing previous studies led on animals' PTP. This model comprises four main parts: a clock, working memory, reference memory, and a comparator. The clock part is composed of a pacemaker, a switch, and an accumulator. The pacemaker emits a pulse into an accumulator via a switch. These stocked pulses are compared to a remembered amount of pulses in reference memory. This comparison is operated by the comparator. If the two values (i.e., accumulator and stored value) are close enough, a response will be made (i.e., the two values are equal). In some cases, the value in the accumulator can be transferred to working memory, the comparator can then compare it to the value in reference memory (e.g., when two successive durations are compared). This model presents several properties: (i) the pacemaker can be influenced by various external stimuli (e.g., drugs); (ii) the switch can be operated in different modes (e.g., when a break is operated in the middle of a stimulus, the switch can retain the pulses, allowing the inclusion of only the first and last part of the duration); (iii) the switch can open only at the beginning of each stimulus too (event mode); and (iv), working memory allows a quick reset, which permits a comparison between a first event and a given duration (e.g., 2s) and the second one to another one (e.g., 8s). These models were later tested on humans, and showed that PTP relied on a SET model as well (e.g., Allman & Meck, 2012; Church, 2003).

Nonetheless, compared to the cognitive models of RTP, the timer's models do not account for the observed effects of attention on time perception. While in RTP the effects of attention are studied towards the stimuli (i.e., being aware or not of the stimuli to be processed) due to the participant not being aware of time itself; in PTP, the effect of attention is studied with regard to timing itself. The details of the studies on time perception and attention are explored later in this chapter. Nonetheless, it can already be noted that most of the studies exploring the effect of diverted attention on time perception lead to an underestimation of duration (e.g., Brown & Perreault, 2017; Osugi, Takeda, & Murakami, 2016). The current prominent model accounting for this relationship is the Attentional Gate Model (AGM), which postulates the existence of a gate between the pacemaker and the accumulator (Zakay & Block, 1995). The gate is a cognitive mechanism which opens according to the attention to time. The more attention is allocated, the wider the door is opened. Therefore, more pulses reach the accumulator and thus lengthen the perceived duration. Finally, the model includes a switch, allowing the opening or closing of the door. The switch operates in an 'all-or-none' design which allows the door to open at the beginning of a relevant interval, and to close at the end of it.

There is one model that attempted to unify both RTP and PTP despite these two paradigms being systematically separated before, the Dual-Process Contingency Model (DPCM, Thomas & Weaver, 1975). In the DPCM, both time perception paradigms rely on time processing (i.e., comparison of perceived time and recorded duration in working memory) and information processing (i.e., estimating time via perceived changes in the environment). The importance of such processes varies depending upon the paradigm (i.e., time processing will be more important in PTP, and inversely for information processing). This model is determined by nine postulates: (i) timing can be determined by a timer or by information (i.e., timer's or cognitive models), both being integrated; (ii) the importance of each temporal source depends on the attentiveness towards it (e.g., if attention is focused on time, the timer will prevail); (iii) the timer produces pulses, and the duration is a function of the number of these; (iv) when the timer cannot be retrieved, the information processed during the duration will determine the perceived duration through contextual changes; (v) the timer can produce pulses at all times if attention is focuses on it; (vi) if not stored in long-term memory, the duration measured by the timer has to be retrieved immediately, or it will be set back to zero with a new interval; (vii) when the timer is used, and attention is brought to time, the estimation is prospective; (viii) as information can be processed at any time, it can be retrieved easily too, but its degree of attention will decrease with more non-temporal information processing; and (ix), in a retrospective design, attention is allocated to the memory-based processes. To date, the model has only been validated twice with very short duration that is inferior to the second in Thomas and Weaver's (1975) research and between 12 and 15 seconds in research led by Zakay (1993).

1.3. Measures of time perception

Throughout the decades of experimental testing on time perception, a few tasks have been frequently used. They explore different facets of time perception and rely on different components of it. To facilitate understanding of the following sections of this chapter, these tasks are briefly described below.

Estimation Task (*ET*): In this task, the participant has to process a stimulus (e.g., a video, an image, or a series of words) for a random duration. Once the stimulus has been displayed, the experimenter asks the participant how long the stimulus lasted. This type of task is particularly efficient for longer durations (i.e., several seconds or minutes), although participants tend to round up their estimation (i.e., 10s, 2min) and consequently, a precise duration should be chosen (e.g., 17s, 168s).

Temporal Reproduction Task (*TRT*): This type of task is relatively similar to the ET. Here, the participant must process a stimulus for a random duration. However, when the stimulus is over, instead of having to estimate its duration, the participant is asked to reproduce it. The way the participant has to reproduce the duration can vary greatly. Many of the studies make the participant press a button for a duration judged as equal to the stimulus'. This type of task is particularly efficient for durations longer than one second, although it becomes harder to use in longer durations (e.g., several minutes).

Temporal Production Task (*TPT*): In these tasks, participants are told a duration that they have to produce. The production process can either be as in the TRT (i.e., pressing a button), or performing a task for the requested duration. The testable duration under this paradigm varies depending on the production means used. For example, when the participant has to press a button, the experimenter is confronted with the same time limits as the TRT. However, when the participant has to perform a task, the duration can be longer (i.e., several minutes).

Temporal Comparison Task (*TCT*): In this task, the participant is either presented with two stimuli or has to perform two subsequent tasks. The tasks and stimuli can present the same duration, or two different (close) durations. Afterwards, the participant has to decide which stimulus was longer. If the studies use stimuli, it is more suitable to test short durations (i.e., less than a second, or only a few seconds). As with TPT, if the participant has to perform two tasks, it can be of a longer duration. Nonetheless, since this method uses working memory, a duration that is too long can affect the memory of the first duration.

Temporal Generalization Task (*TGT*): This kind of task is close to the TCT in its functioning. Instead of being presented with two successive stimuli and having to compare them, the participant first familiarises themselves with a given duration in a training block. Afterwards, the participant is presented with stimuli with random durations and must decide whether these durations are shorter or longer than the previously memorized duration. This method is neither suited for task performing nor for long durations and is usually preferred for durations either under a second or just a few seconds.

Temporal Bisection Task (*TBT*): In this task, the participant first familiarizes themselves with two different durations (i.e., called anchors) during a training block. Afterwards, the participant will be presented stimuli with random durations between these two anchors (i.e., never of the same duration as the anchors) and will have to decide to which anchor they are closer. These tasks are not suitable for long durations and are usually preferred for durations either shorter than one second or of a few seconds.

1.4. General method

An extensive literature research was conducted using four different databases accessed from *Nottingham Trent University*: *Google Scholar, ScienceDirect, PubMed,* and *PsycINFO.* All searches included a common set of search words (i.e., time perception, timing), and other words to specify the particular domain studied (i.e., emotion, cognition, attention, difficulty, memory, inhibition, executive functions). Studies were included if they: (i) dated from the year 1964 (as the first extensive model of time perception was published in 1963 by Treisman), (ii) included an experimental design, (iii) included healthy participants, (iv) were published in English or French (the languages spoken by the co-authors), and (v) were peer-reviewed.

The search undertaken on *ScienceDirect*, *PubMed*, and *PsycINFO* included the same type of research terms. The only difference was that *ScienceDirect* allowed searching research terms in the title, abstract, and paper keywords at the same time, while *PubMed* only allowed searches in the title and abstract, and *PsycINFO* only in the abstract. Using the words ‘time perception’ and ‘timing’ associated with the specific area sought (i.e., words describing either emotion or cognition) led to the following number of published papers. On *ScienceDirect*, there were 34 papers on emotion and 208 on cognition. On *PubMed*, there were 67 papers on emotion and 337 on cognition. On *PsycINFO*, there were 52 papers on emotion and 228 on cognition. Due to the inability to search terms only in the abstract or keywords on *Google Scholar*, the terms used were searched only in the titles. This led to 21 papers on emotion and 94 on cognition, leading to a total of 930 papers when the database searches were combined. After collating the results of the different databases to merge the duplicated papers, sorting the unrelated papers, and adding new papers cited in the ones selected, the final number of selected papers was 86.

1.5. Emotional interference

After reading the papers selected in the literature search, four types of study related to emotional interference of time perception were emphasized: (i) studies exploring visual stimuli (i.e., pictures, videos; *n*=9); (ii) studies including social stimuli (i.e., faces or postures; *n*=13); (iii) studies using auditory stimuli (i.e., sounds and music; *n*=8); and (iv) studies exploring how the feeling of control, the unconscious effect of emotion, or the awareness of the emotional interference affect time perception (*n*=4).

1.5.1. Visual stimuli

Introduction

Studies exploring emotional stimuli in a visual modality have yielded mixed results. Some of them indicated that watching an emotional picture or video led to an overestimation of their duration (e.g., Grommet et al., 2011; Grondin, Laflamme, & Gontier, 2014; Shi, Jia, & Müller, 2012), while other studies tended to find the opposite trend (e.g., Smith, McIver, Di Nella, & Crease, 2011; Tipples, 2010). These results can either be explained by an arousing or attentional effect. An arousing effect accelerates the pulses produced by the pacemaker, thus increasing the number of pulses in the accumulator and the perceived duration. This hypothesis would be verified by a multiplicative effect with duration (i.e., a stronger effect for longer duration), as the pacemaker would keep emitting more pulses during the whole duration. Alternatively, an attentional effect could lead to two outcomes. A first one is participants divert their attention from the task, and thus focus on the time it takes to open the attentional gate (i.e., AGM) and increase the number of pulses recorded. This hypothesis would then lead to an additive effect (i.e., not varying with the duration), with the gate opening only when the participants divert their attention from the task, as an isolated effect. The second possibility is participants orient their attention more actively toward the stimuli, the task itself, thus closing the attentional gate, and limiting the number of pulses recorded, leading to an underestimation of the duration. A deeper analysis of these studies is required to achieve any conclusion regarding the underlying processes determining the interaction of emotion and time perception. Accordingly, the following section summarises the studies yielding a lengthening or shortening effect separately in order to allow a comparison of the stimuli and methods used.

Lengthening effect

The literature on the lengthening effect of emotion is currently struggling to exhibit either an arousal or attentional interference on time perception. For example, while both Grommet et al. (2011) and Fayolle, Droit-Volet and Gil (2014) showed a lengthening effect it their studies, their conclusions differ concerning its cause. Using pictures depicting fear (e.g., bear, shark, or dogs) in a TBT (anchors either 250-1000ms or 400-1600ms), Grommet and et al. (2011) showed that lengthening did not vary with the duration. Therefore, it would appear that the lengthening effect observed is due to an attentional effect (i.e., additive effect, or isolated effect). On the contrary, Fayolle et al. (2014), using fear-evoking videos rather than pictures, showed that the lengthening effect observed varied alongside the duration, contrary to Grommet et al.'s study (2011). Pointing out that pictures may only elicit a pinpoint emotional effect and thus prevent any multiplicative effect, Fayolle et al. (2014) asked their participants to perform a first TBT (anchors either 200-800ms or 500-1600ms), then made them watch an emotional video, and then asked them to perform the same TBT. The participants overestimated the duration after watching the fear-evoking video, with an overestimation which was larger for the longer duration (i.e., 500-1600ms), supporting the arousal hypothesis.

Further supporting the arousal hypothesis, Gil and Droit-Volet (2012) explored the temporal estimation (i.e., within 200-800ms or 400-1600ms) of participants observing pictures extracted from the International Affective Picture System (IAPS, Lang, Bradley, & Cuthbert, 1999). The purpose of this research was to study the interaction between arousal, valence, and the type of emotion (i.e., disgust, sadness, and fear). High-arousing disgusting pictures were overestimated more than the low-arousing disgusting ones, both being overestimated compared to neutral pictures. Although there was only a significant difference between both types of sad pictures compared to neutral pictures, a trend was observed for the difference of estimation between the low- and high-arousing sad pictures. The direct effect of arousal on the estimation is a testimony of the importance of arousing in time perception. Following the same assumption, Grondin et al. (2014) compared the effect of low-arousing disgusting pictures (i.e., disgusted faces) or high-arousing disgusting pictures (i.e., mutilation) on time perception. In the TCT used, the durations (i.e., 482ms vs. 400ms) were demarcated by two pictures either from the same category (i.e., neutral, mutilation, or disgusted face) or not. The results showed that the participants tended to overestimate the duration when one of the stimuli included a mutilation picture; the overestimation was increased when both the pictures depicted mutilation. Therefore, this study confirms the previous study by Gil and Droit-Volet (2012) and tends to support the arousal hypothesis.

Shortening effect

To the best of the author's knowledge, only four studies have reported a shortening effect when including visual emotional stimuli. The first study explored the joint effect of arousal (i.e., low- and high-arousing pictures) and valence (i.e., pleasant, unpleasant, and neutral) on time perception through an analog task (i.e., comparing two duration lengths by crossing a straight line) and a TRT (2s, 4s, and 6s) (Angrilli, Cherubini, Pavese, & Mantredini, 1997). The results showed that the main effects of valence and arousal were not significant, but that their interaction was. When the pictures were highly arousing, the positive pictures were underestimated compared to the negative ones, with an opposite trend when the pictures were not as arousing. These results are of interest and could indicate the existence of two different mechanisms for the high and low arousing pictures. An approach-avoidance mechanism would be at stake for the highly arousing pictures. The participants would avoid the negative pictures and as a result overestimate their duration (i.e., due to their attention being used for time estimation). On the other hand, they would approach the positive ones, underestimating their duration (i.e., their attention to time being limited). With regards to the low-arousing pictures, it would instead be an attentional effect, as the more analysed negative pictures would be more underestimated than the less analysed positive pictures.

Smith at al. (2011) replicated these results using a TBT (i.e., 100-300ms and 400-1600ms), including pictures varying in term of arousal (i.e., high and low) and valence (i.e., positive, negative, and neutral). Interestingly, while the highly arousing negative pictures were globally underestimated in the shorter duration (i.e., 100-300ms), the pictures underestimated in the longer duration (i.e., 400-1600ms) were the low-arousing negative ones. Although there is an effect of valence, as the negative pictures were systematically underestimated, the effect of arousal is less clear due to its opposite effect depending on duration. Apparently, a long aversive stimulus would elicit a defensive system, the lengthening effect allowing the participant to explore the stimuli deeper to prepare a defensive response. On the contrary, a short aversive stimulus would elicit an attentional effect, the negative stimuli being processed faster for the same purpose than the longest ones.

Instead of using pictures, Tipples (2010) included words varying in terms of arousal (i.e., high and low) and valence (i.e., positive, negative, neutral, and taboo) in the TBT used (i.e., 400-1600ms). Even though the words have been controlled for numerous variables (i.e., valence, arousal, imageability, personal use, offensiveness, 'tabooness', and familiarity), this study's results should be taken cautiously due to the complexity of this type of stimuli compared to pictures. The study showed that taboo words were systematically underestimated compared to other types of words, indicating an attentional effect as these words would gather more attention than the other words, limiting the attentional focus on time.

Only one study directly tried to explore whether the emotional interference observed in time perception was due to an attentional or arousal effect (Lui, Penney, & Schirmer, 2011). Their research piece included five experiments exploring potential confounding variables. The first experiment included a TCT with either negative or neutral pictures in which the participants first saw a baseline duration (i.e., 1200ms), then the picture, then another duration either shorter (i.e., 1040-1200ms) or longer (i.e., 1280-1360ms). The results showed that negative pictures tended to be underestimated, which could be due to an attentional bliss (i.e., not noticing the onset of the second duration due to inattention). In order to eliminate this possibility, the second experiment used the same task with a longer delay between the picture and the second duration, replicating the first experiment's results. The author's third experiment aimed to explore the different effect of positive pictures on the participant's time perception. First, it showed the same trend of results for previous experiments; second, their analyses showed that the effect was of the same magnitude as that for the negative pictures. The fourth experiment replicated the previous results with musical tunes instead of visual ones. Finally, to ensure that it was the stimuli after the picture which was underestimated and not the previous ones being overestimated, a fifth study used only one duration after the picture was showed. In this experiment, a TRT (1100, 1700, 2300ms) was preferred to the previous TCT. The results showed that participants underestimated the duration of the negative stimuli, thus confirming the results of the previous experiments.

Visual stimuli – conclusion

Despite the mixed results and the relative lack of studies, some similarities arose from these experiments. All of the research using pictures found a lengthening effect when exploring durations between 200 and 1600ms. Indeed, the studies demonstrating a shortening effect either used longer durations (i.e., between 2 and 6 seconds; Angrilli et al., 1997) or found it in shorter durations (i.e., around 130ms; Smith et al., 2011). This overestimation effect appears to be due to increased arousal, even though only one study found a multiplicative effect (i.e., Fayolle et al., 2014). According to the same authors, the multiplicative effect was only achieved with long lasting emotion (i.e., mood change), the pictures in the other studies only achieving a punctual, brief change in emotion. Furthermore, studies showed that the most arousing pictures depicting the same emotion elicited a longer duration perception (Gil & Droit-Volet, 2012; Grondin et al., 2014).

Regarding the shortening effect, the study by Angrilli et al. (1997) using a longer duration noted that two types of mechanisms were at stake depending on the level of arousal. In the high arousing pictures, the positive ones tended to be underestimated more than the negative ones, the opposite trend being observed for the low arousing pictures. Consequently, it appears that over two seconds, highly arousing pictures engage an approach-avoidance mechanism, while the low arousing ones engage an attentional mechanism. Finally, the study by Smith et al. (2011) showed an interesting interaction regarding duration, because the negative pictures were underestimated in very short durations (i.e., up to 130ms), contrasting with the overestimation for longer durations. Referring to Electroencephalography (EEG) studies, the authors suggested that the shortest duration effect would be due to the earliest stage of attention processing, with the stimuli recognized as 'threatening' being processed faster to allow a swift reaction of the body. With regards to the longer duration, in order to prepare the most adapted reaction, the neural system would permit a thorough analysis of the stimuli, consequently diverting attention from time, hence the overestimation.

1.5.2. Emotional expressions

The studies in this category mainly used pictures or animated pictures in order to examine participants' temporal responses to varied emotional expressions. These studies could arguably be associated with the previous section on visual stimuli. Nevertheless, exploring the emotional expressions separately appears more appropriate due to their complex nature compared to the simple visual stimuli described in the previous section. Contrary to the previous section that yielded mixed findings, the studies examining emotional expressions all showed the same trend of results, that is, an overestimation of temporal duration when investigating emotion (e.g., Gil & Droit-Volet, 2011; Lee, Seelam, & O'Brien, 2011; Tipples, 2011), especially when faces exhibited anger (e.g., Droit-Volet, Brunot, & Niedenthal, 2004; Tipples, 2008). Due to the globally clear effect of emotional expressions on time perception, the following paragraphs will explore the variable affecting this association.

Stimuli dynamism

The first variable explored stimulus dynamism which would affect the association between facial expression and time perception. Most of the studies on the topic included static stimuli (i.e., pictures of an expressive face), while an individual will mostly encounter dynamic/mobile faces in real life. Despite this fact, only two studies explored the effect of these more ecologically valid stimuli on time perception. First, Fayolle and Droit-Volet (2014) explored how faces shifting from a neutral toward an emotional expression (i.e., anger and sadness) would affect the participants' results on a TBT (i.e., 400-1600ms). The results showed that while only the angry emotion was overestimated in the static group, both emotions were overestimated in the dynamic group. In a second experiment similar to the first one (i.e., with only the removal of the neutral expressions), the authors showed that the angry faces were overestimated compared to the sad expression, despite the lack of difference in the participants' estimation of these emotions' arousal levels. Li and Yuen (2015) led a similar study which included dynamic (i.e., morphing from a neutral expression) version of emotional expressions (i.e., neutral, happiness, sadness, and anger) in their TBT (i.e., 400-1600ms). Moreover, the authors included faces from both genders to control this effect. Despite the lack of a gender effect, there was a significant effect of dynamism. While the static emotion did not reach significance, the presentation duration of the pictures morphing from a neutral expression were overestimated, this effect being stronger for anger. To verify that the effect observed within the dynamic group was not solely due to morphing but a direct effect of emotion, Li and Yuen (2015) led another experiment where the stimuli morphed between two emotions rather than from a neutral expression. The results showed that only switching towards a happy or angry emotion lengthened the duration, thus excluding the sole effect of morphing in the previous experiment.

Model's gaze

The second variable explored in this section is gaze, which is known to affect the behaviour of an individual depending on its orientation (i.e., direct or averted). Doi and Shinohara (2009) observed how gaze (i.e., straight or averted) affects the effect of an emotional expression (i.e., happiness and anger) on a TBT (i.e., 600-1400ms). There was an interaction between the emotion and gaze where the presentation of an angry straight face was estimated as lasting longer than that of an angry diverted face, this result not being significant for the happy expression. Extending these results, Kliegl et al. (2015) included three different gazes (i.e., 0°, 45°, and 90°), different emotions (i.e., anger, sadness, and neutral), and a systematic gender comparison (i.e., same or opposite gender between the participant and the stimulus) within a TBT (i.e., 400-1600ms). The results showed a main effect of emotion (i.e., only angry faces being overestimated) and a main effect of gender (i.e., females judging male faces to last longer and vice versa). Finally, as in the previous study, gaze influenced the estimation of angry faces (i.e., diminishing when the model was not facing the participant), with no effect for sad faces.

Embodiment effect

The embodiment effect is the unconscious imitation of an individual by another individual in front of them. This effect can influence cognition, even by simply asking participants to hold a pen in their mouth, which inhibits their facial expressions (Lobmaier & Fischer, 2015). Replicating this method, Effron et al.

(2006) explored how the embodiment effect influences the effect of facial expression (i.e., neutral, happiness, and anger) on a TBT (i.e., 400-1600ms). The results showed that when the facial expressions of the participants where inhibited, there was no difference between the different stimuli. However, the participants not holding a pen in their mouth overestimated the duration of angry and happy expressions. To explore how ethnicity may affect the embodiment effect, a study compared whether being confronted with another ethnic group than their own affects the participants' processing of emotional faces and accordingly its impact on time perception (Mondillon, Niedenthal, Gil, & Droit-Volet, 2007). In a first experiment, Caucasian participants observed Chinese models, while the opposite order was used in the second experiment. Using a TBT (i.e., 400-1600ms) with both angry and neutral faces, the authors showed that the Caucasian participants only overestimated the duration when confronted with their own ethnicity. On the other hand, Chinese participants overestimated the presentation duration of angry faces with both ethnicities, which could, according to the author, be due to the Chinese participants being more familiar with Caucasian faces as the former lived in France.

Participant's age

The final variable which may affect this relationship is the age of the participants since it has been shown that time perception differs between children (e.g., Droit-Volet, Clément, & Wearden, 2001; Droit-Volet, Delgado, & Rattat, 2006) and elderly participants (e.g., Coelho et al., 2004; Ferreira, Paiva, Prando, Graça, & Kouyoumdjian, 2016). Especially, it has been noted that emotion affects these groups differently (e.g., Gil, Niedenthal, & Droit-Volet, 2007; Nicol, Tanner, & Clarke, 2013). Concerning the children, Gil et al. (2007) adopted a developmental exploration of the relation between time perception and expressions by comparing different age groups (i.e., three, five, and eight years old). Participants were asked to complete a TBT (i.e., 400-1600ms and 600-2400ms) including both neutral and angry expressions. There was no interaction between the emotional expression and age, only a main effect of emotion (i.e., angry faces overestimated), meaning that the effect of emotional expression does not differ between the children.

Regarding elderly people (i.e., between 65 and 85 years old), it has been shown that they tend to focus more on positive emotions instead of negative ones (e.g., Coelho et al., 2004; Ferreira, Paiva, Prando, Graça, & Kouyoumdjian, 2016).

Since emotion can affect time perception, it was assumed that positive emotions interfere more among older participants, while negative emotions would have the same effect among younger participants (Nicol et al., 2013). In their study, Nicol et al. (2013) compared young participants (i.e., about 22.3 years) to older participants (i.e., 67.6 years) on a TBT (i.e., 400-1600ms) including emotional expression (i.e., anger, sadness, happiness, and neutral) as well as on the Positive and Negative Affect Scale (PANAS, Watson, Clark, & Tellegen, 1988). The results showed that the older participants had higher scores on positive affect and estimated the happy expression to last longer than the other ones. On the other hand, younger participants had higher scores for negative affect and judged the angry expressions to last longer. An unexplained result is the older participants estimating the sad expression to last longer than neutral expressions. More interestingly, the older participants estimated the happy expression to last longer than the young participants did, further supporting the effect of positivity.

Emotional expression – conclusion

In this section, four main variables were explored: dynamism (i.e., static vs. morphing faces), gaze (i.e., straight or diverted faces), embodiment (i.e., emotion mimicry), and age. First, dynamic expressions elicited a stronger effect of emotional interference than static expressions (Fayolle & Droit-Volet, 2014; Li & Yuen, 2015). Additionally, while Li and Yuen (2015) failed to find any effect of emotion using static faces, dynamic expressions still yielded significant results. Second, a straight gaze will lead to an overestimation of angry faces, and the effect will diminish, if not disappear, with a diverted gaze, pointing to a ‘fight-or-flight’ effect (Doi & Shinohara, 2009; Kliegl et al., 2015). If someone’s anger is not directed toward an individual but another person, they are not threatened and there is no need for the body to prepare for protection. Third, studies exploring the embodiment effect yielded two findings. The first one is that when holding a pen in one’s mouth, and thus being unable to mimic an emotional expression, the lengthening effect of both happy and angry emotions was nullified (Effron et al., 2006). The second finding is that when participants observed someone from another unfamiliar ethnic group, the effects of emotional expressions were cancelled (Mondillon et al., 2007). Finally, the impact of age was explored among both children and elderly participants. Even though there was no difference between the different children's age groups in Gil et al.' study (2007), no conclusion can be drawn on the difference between children and adults due to the absence of adults in this experiment. Regarding the elderly participants, they appeared to overestimate positive expressions compared to younger participants, which may be an effect of their overall positivity (Nicol et al., 2013).

1.5.3. Auditory stimuli

Studies using auditory stimuli fall into two main types: experiments using basic sounds (i.e., tones) and experiments using music. The first type yields the same kind of results as simple visual stimuli (i.e., mixed and contradictory results) with half the studies exhibiting an overestimation of emotional stimuli (Droit-Volet, Mermillod, Cocenas-Silva, & Gil, 2010; Wackermann, Meissner, Tankersley, & Wittmann, 2014) and the other half showing the opposite (Fallow & Voyer, 2013; Noulhiane, Mella, Samson, Ragot, & Pouthas, 2007). With regards to musical studies, despite the varying results, these may be directly dependent on the experimental paradigm used. While RTP studies systematically exhibit an overestimation of duration (Bisson, Tobin, & Grondin, 2009; Bueno & Ramos, 2007), PTP studies show incongruent results which require further research (Droit-Volet, Bigand, Ramos, & Bueno, 2010; Droit-Volet, Ramos, Bueno, & Bigand, 2013).

Basic sound

Two studies exhibited an underestimation effect with these types of stimuli. First, Noulhiane et al. (2007) explored the impact of sounds varying in terms of arousal (i.e., high and low) and valence (i.e., pleasant and unpleasant – neutral) on their participants' TRT (i.e., 2, 4, 6s) results. Both low-arousal sounds were underestimated compared to the neutral sound (only for 4 and 6s). In addition, within the shortest duration, the positive sounds were estimated to last shorter than the negative ones and the highly arousing sounds as shorter than the low arousing ones. Fallow and Voyer (2013) replicated these results by using the word 'Bower' pronounced either angrily or neutrally within a TBT (i.e., 260-440ms). Like the previous study, the emotional stimuli were underestimated compared to the neutral ones.

As for the underestimation studies, two pieces of research observed an overestimation of duration with emotional stimuli. A first one included two experiments with aversive sounds (i.e., 50ms burst of 95 dB white noise) and non-aversive sounds (i.e., 50ms beep of 50dB) in a TBT (i.e., 400-800ms, 800-1600ms). In the first experiment, the sounds followed the interval while they preceded it in the second experiment. Both designs elicited similar results (i.e., an underestimation effect), although this effect was stronger in the second experiment. This potentially indicates an expectation effect where the participants being stressed about the upcoming sound overestimated the duration. The second study compared positive sounds (e.g., boy laughing, erotic sounds), negative sounds (e.g., person vomiting, baby crying), and neutral sounds (e.g., animal noises, rain) within a TRT (i.e., 5s) (Wackermann et al., 2014). The positive sounds were systematically overestimated and the negative ones were only significantly overestimated when incorporating the first author's own model of time perception (Wackermann & Ehm, 2006).

Musical stimuli

The complexity of the musical stimuli (e.g., varying tempo, rhythm, tone) may account for the varying results observed in the PTP studies. Taking into account these variables, Droit-Volet, Bigand, Ramos, and Bueno (2010) used a single music piece solely varying in tone (i.e., major-positive, minor-negative, and sine wave-neutral) within their TBT (i.e., 500-1700ms and 2000-6800ms), allowing the control of the other aspects of the music extract. Both emotional pieces (i.e., major and minor) were underestimated compared to the neutral one (i.e., sine wave), with no difference between them. The authors led two extra experiments exploring other durations or the absence of neutral stimuli, not altering the results. Building up from the previous results on valence, the same authors explored the combined effect of arousal (i.e., varying tempo) and pleasantness (i.e., backward or forward music) on time perception (Droit-Volet et al., 2013). The first experiment using a TBT (i.e., 500-1700ms and 1100-4400ms) showed that the fast tempo stimuli were overestimated compared to the slower ones. The tempo also interacted with the pleasantness of the music as the tempo effect was stronger in the forward version than in the backward music. To confirm that the tempo effect was due to arousal, the authors led another experiment with four pieces of music sharing the same tempo but varying in terms of arousal levels (i.e., simple or complex timbre) and pleasantness (i.e., forward or backward). The results indicated no effect of timbre on estimation, indicating that the previous results were not due to arousal (i.e., resulting from tempo only). Finally, since the structure of music is affected when played backward, the authors manipulated the pleasantness of the music excerpts by comparing tonal (i.e., pleasant) and atonal (i.e., unpleasant) music. In this study, the pleasant music was estimated as shorter than the unpleasant one.

The studies in an RTP design all show a lengthening effect of music on time perception. Bueno and Ramos (2007) compared consonant, pleasant music (i.e., Ionian and Aeolian music) to dissonant, unpleasant music (i.e., Locrian music) on a single ET measure (64.3s). The unpleasant excerpt was overestimated compared to the pleasant ones, which were both more accurately estimated by the participants. Bisson, Tobin, and Grondin (2009) replicated the previous study with longer duration (i.e., 180s, 300s, 420s) and music varying in terms of valence (i.e., joy, sadness, neutral). The participants had to compare the three durations between each other and to a standard duration as well as estimating them. Participants tended to judge the duration of the joyful song as longer than the sad one when comparing them (with no difference in terms of verbal estimation) and both emotional pieces were overestimated compared to the neutral one.

Auditory stimuli – conclusion

The first thing to note from studies including auditory stimuli is the small number (n = 6) of them compared to the studies using visual stimuli (either pictures [n=9] or emotional expressions [n=13]). Therefore, any conclusions must be treated cautiously, as more studies are needed in this specific field. Regarding the studies using basic auditory stimuli, the results are mixed as half the studies showed that negative sounds were underestimated (Fallow & Voyer, 2013; Noulhiane et al., 2007), while the two other studies showed the opposite effect (Droit-Volet, Mermillod, et al., 2010; Wackermann et al., 2014). It is noteworthy that the studies by Droit-Volet et al. (2010) used aversive sounds rather than actual emotional sounds, and these might explain the differing results. Besides, the fact that the durations were more overestimated when the aversive sound followed the interval indicates that the participants may have overestimated the duration due to their negative expectations.

With regards to musical influence on time perception, results demonstrate an overestimation effect in retrospective designs (Bisson et al., 2009; Bueno & Ramos, 2007); less coherence is observed in prospective designs. This lack of clarity in PTP studies may simply be due to the way the authors modified the music to achieve emotional valence. Indeed, the studies in this section either changed the music mode (i.e., major, minor, and sine-wave; Droit-Volet, Bigand, et al., 2010) or tone (i.e., tonal or atonal; Droit-Volet et al., 2013). The main difference between these two methods was that the first one made the participants feel an emotion, to change their moods, while the second one made the music either pleasant, or unpleasant to hear. Consequently, it could be that actual emotionally charged music leads to an underestimation of temporal duration, whereas an unpleasant one leads to an overestimation effect.

1.5.4. Control and consciousness

Two other processes stood out when analysing the papers extracted from the database search (i.e., perceived control of the situation and consciousness of the interference). First, it is a known fact that emotion can be processed unconsciously (i.e., Damjanovic, Meyer, & Sepulveda, 2017; Doi & Shinohara, 2016) and that RTP is unconscious. Despite these facts, only one study has explored the effect of unconscious emotion (i.e., neutral, positive, and negative pictures) processing on time perception (Yamada & Kawabe, 2011). In this study, half the participants performed a TRT (2700ms) in a masked condition (i.e., unconscious perception of the stimuli), while the other half performed the same task in an unmasked condition (i.e., conscious perception). Only the negative pictures led to a significant overestimation effect, the positive pictures not affecting the participants' time perception. Furthermore, this overestimation remained significant in the masked condition, supporting an unconscious effect of emotion on time perception.

Interestingly, it appears that having knowledge about emotional interference on time perception may affect this same interference (Droit-Volet, Lamotte, & Izaute, 2015). In their study, the authors used a TBT (i.e., 400-1600ms) including emotional expressions (i.e., anger and neutral). Part of the participants did not receive any extra information, other participants were told the true effect of emotion (i.e., overestimation of time), and the last group received false information (i.e., underestimation of time). This study showed that only the false information and no information groups exhibited an impaired time perception. In a second experiment the authors explored more emotions (i.e., anger, disgust, shame, and neutral) and either told the participants no information, or false information (i.e., low-arousing pictures leading to overestimation), not including a true information group. The only significant effect was observed with angry faces where there was a significant interaction between the group and emotion. This interaction showed that there was a lengthening effect in the group without information, while there was no effect in the group given false information. These results suggest that participants can partially control the interference caused by emotion because the interference disappeared once they were informed of its existence.

Other studies explored how individuals can control emotional interference on time perception through the perceived control one has over the situation itself. Buetti and Lleras (2012) compared arachnophobes and non-arachnophobes in five experiments which included pictures varying in terms of arousal (i.e., low- and high-arousal) and valence (i.e., positive and negative), as well as spider pictures. All the experiments included a TBT (i.e., 400-1600ms) and showed that the spider pictures were judged as more arousing and negative than the highly arousing negative pictures (i.e., for the arachnophobes). In the first experiments, non-arachnophobes saw 75% negative pictures, diminishing their perceived control over the situation. This showed an interaction between valence and arousal, high-arousing negative pictures being overestimated compared to positive ones and the opposite effect for low-arousing pictures. The second study replicated the previous results with arachnophobes; the more phobic the participant was, the longer were the spider pictures' durations estimated. The authors started manipulating perceived control in the third experiment where the participants were told that by pressing a button, more positive pictures would appear. On top of this, the proportion of negative pictures dropped to 25%, which increased the participant's perceived control. The results showed no significant effect of the negative pictures, spider pictures included. In the fourth study, the proportion of negative pictures remained at 25% to the exception that participants were not told that pressing a button would change the proportion of pictures, diminishing their perceived control. The results showed that negative pictures were overestimated, showing that the lack of significance in the third study was not solely due to the diminished proportion of negative pictures.

Similar to the previous study, Mereu and Lleras (2013) manipulated their participants' perceived control over the appearance of negative pictures while performing a TBT (i.e., 400-1600ms). The participants were split between three groups: (i) 75% of positive pictures who were deceptively told that their action was impacting the next picture's valence; (ii) the opposite percentage with the same false information given; and (iii) 75% of positive pictures without being deceived. The latter group showed lower perceived control, which did not vary between the two other groups. Concerning time perception, only the group with 25% positive pictures and the not-deceived group with 75% positive pictures overestimated the duration of negative pictures. Although the difference between the 75% and 25% group could be explained through the sole proportion of pictures, the difference between the two "75%" groups can only be explained through the perceived control effect.

1.6. Time perception and cognition

In relation to the associations between cognition and time perception, 52 papers were identified. These studies explore numerous facets of cognition both in retrospective and prospective designs, the second paradigm being more prominent. For clarity's sake, these studies will be separated into six different sub-headings in this section: (i) coding simplicity (*n*=10), (ii) cognitive load (*n*=14 papers), (iii) attention (*n*=9), (iv) executive functions (*n*=7), and (v) ageing (*n*=12). The areas of coding simplicity, cognitive load, and ageing are sub-divided into further sub-sections.

1.6.1. Coding simplicity

Coding simplicity refers to the 'Storage Size' hypothesis which states that time perception relies on the number of items stored in memory, their complexity, and how they are coded (Ornstein, 1969). Since Ornstein published his experiments, several authors have tried to replicate his results, extend them, or challenge them (e.g., Bi, Yuan, & Huang, 2013; Block, 1974). These studies showed that while in RTP, the number of stimuli and their complexity lead to an overestimation of temporal duration (Block, 1974; Vitulli & Shepard, 1996), the results from PTP studies being less consistent (e.g., underestimation effect, Bi et al., 2013; Overestimation effect, Macar, 1996).

In PTP, Macar (1996) first explored the complexity (i.e., words or strings of "X") and periodicity (i.e., appearing periodically or aperiodically) of the stimuli and also explored the effect of quantity (i.e., 12, 18, or 36 stimuli) in a TRT (i.e., 18s). The participants either watched the strings of "X" passively, counted the words ending in 'e', counted the animal words, or counted both kinds of words. A control series with a straight line was created (i.e., simply observing a straight line for the whole task). There was no significant difference between the straight lines or X-letter conditions, all the other conditions being underestimated compared to these two (i.e., the animal condition being judged the shortest). While aperiodicity significantly reduced the perceived duration of the series, the number of stimuli lengthened it (only significantly between the 12- and 18-word conditions). Even though this appears to fit Ornstein's theory, and the results found in RTP, the opposite trend of results was found by Bi, Yuan, and Huang (2013). In this study, the participants were asked to perform a memory task (i.e., set of stimuli of 2, 4, or 6 items) and a TRT (i.e., 2500ms). The results showed that when the set of stimuli included 4 or 6 items (i.e., compared to 2), the participants tended to underestimate duration which directly contradicts the previous results.

On the same topic, Fortin et al. (1993) carried out a series of experiments on the association between working memory and time perception, showing that the number of stimuli was positively associated with the temporal estimation. In their first paper, participants had to decide whether a probe was presented in a previous set of images or not while producing regular 2-second intervals (Fortin, Rousseau, Bourque, & Kirouac, 1993). The participants produced shorter intervals (i.e., overestimation of time) when more items were included in the first set of pictures. These results were replicated when the participants had to find a previously introduced picture in a set of random pictures only if the picture was not part of the new set. In a further piece of research, Fortin and Rousseau (1998) reproduced the previous results with a TRT (i.e., 1600ms, 2000ms, and 2400ms). In this experiment, participants saw a set of stimuli, were presented an interval, and then saw another stimulus (i.e., either part of the previous set or not). The participants then had to wait for the same duration as the interval to decide whether the word was previously presented or not. Although this study showed that the more stimuli, the longest the estimation, their second experiments showed the opposite results when the stimulus appeared within the interval to be measured. A final paper replicated the previous study's results with more durations (i.e., 1850ms, 2150ms, 3700ms, 4300ms, 5550ms, and 6450ms) (Fortin & Couture, 2002).

Stimuli complexity

Regarding complexity, Ornstein (1969) postulated that more complex stimuli would take more space in the storage and as a consequence would lengthen the duration. In his second experiment, participants evaluated figures varying in the number of interior angles and compared the duration of two different figures (i.e., both lasting 30s). Only the presentation duration of the simplest figure was underestimated compared to the most complex ones, the difference being non-significant between all the other figures. In conclusion, the hypothesis on the complexity of the figure itself was only partially supported.

Block (1974) tried to replicate these results in his second experiment where participants listened to three segments (i.e., music for 200s, blank for 160s, and music for 140s) while observing slides with four words (i.e., either of the same category or from different ones – coding complexity). When participants compared the second duration to the first, the group who observed the complex slides estimated the time as longer than the participants processing the simpler slides. However, Block (1978) failed to replicate these results in another experiment where the participants had to process either a complex (i.e., irregular black block distribution) or simple (i.e., regular distribution) stimuli pattern and compare their duration. This would indicate that for complexity to affect RTP, the level of processing would need to be higher than a figure structure.

Coding complexity

Ornstein (1969) postulated that the more complex the coding of a stimulus would be, the longer its duration would be estimated. The author supported this hypothesis by making participants listen to either simply coded stimuli (i.e., each sound repeated 20 times before passing onto the next one) or complexly coded stimuli (i.e., all the sounds repeated 20 times but placed randomly) for five minutes. The participants judged the presentation of the complexly coded stimuli as lasting longer than the other tape. These results were replicated in Ornstein's other experiment (1969) in which participants observed a series of curves which could either be placed randomly (i.e., complex), structured in a random shape (i.e., moderately complex), or form the word 'man' (i.e., easy). The easier configurations of the curves were estimated as shorter, results which were replicated in the last study led by Ornstein (1969) where he replaced the random shape with an insect shape. Similarly, Block (1978) exposed his participants to series of black and white figures either coded in a predictable pattern (i.e., a black block going through a white line) or unpredictable one (i.e., random pattern). The less complex coding (i.e., predictable pattern) was judged as shorter than the other one, supporting Ornstein's theory.

Coding simplicity – conclusion

In this section, coding simplicity was divided into three main sections (quantity, stimulus complexity, and coding complexity). Duration estimation in RTP is a direct positive function of the number of stimuli (Block, 1974; Ornstein, 1969). These results are not as consistent in studies exploring PTP, as one study showed that the time estimation increased with the number of stimuli as in RTP (Macar, 1996), while another showed the opposite results (Bi et al., 2013). This difference could be due to the method used, Macar (1996) using a TCT while Bi et al. (2013) used a TPT. This hypothesis is supported by Fortin et al.' studies showing that when the memory set size of working memory tasks increased, time perception lengthened (Fortin & Couture, 2002; Fortin & Rousseau, 1998; Fortin et al., 1993). When TCT relies on working memory (i.e., participants comparing a new duration to a stocked one), it appears logical that the number of stimuli lengthened the duration as in Macar's study (1996). On the contrary, since TPT does not rely on working memory, it would explain the lack of significant results in Bi et al.'s (2013) paper.

The results varied for the stimulus complexity as well with either an overestimation for complex stimuli (Block, 1974), partial results (i.e., underestimation of one condition; Ornstein, 1969), or no results (i.e., Block 1978). These differences of results could be due to words in Block's (1974) study requiring more resources than the figures in the two other studies. Finally, it appears that a higher complexity of the stimuli's coding leads to an overestimation of duration in RTP (Block, 1978b; Ornstein, 1969).

1.6.2. Cognitive load

Studies exploring the impact of varying cognitive load on time perception have used two principal methods to manipulate the difficulty of the experiment. The first one asks participants to perform different tasks with different levels of cognitive requirement (e.g., either reading or memorizing words), while the second uses the same task with different levels of processing (e.g., multiplying 2 and 6, or 24 and 6). Both these experimental methods appear to show similar results, i.e., an underestimation of time perception (e.g., Baldauf, Burgard, & Wittmann, 2009; Marshall & Wilsoncroft, 1989).

Variation of the task

Words are stimuli of choice when one wants to create several tasks using the same stimuli (e.g., observing the words, count the letters, memorize the words). For example, McClain (1983) asked his participants to either rewrite words (i.e., 15, 30, 45 items), semantically encode these, or to do both these task for 120s. Afterwards, they were asked to estimate this duration either prospectively or retrospectively. There was a significant interaction between the type of task and number of words in the PTP, while no significant effect was observed in the RTP. This interaction shows that the number of words was negatively associated with the estimation when participants had to encode the words and positively when they had to rewrite them. This extends the previous section's conclusion, as the level of processing directly affected the number of items' effect on time perception. In another study, participants were asked to either read words, perform a naming task, or to provide synonyms for 14 seconds before reproducing this duration prospectively (Zakay, Nitzan, & Glicksohn, 1983). The participants underestimated the duration when the task was more complex (i.e., synonym). Using numbers rather than words, Burnside (1971) made participants either perform multiplication, addition, or reading for varying durations (i.e., 10s, 12s, 14s, 16s, 18s, and 20s). Participants underestimated the duration of the arithmetic conditions compared to the reading one.

The other way to manipulate the level of processing that does not control the stimuli is to include different tasks. In a first study, participants were asked to perform an experiment varying in terms of complexity (i.e., only a TPT, TPT and tracking task, listening to the radio, observing and counting the movement of a stimulus, arithmetic problems, and long-term memory questioning). The results showed that the accuracy of the production significantly decreased as the cognitive demand of the task increased. In another study by Wilsoncroft and Stone (1975), participants were asked to perform a first task (i.e., mirror-drawing, simple arithmetic, or reading) for varying durations (i.e., 12s, 14s, 16s, 18s, or 20s). After a sound, they were asked to perform either the same task or another one for a duration they estimated as the same as the first task. When the arithmetic task was first, it was underestimated and in contrast, it was overestimated if it was the second task (no other comparison reached significance). More recently, Marshall and Wilsoncroft (1989) explored the effect of timing strategy within three different temporal tasks (i.e., TPT, TRT, and ET) with the same duration of 30 seconds. Participants performed four tasks: listening to two sounds delimiting an interval, trying to tap regularly during the same interval (i.e., counting strategy), reporting the hue of dots, or performing a Stroop task. The counting strategy only improved the ET accuracy. Also, the Stroop and colour tasks were underestimated in comparison to the simple task in all the temporal tasks, and shorter than the strategy task in the TPT.

Variation of the difficulty

In this section, the different studies varying the difficulty of their tasks will be separated based on their temporal task (i.e., TPT, TRT, and ET), the two RTP studies being explored separately. Irrespectively of the method, it has been observed that an interval is systematically underestimated with higher complexity utilizing a prospective paradigm (e.g., Brown & Smith-Petersen, 2014; Zakay, 1998), while only one of the RTP studies showed similar results (Hicks, Miller, & Kinsbourne, 1976).

Temporal Production Task

Baldauf et al. (2009) asked their participants to drive in a virtual environment with three difficulty settings (i.e., easy, medium, hard) while producing regular intervals (i.e., 17s). This study showed that the participants underestimated time in the hard setting, but overestimated it in the medium and easy ones. The two following studies led by Brown (1997, 2000) explored a bidirectional interference effect between a temporal and non-temporal task. In this kind of design, both tasks were performed alone first and then altogether (i.e., dual-task setting) by the participants. In the first experiment by Brown (1997), the participants performed a TPT (i.e., 2 and 5s) and a Pursuit Rotor Tracking (i.e., difficulty based on the speed of the item to track). The results showed that the variation of the production was higher in the dual-task paradigm, with no difference between the two levels of difficulty. In Brown's second experiment, participants were asked to find a specific letter among distractors either looking like the letter (i.e., hard setting – e.g., X and K) or looking different (i.e., easy setting – e.g., X and O). The participants underestimated the duration in the dual task setting, and the underestimation was stronger in the hard setting. Finally, the last experiment within this study replicated the results with subtraction problems, with a bidirectional interference (i.e., lower performance in the subtraction task). In their later study, Brown and Merchant (2007) replicated the same results by using a Sequence-Reasoning task (e.g., A follows B) varying in difficulty (i.e., either positive or negative sentences). Although there was no effect of difficulty, the participants had diminished performance on the sequencing task when in the dual-task paradigm (i.e., bidirectional interference). In this study's second experiment, the participants were asked to observe stimuli evolving in a logical order (i.e., 1A, 2B, 3C) and press a button if one of these did not fit. In the easy setting, participants only observed the letter, observing both stimuli in the hard setting. Only the hard task led the participant to underestimate the duration and a bidirectional interference.

Temporal Reproduction Task

In the following two studies, the participants first performed a task for a specific duration and were asked to press a button for the same estimated duration. In the first study (Wilsoncroft, Stone, & Bagrash, 1978), participants performed arithmetic problems including numbers with either one or two digits varying in difficulty (i.e., numbers between 2 and 5 or 6 and 9) for varying durations (i.e., 8s, 12s, 16s, and 20s). Both single digit arithmetic tasks were underestimated, the easy version being the most underestimated. The other task using TRT included a temporal order task (i.e., stimuli order of appearance) with 10, 15, and 20 words (14s, 21s, and 28s, respectively). Moreover, participants either only observed the words or were asked to do oral arithmetic at the same time (i.e., either subtracting 3 or 7 from digits). A bidirectional interference between the temporal order task and the TRT was observed, with participants being less accurate in both tasks in the dual-task setting.

Retrospective Time Perception

Both studies in this section explored PTP as well as RTP, the PTP sections showing the same results as before. In the first study by Hicks, Miller, and Kinsbourne (1976), participants were asked to sort cards (for 42s) by either piling them into one deck, two decks based on their colour, or four decks based on the colour and shape. When asked to estimate the duration, there was no difference between the three conditions in RTP. The results in the PTP were significant, the participants underestimating the duration when the task was more complex, results replicated in another study (Hicks, Miller, Gaes, & Bierman, 1977). In the second study (Brown, 1985), participants were asked to either observe a figure, follow its line with their finger, or follow its line through a mirror. Participants were asked to both reproduce and estimate the durations (i.e., 16 and 32s). The author did not separate PTP and RTP in his analysis and showed that participants underestimated the 32-second duration when following the line (both conditions).

Cognitive load – conclusion

This section separately evaluated studies varying the task and the studies manipulating same task difficulty. The first experimental designs yielded consistent results, which was a clear underestimation of the duration in the PTP design when the task required deeper processing levels (e.g., Marmaras, Vassilakis, & Dounias, 1995; Wilsoncroft & Stone, 1975; Zakay et al., 1983). The only study using this method under the RTP design found no effect (Mcclain, 1983). Studies manipulating the difficulty of the task in PTP showed that the participants systematically underestimated durations when performing a concurrent non-temporal task (Baldauf et al., 2009; Brown, 1997; Wilsoncroft et al., 1978). In RTP, the results were inconclusive, as the only study showing a significant underestimation did not analyse RTP and PTP separately (Brown, 1985). Finally, three studies yielded bidirectional interference, meaning that both the temporal and non-temporal tasks were affected by the dual-task design. These experiments showed that time perception via a PTP design share the same attentional pool as the processes for both sequence reasoning and monitoring (Brown & Merchant, 2007) and arithmetic problems (Brown, 1997; Brown & Smith-Petersen, 2014).

1.6.3. Attention

Attention plays a crucial role in time perception, even if it is hypothesized that it affects RTP and PTP in an opposite way. In RTP, a task requiring more attention would lead to overestimation due to the larger number of events happening within the interval, while in PTP, attention will be diverted from time (i.e., underestimation effect). Studies exploring the effect of attention on time perception can be classified into studies using a dual-(multi)task design (conscious attention allocation), and studies cuing the stimuli (i.e., spatial and transient attention). Despite the discrepancies, the main finding was that in PTP, the duration appears to be underestimated when attention is diverted from time perception. Concerning RTP, only one study fits this descriptor, and for this reason nothing definitive can be concluded, even though the study showed that with more required attention, participants were less precise in their estimation (Brown, 1985).

To measure the impact of attention on PTP, experimenters need to divert participants' attention from time itself, mostly by making them perform another non-temporal task. In their study, Burle and Casini (2001) explored a dual-task paradigm and its interaction with activation levels (i.e., hearing clicks in an intense or slow rhythm). The participants were asked to produce a regular interval (i.e., 1100ms) either alone or while performing a reaction time task. In the dual-task paradigm, the participants overestimated the duration, with no interaction with the activation levels. While this study used a non-temporal concurrent task to divert the participant's attention, Brown and West (1990) explored how two concurrent temporal tasks would interfere with each other. The participants were asked to observe either one, two, three, or four stimuli simultaneously with either short durations (i.e., 6, 8, and 10s) or long ones (i.e., 12, 14, and 16s). After observing the stimuli, the participants were asked to reproduce one of the durations observed. The experiment showed that the more stimuli the participants were asked to attend to, the more errors there were in their time judgment. The authors further replicated these results using a TPT instead of a TRT with the same method and durations.

Basing their thoughts on these results, several authors explored whether individuals could consciously direct their attention away from time. For example, in a study by Kladopoulos, Hemmes, and Brown (2004), participants either only performed an ET (i.e., 40 and 60s), an ET while reading words, or an ET and a memory task. This showed the classical underestimation when the participants also performed a memory task in spite of not showing any difference when reading the words. In their second experiments, in addition to making the participants perform both the memory task and the ET, the authors asked the participants to focus solely on the ET, the memory task, or on both equally. The results showed that the participants overestimated the duration when focusing on the ET compared to the two other conditions. Using a similar design, Macar, Grondin, and Casini (1994) made their participant perform both a word categorization task (i.e., words distributed either periodically or aperiodically) and a TRT (i.e., 12 and 18s). Besides, participants were asked to focus on the non-temporal task at 100%, 75%, 50%, 25%, or 0%, and to focus on the TRT for the remaining percentage. The more attention was directed to the categorization task, the more error there was in the TRT and the less error there was in the categorization task, results which were replicated in two other experiments using a discrimination task. In another study, participants were asked to observe a Light Emitting Diode (LED) and judge its duration and intensity variation while distributing their attention between the tasks in the same way as the previous study (Casini & Macar, 1997). For the duration, participants were asked to decide whether the light lasted 2.5s or 3.5s. Regarding the intensity variation, the LED was either getting brighter toward the beginning or the end of the interval, the participant having to decide if the change in luminosity was important or not. Participants underestimated the duration when they focused on the light intensity or when the increment occurred at the end of the interval.

Another way of testing the attentional effect is the use of cues, exploring the attention orientation. In these cases, participants received a cue with regards to the following stimulus (e.g., its duration, location, and modality), which helps them to focus on the stimulus because they were prepared. For example, Mattes and Ulrich (1998) cued the upcoming type of stimulus (i.e., auditory or visual) to their participants, the cue being either right or wrong. Participants tended to overestimate the duration when the cue was right. In their following experiment, the authors cued the position of the stimuli rather than their modality, replicating the previous results. Osugi, Takeda, and Murakami (2016) replicated these results in their own study. Finally, this cueing effect has been explored within transient attention (i.e., attention driven by sudden change in the visual field) which operates in very short duration (i.e., around 100ms) by Yeshurun and Marom (2008). Two discs (i.e., lasting between 23 and 94ms) appeared in front of the participants, one of them being cued about where and when it would appear, while the other one was only cued about when it would appear. The results showed that the disk cued on its location was perceived as lasting longer than the other disk (i.e., only for duration shorter than 94ms). These results fit the activation of transient attention (i.e., around 100ms), especially because the author replicated these results with longer durations (i.e., 23ms to 165ms), showing that it remained significant up to 118ms only.

Attention – conclusion

As stated earlier, studies exploring how attention can affect time perception fall into three types: studies using a simple dual-task design, studies asking participants to distribute their attention consciously, and studies using cues to direct the participants' attention. The simple dual-task studies all showed similar results, an underestimation when participants performed a non-temporal task while estimating a duration (Burle & Casini, 2001; Chinchanachokchai, Duff, & Sar, 2015; Kladopoulos et al., 2004). Similarly, Brown (1990) showed that when performing two concurrent temporal tasks, participants were less accurate and underestimated the duration. Regarding endogenous attention, several authors showed that when participantsconsciously diverted their attention from time, they underestimated the duration (Casini & Macar, 1997; Kladopoulos et al., 2004; Macar et al., 1994). Finally, the studies exploring exogenous attention (i.e., uncontrolled diversion of the attention from time through cuing on a non-temporal stimulus) showed that stimuli that were cued were perceived as longer in presentation duration than uncued stimuli, (Mattes & Ulrich, 1998; Osugi et al., 2016). In addition, Yeshurun and Marom (2008) showed that time perception can be influenced in the earliest stage of cognition based on the significant effect of transience on time perception.

1.6.4. Executive functions

Although the following studies manipulated the effect of cognitive load on time perception too, they were separated from the previous section due to the specific exploration of executive functions. These studies exhibited a bidirectional interference between time perception and executive functions, indicating the use of the same attentional pool (i.e., time perception as an executive function). The following studies based their research on two pre-existing models of executive functions (i.e., Baddeley's working memory model and Miyake's executive function model). Miyake's (2000) model of executive functions includes three main components: (i) shifting (i.e., the ability to switch between two different tasks), updating (i.e., the ability to replace outdated information by new useful information), and inhibition (i.e., the ability to retain a response, to stop a behaviour). Baddeley's (1992) model of working memory includes three main components: (i) the Central Executive (i.e., supervising and coordinating the two following components and managing cognitive skills), (ii) the visuospatial sketchpad (i.e., stores visuospatial information and processes it), (iii) the phonological loop (i.e., constituted of the phonological store and articulatory control process, handles auditory and written stimuli).

Despite the two following studies not mentioning Miyake model's in their manuscript, they can be associate to this model based on their exploration of inhibition which is included in it. In Brown and Perreault's (2017) study, participants performed a Go/NoGo task (i.e., pressing a button in front of a specific stimulus, but not in front of another) with two levels of difficulty (i.e., either 75% of NoGo trials or 25%) and a TPT (i.e., regular 5s intervals). The participants were asked to perform all the tasks individually, as well as the TPT and Go/NoGo (with both levels of difficulty) in a dual-task setting. The study showed a bidirectional interference with the participants underestimating time in the TPT and having a slower reaction time (RT) and lower sensitivity in the Go/NoGo task. The second study on inhibition explored it among children (Meaux & Chelonis, 2003) with both a TRT (i.e., 3s, 6s, 12s, and 24s) and the Conners' Continuous Performance Task (i.e., inhibition measure; Conners, 1995). Besides, the participants' parents filled in a questionnaire on their children's time perception and organisation of behaviour in relation to time (i.e., the Conners ADHD/DSM IV Scale, Conners, Sitarenios, Parker, & Epstein, 1998). The results showed that both the questionnaire and the measure of inhibition negatively correlated with time perception, indicating that these two variables are associated among children. Nevertheless, this was not an indication of a bidirectional interference like the previous study, as it was not set in a dual-task design. Another study indirectly associated with Miyake's (2000) model explored the interaction between time perception and shifting (Fortin, Schweickert, Gaudreault, & Viau-Quesnel, 2010). In their study, participants had to undergo a task-switching task simultaneously with a TPT (i.e., 2s). The authors found no difference in time perception between the switching and non-switching trials and reproduced these results in two other experiments varying the interval between the stimuli or type of trials present within a block.

The only study exploring the entirety of Miyake's model (i.e., the three components) was split into three different experiments exploring a single component along a TPT (i.e., 5s) (Brown, Collier, & Night, 2013). The participants performed both tasks alone, then simultaneously, by either focusing on both or one of them. The focus of their first experiment was the shifting component, the authors showing that the participants underestimated time and that the RTs in the shifting task were higher in the dual-task setting, indicating a bidirectional interference. In the experiment on the updating component, the previous results on shifting were replicated with the Mental Counters Task (Larson, Merritt, & Williams, 1988). Nonetheless, the interference on the updating only occurred when the participants solely focused on the TPT. Finally, the last experiment exploring inhibition (i.e., through a Stroop task) showed the same results as the shifting study, that is, a bidirectional interference with time perception.

Only one study has explored Baddeley's model (Baddeley, 1992) by using a single task investigating the central executive component (i.e., a random number generation task; Brown, 2006) coupled with a TPT (i.e., 5s). The participants were asked to perform both tasks alone before performing them in a dual-task setting, showing the same trend of results as for Miyake's model, that is, a bidirectional interference. Basically, the participants underestimated time and produced more redundant and less random numbers in the dual-task. The two following studies exploring Baddeley's model incorporated Miyake's model to reach a deeper understanding of executive functions.

The first study (Ogden, Wearden, Gallagher, & Montgomery, 2011) included a TPT (i.e., 2s) plus the four following tasks exploring executive functions: (i) the Random Letter Generation (i.e., RLG, exploring the central executive component in Baddeley's model), (ii) the Serial Subtraction of Sevens (i.e., SSS, measuring the updating component in Miyake's model), (iii) the Controlled Oral Word Association (i.e., COWA, testing access to semantic memory), and (iv) the Plus-Minus Task (i.e., PMT, testing the shifting component from Miyake's model). Among the previous tasks, only the RLG did not affect the time perception of the participants (only a higher variability of the production was observed) which contradicts Brown's (2006) study. Concerning the non-temporal tasks, only the RLG and SSS were affected by the dual-task setting, indicating that solely the updating component exhibited bidirectional interference. The previous authors led further studies exploring the difference in interaction between different temporal tasks (i.e., TGT – 100 to 700ms, TRT – 400, 600, 800, and 1000ms, and ET – 77, 358, 582, 767, 958, and 1183ms) and executive functions (Ogden, Wearden, & Montgomery, 2014). The executive functions explored were shifting (i.e., Number-Letter Task), the central executive (i.e., Random Letter Generation), access (i.e., Chicago Word Fluency Test), and working memory (i.e., Computation Span). Compared to the previous studies, this one explored the interaction through a correlational approach rather than a dual-task setting due to the numerous tasks (i.e., 7 tasks). There was a positive correlation between the correct responses in TGT and both updating and access measures as well as between reproduction accuracy and shifting. There were also negative correlations between the variability of the reproduction and both updating and access measures. After comparing the high and low scores in access and updating, all the participants in the high group performed better in TGT. Regarding ET, only the group with higher scores in the access task performed better. As for TRT, none of the groups performed better on this task.

Executive functions – conclusion

The studies exploring executive functions based their theories on either the Miyake and/or Baddeley model. With regards to Miyake's model, the two studies exploring the interaction between inhibition and time perception appear to indicate a bidirectional interference, one of these studies only showing a correlation (Brown & Perreault, 2017; Meaux & Chelonis, 2005). Even though Fortin (2010) failed to find any effect of a shifting task on TPT, Brown (2013) studied the entirety of Miyake's model's effect on time perception, every participant having to produce a regular interval while performing either a shifting, updating, or inhibition task. This study showed that all the executive function tasks not only impaired production (i.e., underestimation of duration), but were impaired with regards to accuracy or longer reaction time when performed at the same time as a temporal task.

The only study focusing solely on Baddeley's model explored the central executive component, the other components concerning storage abilities (Brown, 2006). Like Brown (2013), this study showed a bidirectional interference effect. Finally, Ogden explored the executive functions by merging both Miyake's and Baddeley's models in order to achieve a deeper understanding of executive functions (Ogden et al., 2011, 2014). These studies showed deep relationships between time perception and executive functions, even though these varied depending on the temporal task used. The almost systematic bidirectional effect between temporal and executive functions tasks points towards a common attentional pool between these processes. Since these two functions share a common attentional pool, this would mean that time perception is an executive function.

1.6.5. Age

Studies investigating the effect of age on time perception fall into two types. The first one is a developmental approach among children, while the second one tests the impact of cognitive aging among elders (i.e., aged around 60 to 70 years old). The first approach is based on the observation that time perception is not inborn, since children only start to discriminate time at the age of four months, exhibit the same properties of adult time perception by the age of three years, and start being as sensitive as adults at the age of eight years (Droit-Volet, Clément, & Wearden, 2001; Droit-Volet, Delgado, & Rattat, 2006). Regarding studies on older participants, they are based on the fact that cognitive functions deteriorate with old age (e.g., Giulioli & Amieva, 2016; Petersen, 2016). Since time perception greatly relies on cognitive function, authors tested whether time perception deteriorated as much among older participants, and if this was due to their dulled cognition.

Children

It appears that cognition impairs time perception among children in similar ways as it does for adults (i.e., underestimation of time; Arlin, 1986a, 1986b). Separating the effect of stimulus quantity and the level of processing required, Arlin (1986a) explored how cognitive load affects 12-year olds' time perception (i.e., TCT – 8s). The children were observing pictures (i.e., either 4 pictures of 2s, or 8 pictures of 1s) and either were asked to decide if the drawing represented a living or non-living thing (i.e., deep processing) or were simply asked to repeat their name (i.e., shallow processing). There was a main effect of quantity (i.e., leading to an overestimation) and processing depth (i.e., leading to an underestimation). In order to explore a developmental trend, the second experiment used the same design with four groups of children from different age groups (i.e., 6-year olds, 8-year olds, 10-year olds, and 12-year olds). Because the experiment included younger participants, the previous method was adapted to include fewer pictures (i.e., 3 and 6). The experiment replicated the previous effect of quantity and depth of processing with a main effect of the children's age and an interaction between age and processing level. The study demonstrated that processing depth was stronger among older participants than younger ones. In his second study, Arlin (1986b) explored the effect of quantity and complexity of the stimuli (i.e., single line or three-line figures) among children (i.e., 6-, 9-, or 12-year olds) to investigate attentional level. Participants faced either four screens lasting 3s or two screens of 6s (both lasting a total duration of 12s) and either compared the figures actively or simply watched them to fluctuate the attentional level. Although there was a main effect of age, attentional demand (i.e., underestimation of time with more attentional demand), and quantity (i.e., overestimation with higher quantity), there was no effect of complexity (contrary to adults' studies). Additionally, there was an interaction between age and both attentional and quantity effects, the two older groups showing an important attentional effect which was almost non-existent in the youngest groups. The effect of quantity, on the other hand, showed the opposite effect (i.e., being stronger among the youngest group than the other groups).

The following studies replicated with children the attentional effect observed among adults (i.e., underestimation when attention diverted from time in PTP). Exploring this effect in RTP and PTP, Zakay (1992) made 8-year olds estimate the duration of a lightbulb (i.e., 3 or 6s) varying in terms of light intensity (i.e., low or high). The participants could either do it twice prospectively, or once retrospectively followed by a second time prospectively. The results showed that the intense light was estimated to be shorter in duration in the group performing the prospective task twice, while the opposite effect was observed for the group performing the retrospective task. In the second experiment, Zakay explored the effect of distraction on the previous results, by making the RTP group do the same task in a TPT with longer duration (i.e., 6 and 10s). The participants were asked to perform three productions, the second one being interrupted by a noise for 1.5s. On top of replicating the results regarding the light intensity, the author showed that the distraction led to an underestimation of time. Gautier and Droit-Volet (2002a) also explored attentional interference on time perception, opting for a developmental approach by comparing 5- and 8-year olds in a dual-task paradigm. Participants were asked to perform a TRT (i.e., 6 and 12s) either in a single task paradigm or while naming pictures (i.e., easy – entirely drawn pictures, hard – degraded pictures). The dual task was systematically underestimated compared to the single task, with the effect being stronger in the longer duration. However, there was no effect of age, its interaction with task being marginally significant (p=.059). When comparing the task effect in the two age groups, it was observed that in the 5-year old group, both dual tasks were underestimated more than the single task, while in the 8-year old group, only the hard dual-task was underestimated. In another study, the same two authors tested how distraction affected time perception (i.e., TBT – 2 and 8s) among children (i.e., 5- and 8-year olds; Gautier & Droit-Volet, 2002b). There was no main effect of distraction, yet there was an interaction with age group, the younger children exhibiting an overestimation effect on the distractor trials, the opposite effect being observed among older children.

In addition, studies on children explored the interaction between executive functions and time perception. For example, Rattat (2010) explored separately the central executive and the storage components among 5- and 8-year olds. In the first experiment, they performed both a TRT (i.e., 6 and 12s) and a random two-choice reaction time task (i.e., CRT-R to measure the central executive component; Szmalec, Vandierendonck, & Kemps, 2005) either simultaneously or separately. In addition, the participants performed the CRT-R either in an auditory or visual modality. The children under-reproduced the duration in the dual-task setting, the younger participants only showing this effect in the longer duration. The performance in the CRT-R equally worsened in the dual-task, indicating a similar bidirectional interference as observed among adults. In the second experiment testing the storage components, the children (i.e., 5- and 8-year olds) were asked to perform the same TRT (i.e., 6 and 12s) as well as a digit memory task and a visuospatial memory task (i.e., either in a single-task or dual-task paradigm). As in the first experiment, the storage tasks could either be performed in visual or auditory modality. In the visual modality, the participants under-reproduced the interval in the dual-task condition, especially for the 12s duration as this difference was stronger for this duration in the visuospatial task. The same under-reproduction was observed in the auditory modality with no difference between the durations. Regarding the non-temporal tasks, there was an interaction between task condition, memory task, age, and modality. For the visual modality, the accuracy of the visuospatial task worsened in the dual-task paradigm for all the participants, but the digit task variables worsened only among the 8-year olds. In the auditory modality, only the digit task accuracy dropped in the dual-task setting, with a stronger effect in the 12s duration.

Exploring the interaction between time perception, memory, and attentional levels, Zélanti and Droit-Volet (2011) recruited children (i.e., 5- and 9-year olds) and adults (23-year olds). The participants were asked to perform a TBT (i.e., 0.5-1s, 1.25-2.5s, 4-8s, and 15-30s), and to complete the Wechsler Memory Scale (Forward Digit Recall for short memory, and Backward Digit Recall for working Memory; Alloway, Rajendran, & Archibald, 2009), the Auditory Attention and Response Set Tasks from the Developmental Neuropsychological Assessment (NEPSY) for Attention (i.e., measuring both attention and executive function; Korkman, Kirk, & Kemp, 1998), and the attention/concentration index of the Children Memory Scale (CMS) with the Numbers and Sequences test (Cohen, 1997). The results showed that for the durations shorter than a second, the short-term memory measure predicted the variability improvement associated with aging, while for longer durations, this improvement was predicted by NEPSY tasks scores.

Hallez and Droit-Volet (2017) explored which cognitive skill may explain the difference in time perception between the single and dual-task paradigms among children. For this purpose, children (i.e., 5-, 6-, or 7-years old) performed a TRT (i.e., 6 and 12s), a colour discrimination task, and both these tasks simultaneously. Next, the participants were asked to complete tasks assessing short-term and working memory (Corsi Block-Tapping Test; Corsi, 1972), information processing speed (Code and Symbol from the Wechsler Intelligence Scale for Children, WISC; Wechsler, 2005), divided attention (i.e., listening to two things at once from the Test of Everyday Attention for Children - TEACh; Manly, Robertson, Anderson, & Nimmo-Smith, 1999), and selective and sustained attention (i.e., Sky search from the TEACh; Manly et al., 1999). There was an under-reproduction in the dual-task condition which was stronger in the 5-year olds compared to the 7-year olds. In the 6s condition, both attention tasks correlated significantly with the reproduction difference between the single and dual-task, only the selective and sustained attention correlating significantly in the 12s duration. Furthermore, when the author added the age groups in the previous model, only the selective attention remained significant in predicting the difference between the single and dual task.

Interestingly, Droit-Volet, Wearden, and Zélanti (2015) designed a comprehensive model of time perception among children (i.e., 5- and 8-year old) and adults (i.e., 24-year old) which included several measures of cognition and how it interacted with time perception. The participants performed three temporal tasks (i.e., a TBT, TGT, and TRT – 0.4-0.8s and 8-16s) and three cognitive tasks. To assess their working memory, the participants completed the Block-Tapping test Backward version (Wechsler, 1998) and the attention-concentration index of the CMS (Cohen, 1997). Participants completed the Selective Visual Attention Test from the NEPSY (Korkman et al., 1998) to assess selective attention and the Stroop test to measure both selective attention and inhibition. Finally, they completed the Trail Making Test Part A (Reitan, 1992) to assess information processing speed. In the long condition (i.e., 8-16s) the accuracy of the TRT was systematically lower and the accuracy of the TGT and TBT was lower only among children. Concerning the short duration (i.e., 0.4-0.8s), there was a lengthening effect for all age groups, with the effect being stronger for the 5-year olds (these effects were not found in the TGT, and only among the 5-year olds for the TBT). Furthermore, the TBT accuracy was predicted by the inhibition score while the TGT and TRT accuracy was predicted by attention. For the short duration accuracy, it was only significantly predicted by the processing speed score, and only in the TRT. Regarding the time perception variability, the TRT was more variable than the TGT and the adults were more constant than the children. Moreover, the variability was significantly associated with the inhibition score in the TBT for both duration range, while the TGT variability was predicted by the selective attention score in the short duration and the inhibition in the long duration.

Elderly

Only three studies explored the effect of aging among older participants compared to children or adults (Baudouin, Vanneste, Pouthas, & Isingrini, 2006; Brown, Johnson, Sohl, & Dumas, 2015; Ranjbar Pouya, Kelly, & Moussavi, 2015). Basing their thoughts on the negative impact of aging on memory, Pouya et al. (2015) hypothesized that elderly participants (i.e., 60-year olds) would have a worse RTP. For this purpose, the participants were asked to perform a ET (i.e., 40s) while navigating in a virtual environment and completing the Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005). The participants overestimating the duration (i.e., 14%) were significantly older and exhibited worse MoCA scores. Furthermore, participants older than 70 years tended to overestimate the duration compared to younger participants; and participants with a high score in the MoCA significantly overestimated duration compared to the other participants.

Basing their thoughts on attention rather than memory, Brown et al. (2015) explored time prospectively instead of retrospectively. In their study, young adults (i.e., 20-year old) and old adults (i.e., 69-year old) performed both a TPT (i.e., 5s) and a Flanker Task (i.e., measuring the ability to control a distractor's influence – interference control). The participants performed the TPT alone, then while performing a simple Flanker Task (i.e., no incongruent flankers), and finally while performing a complicated Flanker Task (i.e., incongruent flankers). Although the study showed that dual-task settings increased the production variability, there was no main effect of age or any interaction with other variables.

The last study on old age explored how executive functions (i.e., according to Baddeley's model) could explain the difference between young (i.e., 28-year old) and old (i.e., 72-year old) people's time perception (Baudouin et al., 2006). Participants either only performed a TRT (i.e., 3, 8, and 14s) or performed the TRT alongside a simple task (i.e., decided if a number is odd or even). To explore Baddeley's model, the participants completed the N-Back Letter Test (i.e., central executive; Baddeley, 1996) and the Alphabetical Span as well as the Computation Span tasks (i.e., storage components; Salthouse & Coon, 1994). Again, there was no main effect of age although it interacted with the condition, showing that the older participants were less accurate in the dual-task in comparison to the young ones. This difference was significantly linked to the storage components of Baddeley's model.

Age – conclusion

Studies on the effect of age on time perception comprise developmental studies exploring the effect among children, and studies testing the impact of cognitive aging on time perception among older participants. Three important results among adults have been replicated among children, namely the effect of quantity and cognitive load (Arlin 1986a, Arlin 1986b) and attentional interference (Zakay, 1992; Gautier 2002a, Gautier 2002b). Concerning attention, it is noteworthy that while distraction led to an underestimation similar to adults with older children (i.e., 8-year old), it led to the opposite effect with younger ones (i.e., 5-year olds). However, these results are contradicted by Arlin's (1986a) results which showed that the children around 6-years old actually underestimated duration more than 9-year olds when distracted. Finally, the children exhibited a bidirectional interference between time perception and the central executive component of Baddeley's model (Rattat, 2010). With regard to the storage components of the same model, the results are more complex even if an interference on the temporal task was observed. Other studies including children used a correlational approach to examine which neuropsychological measures best explain their time perception. These showed that the improvement of duration estimation sensitivity with age was explained by short-term memory for durations under a second, and by attention and executive functions (i.e., NEPSY score) for durations over a second (Zélanti & Droit-Volet, 2011). Additionally, when tested using a dual-task paradigm, 5-year old children's time perception was more affected than that of 7-year olds, this difference being predicted by selective attention (Hallez & Droit-Volet, 2017).

A study comprising both adults and children developed a comprehensive model of time perception including three different time perception measures, as well as working memory, selective attention, inhibition, and processing speed measures (Droit-Volet, Wearden, et al., 2015). The authors observed that time perception accuracy and variability interacted differently with different durations, tasks, and age groups. Accuracy was shorter for long durations (i.e., underestimation effect) and longer for short durations (i.e., overestimation effect). With regards to an age effect, accuracy was only higher for the 5-year old children, while variability was higher for all children compared to adults. In the long duration, accuracy was predicted by the inhibition measure for the TBT and by the attentional measure in the TGT and TRT; while, for the short duration, it was predicted by processing speed (i.e., only for the TRT). Variability was predicted by the inhibition measure in the long duration (i.e., only in TBT and TGT) and by inhibition in the TBT and selective attention in the TGT for short durations.

Among older participants, one study did not show any difference between older (approximately 69 years old) and younger (approximately 20 years old) participants (Brown et al., 2015), contrasted by other studies yielding interesting results (Baudouin et al., 2006; Pouya et al., 2015). The first one showed that the storage components of Baddeley's model were significantly linked to worsened time perception in a dual-task setting among older participants compared to young ones (Baudouin et al., 2006). The second study showed that a lower score on a validated measure of cognition (i.e., MoCA) led to overestimation of duration among old participants (Pouya et al., 2015).

In summary, these studies showed that for both developmental and cognitive aging, cognitive functions such as memory, attention, and executive functions are important in reaching a better understanding of how age affects time perception. Since these studies explored numerous different concepts with various measures, no definitive conclusions can be reached, and more research in this area is needed in order to achieve a more complete understanding.

1.7. Discussion

Emotion, a cognitive skill developed in the earliest stages of development, can easily be disturbed by both cognition and emotion. The effect of emotion is complex and includes studies exploring its interference through both auditory (i.e., sounds or music) and visual stimuli (i.e., pictures or emotional expressions). The studies exploring the impact on emotion with auditory stimuli did not yield any consistent results, with the exception of an overestimation of duration when listening to emotional music in a RTP design (Bisson et al., 2009; Bueno & Ramos, 2007).

At first glance, it would appear that the effect of emotional pictures on time perception would be due to arousal. Indeed, it appears that when inducing a mood change (instead of a pinpointing emotional effect), there is a multiplicative effect observed (Fayolle et al., 2014). Further supporting this point, studies showed that when two pictures depict the same emotion (e.g., disgust), the most arousing one will lead to more underestimation (Grondin et al., 2014). Contrarily, it appears that durations under 200ms are governed by other mechanisms, as Smith et al. (2011) found out that for these durations, emotional pictures led to an underestimation. This indicates an attentional process helping the individual to react promptly when faced with threats.

When it comes to emotional expressions, there was a main overestimation trend observed (i.e., especially for aggressive expressions) which was mediated by dynamism, gaze, and embodiment. While adding dynamism (i.e., morphing between two emotions, or shifting from neutral to emotional expressions) strengthened the effect (Dymond et al., 2014; Fayolle & Droit-Volet, 2014), the opposite results (i.e., nullifying the effect) were achieved by preventing the embodiment effect (i.e., Effron et al., 2006; Mondillon et al., 2007) or an averted gaze (Doi & Shinohara, 2009; Kliegl et al., 2015). The fact that an averted gaze nullifies the effect suggests a 'fight-or-flight' effect, an aggressive face being non-threatening when not directly targeting participants.

It was also shown that participants did not need to consciously process emotional stimuli to interfere with time perception (Yamada & Kawabe, 2011), but that when consciously processing stimuli, interference could be nullified by knowledge of the actual interference (Droit-Volet, Lamotte, et al., 2015). In addition, when participants felt in control of the situation, even when entirely fictitious, the impact of emotional pictures disappeared (Buetti & Lleras, 2012; Mereu & Lleras, 2013).

Regarding cognition, several authors tested Ornstein's storage size hypothesis (1969), which states that time perception is governed by the number of stimuli, their complexity, and the way they are coded into memory. Although the number of stimuli systematically increased the perceived duration in a retrospective design (Block, 1974; Ornstein, 1969), studies on PTP showed either a lengthening effect (Macar, 1996) or a shortening effect (Bi et al., 2013). It is noteworthy that Macar's study (1996) used a TCT which relies on working memory (i.e., comparing a memorized duration to a new duration), while Bi et al.' study (2013) used a TPT, a difference that may explain the results. This concurs with Fortin et al.' (1993; 1998; 2002) results showing that when the number of stimuli increased in a memory task, the duration was perceived as longer. Despite the lack of research, it appears that measures involving working memory in PTP (i.e., TGT, TCT, and TRT) result in a lengthening of duration when participants are asked to process more stimuli, while other measures lead to a shortening effect (i.e., TPT, ET). Stimuli complexity, on the other hand, led to diversified results (i.e., either partial or total overestimation or no results) probably due to the stimuli included. The only study which achieved an overestimation used words (Block, 1974), while the other two studies used more or less complex figures (Block, 1978a; Ornstein, 1969). Consequently, it could be hypothesised that only more complex stimuli requiring deeper processing (e.g., words and complex numbers) elicit the complexity effect. Finally, the complexity of coding in memory has demonstrated incontestable results, with all studies showing that the stimuli coded in the hardest ways were systematically estimated to be longer in RTP (Block, 1978b; Ornstein, 1969).

Distancing themselves from Ornstein's theory (1969), several authors have explored the effect of cognitive load on time perception, either by changing the task or changing the difficulty of a task. While studies varying the task systematically led to an underestimation of duration using a prospective design (e.g., Marmaras et al., 1995; Wilsoncroft & Stone, 1975; Zakay et al., 1983), no effect was found in RTP. The absence of effects in RTP is logical, because such perception relies on memory, which was not affected in these tasks. The same underestimation effect was achieved in PTP when using the same task with different difficulty settings (Baldauf et al., 2009; Brown, 1997; Wilsoncroft et al., 1978). Only one study varying the difficulty of a same task found the same effect between RTP and PTP

(Brown, 1985). Nonetheless, since the study did not analyse these paradigms separately, it is not possible to conclude that RTP is affected by deeper processing. And since Hicks et al., (1976) failed to report significant results concerning RTP and task difficulty, it is likely that RTP is simply not affected by cognitive load. Based on the same design, several studies explored the associations between executive functions and time perception (Brown et al., 2013; Fortin et al., 2010; Meaux & Chelonis, 2003), basing their research on both Miyake's model (i.e., updating, shifting, inhibition; 2000) and Baddeley's model (i.e., central executive, visuospatial sketchpad, and the phonological loop; 1992). These studies almost systematically demonstrated bidirectional interference between the temporal and non-temporal concurrent tasks, indicating that both executive functions and time perception rely on the same attentional pool (e.g., Brown et al., 2013; Brown & Perreault, 2017; Ogden et al., 2014). Therefore, the authors implied that time perception was an executive function, to the same extent as the other skills (e.g., inhibition, shifting).

In relation to the effect of attention on time perception, findings concurred with the Attentional-Gate Model of time perception (AGM, Zakay & Block, 1995). According to this model, if attention is diverted from time perception, perceived duration is shortened, the opposite effect appears when focusing on time. This effect was found using three different methods: using a dual-task paradigm, asking participants to consciously direct their attention (i.e., endogenous attention), or grab the participant's attention via cues (i.e., exogenous attention). All the studies with a dual-task design demonstrated this effect (Burle & Casini, 2001; Chinchanachokchai et al., 2015; Kladopoulos et al., 2004) with Brown (1990) using a noteworthy design. In this experiment, participants were asked to perceive the duration of several concurrent stimuli, not knowing which one they would have to process afterwards. The participants exhibited an effect of attention on both stimuli with their accuracy dropping in the concurrent condition. In the endogenous attention studies, when participants were asked to focus on the non-temporal task, rather than the temporal one, they underestimated duration, the opposite effect being observed when they focused on the temporal task (Casini & Macar, 1997; Kladopoulos et al., 2004; Macar et al., 1994). When participants were cued on either the modality or the location of the next stimulus, they overestimated duration, indicating that exogenous attention plays a crucial role in PTP too (Mattes & Ulrich, 1998; Osugi et al., 2016). Finally, it has been shown that transient attention – attention driven from sudden change in the visual field (i.e., around 100ms) – affects time perception in the same way (Yeshurun & Marom, 2008).

Due to both time perception and cognition varying in the early stages of child development as well as among elderly people (e.g., Coelho et al., 2004; Droit-Volet et al., 2006), several studies explored how these are related across age groups. The first studies with children simply replicated the already known effect of cognition among adults with younger participants, and demonstrated the effects of quantity, cognitive load, attention, and executive functions. More complex studies explored how neuropsychological measures either interact with the difference between age groups in time perception or explain the difference between single-task and dual-task performances. For example, these studies showed that time sensitivity improvement with age among children is explained by the short-term memory for sub-second durations, while supra-second duration relies on executive functions (Zélanti & Droit-Volet, 2011). In another study, five-year old children were more affected than seven-year old children by a dual-task paradigm, with the difference of performance partially explained by selective attention (Hallez & Droit-Volet, 2017). Finally, Droit-Volet et al. (2015) created a comprehensive model of time perception for both adults and children, including several measures of time perception. The study showed that five-year old children tended to overestimate duration compared to older children (eight-year olds) and adults, and that all children had a more variable time perception than adults. Furthermore, several neuropsychological measures interacted with time perception, the accuracy being predicted by inhibition, attention, and processing speed. The variability was predicted by inhibition and selective attention.

Studies recruiting elderly participants have elicited much less interest from researchers than those regarding children. Only three such studies have been conducted. One of these studies failed to find any difference between age groups (Brown et al., 2015), two other studies showed that age, and its relative cognitive levels, impacted time perception significantly. The first study showed that the storage components of Baddeley’s model explained the difference between old and young participants (Baudouin, Vanneste, Pouthas, et al., 2006). This is of interest as the storage components of this model represent memory performance, which is often impaired among older participants (Kirova, Bays, & Lagalwar, 2015; Tromp, Dufour, Lithfous, Pebayle, & Després, 2015). Ranjbar Pouya et al. (2015) showed that participants with a lower score on the Montreal Cognitive Assessment (MoCA) and older participants overestimated the duration compared to other participants.

The studies reviewed in this chapter demonstrate that time perception relies on both cognitive and emotional processes. Unfortunately, none of these studies explored how these processes interact in their interference on time perception. It is noteworthy that one experiment mixed attention and arousal, failing to find any interaction between the variables (Curton & Lordahl, 1974). This could be due to this study not exploring emotion per se but physical arousal (i.e., shock threat and physical exercise). This lack of research is surprising given that it is established that cognitive functions can be affected by emotions, and that both are shown to interact in numerous domains. For example, executive functions from Miyake's models have been shown to be significantly impaired when tasks include emotional stimuli (e.g., Paulitzki, Risko, Oakman, & Stolz, 2008; Segal, Kessler, & Anholt, 2015; Wante, Mueller, Demeyer, Naets, & Braet, 2017). Inhibition has been more thoroughly explored as it was assumed that individuals would exhibit poorer self-control when confronted with intense emotions, which would subsequently be reflected in inhibition measures (Lynam, Smith, Whiteside, & Cyders, 2006; Whiteside, Lynam, Miller, & Reynolds, 2005). In addition, several models of emotional regulation have included executive functions, although Sperduti et al. (2017) found that only the updating component of Miyake's model predicted implicit emotional regulation.

In other research fields, the interaction of cognition and emotion has been thoroughly studied using dual-process models (Lannoy, Billieux, & Maurage, 2014; Mukherjee, 2010). According to these models, there are two systems which interact in order to influence a specific process (for a selective review in the domain of decision-making, see Brocas & Carrillo, 2014). The first one is the 'affective system' which is implicated in the emotional evaluation of stimuli and initiates automatic-appetitive responses based on associative learning (i.e., stimulus-response link). The second system is the 'reflective system', involved in cognitive evaluation of the stimuli relying on memory and executive functions, and initiating the controlled-deliberate responses by evaluating long-term consequences (response-consequences link). In time perception, the situation might be more complex, because the effect of cognition and emotion on time perception varies depending on the variable, method, or paradigm used (i.e., retrospective or prospective). Depending on how the duration is evaluated by the person, the interaction might change entirely. Consequently, it is complicated, maybe impossible, to predict how an interaction between emotion and cognition affects time perception. Nonetheless, some hypotheses can be made, for example, given participants should remember more emotional stimuli, the number of words effect should increase in the retrospective paradigms, leading to more overestimation. Moreover, it has been shown that emotion can direct one's attention in an exogenous way (Hartikainen, Ogawa, & Knight, 2000; Tipples & Sharma, 2000). In the time perception context, this means that emotional stimuli may increase the effect of attention, leading to more overestimation if the participants have to estimate the duration of the emotional stimuli or more underestimation if they have to estimate the duration of the non-emotional stimuli. Studies exploring different aspects of this interaction are needed in order to achieve a deeper understanding of time perception and its interaction with cognition and emotion.

Chapter 2: The effect of gaming on cognition

2.1. Chapter overview

This thesis explores the time perception of gamers in order to understand the time loss effect (i.e., underestimation of the time spent on an activity) observed in gaming disorder. The first chapter of this thesis depicted the complexity of the time perception construct as well as how different factors may influence it (i.e., cognition and emotion). This better grasp of time perception highlights the importance of knowing how cognitive skills may be affected by gaming (both within a disordered or healthy use).

Therefore, the main aim of this chapter is to explore how gaming, whether disordered or healthy, can affect an individual's cognition. This chapter will be divided in an introductive section (i.e., defining what gaming and its associated disorder are), a method section (i.e., how the databases have been searched), a result section (i.e., summarising the research highlighted from the selected papers), and a discussion. Based on these results, the methodology of the thesis will be adapted, the potentially important variables in time perception affected by gaming being measured as covariables.

2.2. Introduction

Since the first commercial videogame in 1972 (i.e., *Pong*) and the arrival of console gaming, videogames have become an important leisure activity worldwide. As videogames evolved, a multitude of different genres were developed varying in the strategy, skills, and attention required, or in the gameplay and commitment needed by gamers. This involvement can lead to an addictive behaviour, a pathological use, of these games (e.g., Billieux et al., 2015a; Griffiths & Davies, 2005). Early studies of videogame addiction used criteria adapted from pathological gambling criteria in the third edition of the Diagnostic and Statistical Manual of Mental Disorders (e.g., Griffiths & Hunt, 1998). Here, gamers experiencing four or more of the indicated symptoms (e.g., chasing, relapse, and salience) were considered addicted. During the two last decades, numerous psychometric scales, addiction models, and proposed criteria have been created to assess this potentially addictive, and/or pathological behaviour leading to great disparity in the field. Recently, the American Psychiatric Association included 'Internet Gaming Disorder' (IGD) in the latest (fifth) edition of the *Diagnostic and Statistical Manual* *of Mental Disorders* (DSM-5; American Psychiatric Association, 2013) in the Appendix that includes possible diagnoses that require additional research before being included in the main text. More recently, Gaming Disorder has been included in the 11th revision of the *International Classification of Diseases* (ICD-11) (World Health Organization, 2016). According to the ICD-11, gaming disorder is characterized by continuous gaming (i.e., whether online or offline) and include three main factors: (i) impaired control, (ii) overlooking other aspect of life (e.g., family, interest) in favour of gaming, and (iii) continuation of gaming despite negative consequences. As this is the latest official nomenclature, the rest of this chapter will systematically use 'gaming disorder' (or similar terms such as disordered gamer) to designate the addicted, problematic, or pathological gamers. The literature on this disorder notes that the gamers will endure negative consequences in different domains of their lives. In relation to interpersonal relationships, Achab et al. (2011) indicated that individuals suffering from gaming disorder had more difficulties with their family and in their relationships compared to healthy gamers. Another study replicated this association for the relationship between gamers and their parents (Burešová, Steinhausel, & Havigerová, 2012). On a personal level, several studies have demonstrated that excessive gamers exhibit personal problems, such as increased financial difficulties (Achab et al., 2011), or academic difficulties (Chiu, Lee, & Huang, 2004; Gentile, 2009). Furthermore, disordered gamers not only lose pre-existing relationships due to excessive gameplay, they also fail to create new relationships outside of the game (Achab et al., 2011; Hellström, Nilsson, Leppert, & Åslund, 2012).

The most studied game genre in the gaming disorder literature is "Massively Multiplayer Online Role-Playing Games" (MMORPGs – e.g., *World of Warcraft, Final Fantasy XIV, Guild Wars 2*). MMORPGs comprise a perpetual virtual world, that is, a virtual universe that does not stop evolving when the player disconnects. Such games require an important commitment in terms of time, as successful gaming requires engaging in activities such as "farming" (i.e., killing monsters repeatedly to earn rewards) to keep one's level and to progress. In MMORPGs, the purpose of the player varies greatly depending on the game played, but the main activity comprises participating in quests with a main purpose (e.g., defeating a monster). Finally, most MMORPGs include a "Player vs. Player" (PVP) component, which is a way to compete with other players. MMORPGs are an adaptation of more traditional “Role-Playing Games” (RPGs – e.g., *Skyrim, Neverwinter Nights, The Witcher 3*), that are offline games in which a player engages in a quest and improves their character for the sole purpose of finishing the game.

Regarding the studies on gamers’ performance, either cognitive or visual, the most studied videogame genres are action videogames, including “First-Person Shooter” (FPS – e.g., *Overwatch*, *Battlefield*, *Call of Duty*) games. In these games, a first-person perspective is used, providing greater immersion for the player, hence the name. Such games can be played either online or offline. In offline games, the purpose is often to advance from one specific point to another without dying, whilst completing various sub-missions. In FPS game scenarios, while players always need to kill their opponents, the main purpose of the session can vary between capturing specific areas to catching flags.

Two widespread videogame genres suffer from a lack of psychological research. The first one is “Real-Time Strategy” (RTS) games (e.g., *Starcraft 2, Warcraft 3, WarHammer 40000*). In RTS games, a player must construct buildings, and use these buildings to create units that will either battle, or collect resources (i.e., used to construct other units/buildings), the purpose of game session being to destroy the enemy base entirely. A second game genre little studied is “Multiplayer Online Battle Arena” (MOBA) games (e.g., *League of Legends*, *Defense of the Ancient, Heroes of the Storm*). In fact, *League of Legends* is currently the most played videogame worldwide with 100 million players (“Number of players of selected eSports games worldwide as of August 2017 (in million),” 2019). MOBAs are closer to RTS games in terms of game length due to the requirement to destroy the enemy base in short game sessions (i.e., approximately 30-45 minutes). In this kind of game, two teams of five players battle on a limited map, with the main purpose being to destroy a central piece of the enemy base (i.e., the nexus), killing the opponents to achieve this objective. Contrary to MMORPGs where the player impersonates a main character, in MOBA games, all the statistics of the character are reset at the beginning of each game.

The gaming studies literature has focused on the more positive impacts of videogames among healthy gamers as well (e.g., Appelbaum, Cain, Darling, &

Mitroff, 2013; Sims & Mayer, 2002). These studies have demonstrated improved performances of gamers on a variety of different tasks. Research has shown that trained competences in videogames can be extended to other fields, including visual performance, surgery skills, and navigation. For visual performances, gamers exhibit better performance on saccadic eye movement tasks (Mack & Ilg, 2014; West, Al-Aidroos, & Pratt, 2013), visual processing levels (i.e., searching for changes between two pictures, detecting stimuli), and ignoring distractors (Chisholm & Kingstone, 2015a; Durlach, Kring, & Bowens, 2009; Green & Bavelier, 2007). Although surgical abilities have only been tested in simulator, there were consistent results in that gamers outperformed medical students on different surgery simulators, such as laparoscopic surgery (Fanning, Fenton, Johnson, Johnson, & Rehman, 2011; Jalink, Goris, Heineman, Pierie, & ten Cate Hoedemaker, 2014) or arthroscopy procedures (Jentzsch et al., 2016). The findings relating to navigation skills among gamers are far from consistent, with one study showing no significant differences between novice and expert gamers (Castell, Jenson, & Larios, 2015). However, this was only a pilot study with twelve participants and the results are then to be discussed cautiously. Another study found no relationship between gaming experience and real-life navigation, but a significant one with virtual navigation (Richardson, Powers, & Bousquet, 2011). Nonetheless, due to the different tasks used between the two studies, no conclusion can be drawn, and more studies are needed in that field to clarify any association between navigation and videogame experience.

The aim of the present review is to explore the cognitive skills among gamers in studies that have used experimental designs. The study of the impact of videogame use on cognitive skills is a relatively new field and has not been studied widely and suffers from large gaps due to inconsistent results, different cognitive skills not studied, among other things. It has been shown that training cognitive skills on a given task extends to other similar tasks (e.g., task-switching, Karbach & Kray, 2009), suggesting that training cognitive skills in-game could improve these skills more generally (i.e., in non-gaming settings). Moreover, studies have shown that substance addiction can lead to impaired cognitive skills (Kanayama, Kean, Hudson, & Pope Jr., 2013; Liang et al., 2013), which stands true in the context of non-substance addictions, such as gambling (Ciccarelli, Griffiths, Nigro,

& Cosenza, 2017; Leppink, Redden, Chamberlain, & Grant, 2016). As a consequence, it is expected that gaming disorder leads to an impairment of cognitive skills. To the best of the authors' knowledge, this literature has not been reviewed and may be useful in advancing the field. The present chapter is divided into two main sections (i.e., the positive and the negative impacts of video gaming on cognitive skills), with further subdivisions according to specific cognitive skills.

2.3. General method

An extensive literature research was conducted using four different databases: *Google Scholar, ScienceDirect, PubMed,* and *PsycINFO.* All searches included a common set of search words (i.e., videogame, gaming, video game), defining the videogame field of study, and other words to specify the cognitive domain studied (i.e., decision-making, time perception, delay discounting, attention, inhibition, and task-switching). Finally, the studies were included if they: (i) dated from the year 2000 (because videogames have greatly evolved since that time), (ii) included an experimental design, (iii) included evaluation of cognitive processes, (iv) were published in English, and (v) were peer-reviewed. Studies in specific areas were further excluded if they had been extensively reviewed before such as functional magnetic resonance imaging (fMRI) or Electroencephalography (EEG) studies examining gaming (Kuss & Griffiths, 2012; Pontes, Kuss, & Griffiths, 2015) and the use of videogames being beneficial to surgical skills (Jalink et al., 2014; Lynch, Aughwane, & Hammond, 2010).

The research on *ScienceDirect, PubMed,* and *PsycINFO* included the same type of research terms. Indeed, the only difference was that *ScienceDirect* allowed research of terms in the title, abstract, and paper keywords at the same time, while *PubMed* only allows research in the title and abstract, and *PsycINFO* only in the abstract. Using the words gaming, videogame, and video game associated with the specific area sought (e.g., attention, and task-switching) led to the following number of papers. On *ScienceDirect*, there were 39 papers on decision-making, eight on time perception, nine on delay discounting, 844 on attention, and 16 on task-switching. On *PubMed,* there were 63 papers on decision-making, one on time perception, nine on delay discounting, 307 on attention, and 19 on task-switching. Finally, on *PsycINFO*, there were 74 papers on decision-making, three on time perception, six on delay discounting, 321 on attention, and 16 on task-switching.

Due to the high number of papers on attention in these searches, the term "cognitive" was added, leading to 125 papers on *ScienceDirect,* 87 on *PubMed,* and 104 on *PsycINFO*.

Importantly, due to the inability to research terms only in the abstract or keywords on *Google Scholar,* several of the exclusion criteria were added directly in the search, that is reviewed field (i.e., fMRI, MRI, EEG, ERP, and surgery) or irrelevant kind of studies (i.e., training and teaching). Yet, as these criteria still yield unmanageable results on this database (e.g., 16,100 papers on decision-making), the terms characterizing the field of research (i.e., gaming, videogame, video game) were searched only in the titles. These last criteria led to 19 papers for decision-making, five for time perception, one for delay discounting, 85 for attention, and one for task-switching, leading to a total of 818 papers. After collating the results of the different databases to merge the duplicated papers, sorting the unrelated papers, and adding new papers cited in the one selected, the final number of selected papers was 38.

2.4. Results: Positive impact

2.4.1. Task-switching

Sophisticated videogames require gamers to switch between several tasks, especially in action videogames (e.g., focusing on enemies, picking up items, and reloading weapons). Task-switching is a representation of cognitive flexibility, it is the ability to alternate between different tasks with distinct demands without sacrificing any accuracy or speed (i.e., shifting; Miyake, 2000). In switching tasks, the variable measured is called the 'switching-cost' (i.e., the increase in reaction time [RT] when a participant must switch between tasks). This variable is measured by comparing the RT to a stimulus when the response needed has changed (or not) from the previous stimulus. A well-validated example of a switching-task is the Letter-Number Task developed by Monsell and Rogers (1995). Here, one letter and one number are presented together in one of the corners of the screen. If the stimulus appears in the upper part of the screen, participants have to decide whether the number is odd or even, and if it is in the lower part, whether the letter is a vowel or a consonant. This ability can be trained through cognitive tasks, leading to diminished switching costs, extending to the other switching-tasks (Karbach &

Kray, 2009; Pereg, Shahar, & Meiran, 2013). Accordingly, researchers in this field started focusing on task-switching improvement in action gamers. Most of these studies have found significant associations between action gameplay and flexibility, with gamers showing lower switching-cost than non-gamers (Colzato, 2010; Dobrowolski, Hanusz, Sobczyk, Skorko, & Wiatrow, 2015; Green, Sugarman, Medford, Klobusicky, & Bavelier, 2012; Karle, Watter, & Shedden, 2010; Strobach, Frensch, & Schubert, 2012). To our knowledge, only two studies have failed to find differences between action gamers and non-gamers (i.e., Cain, Landau, & Shimamura, 2012; Dobrowolski et al., 2015). The study from Dobrowolski et al. (2015) will be discussed separately below, as it distinguishes between different types of videogames and yields different results.

Two studies have attempted to understand these results by exploring the underlying processes accounting for improved performances. In a study including two experiments, Karle et al. (2010) tested both the difficulty level and the switching-level impact on task-switching. The first experiment included both non-gamers and action gamers who played at least six hours per week and judged their gaming expertise with a score of at least five out of seven on a Likert scale. These participants were tested on a switching-task varying in the difficulty to prepare a response or to respond to a trial. To differ the variables, the authors compared the visual perception level (i.e., high-contrast vs. low-contrast), the response mapping (i.e., changing which key to press for a given stimulus), the cue-to-target interval length (i.e., 100ms vs. 1000ms), and the information given by the cue (either giving no information or cueing on the next stimulus type). This study showed that the gamers had a significantly smaller switching-cost than the non-gamers, resulting in both a decreased RT and higher accuracy. Finally, the gap between gamers and non-gamers grew larger during the long cue-to-target interval, or when the cue was informative. These results do not explain the overall superiority of gamers on switching-tasks, even if this gives some leads (e.g., cue-to-target interval and cue effect could indicate an attentional effect). In the second experiment, Karle et al. (2010) tested the switching-level among action gamers (i.e., same protocol as previous experiment) and non-gamers on a switching-task including numbers. To manipulate the switching-level, the test included three different task types: deciding if a presented number was odd or even, if it was lower or higher than five, and if it was a prime number or a multiple number. These three different tasks led to four switching combinations, *repeat* (no switching, two same tasks in a row), *switch* (two different tasks in a row), *two-switch* (three different tasks performed consecutively), and *alternate* (a first task, followed by a second different task, followed by the same first task). The only result of this experiment was a replicated improved switching-cost and accuracy among gamers, with none of the switching manipulation showing any differences between gamers and non-gamers.

The second study exploring the underlying processes of these improved results was led by Green et al. (2012) and comprised three different experiments. The first experiment evaluated the impact of the output type, in other words, testing whether the gamers would be better at switching between tasks when they responded using a keyboard (i.e., a usual tool in gaming) compared a vocal method (i.e., a mostly unused tool for controlling a character). The first experiment included action gamers (spending at least five hours per week on action games for the past six months) as well as non-gamers. The task was a shape vs. colour switching-task, with participants having to assess the shape of the stimulus when it was in the upper-part of the screen, and its colour when it was in the lower part of the screen. Although non-gamers showed shorter RT when they responded orally, there was no such significant difference for the gamers. Considering that the gamers were faster than non-gamers in both conditions (i.e., despite the improvement of non-gamers in the oral condition), it can be inferred that the output type (i.e., responding orally or manually) did not account for the difference between the two groups. In the second experiment, the authors wanted to compare cognitive- and perceptual-switching. For this purpose, action gamers (i.e., same criteria) and non-gamers underwent a switching-task with two types of blocks. The first kind of block included the same task as the first experiment (i.e., shape vs. colour), while the second one needed the participants to decide whether the numbers were odd/even or higher/lower than five. Unfortunately, even though this study replicated the reduced switching-cost among gamers, the task type (i.e., cognitive vs. perceptual-task) did not yield significant results. Finally, the third experiment assessed the stimulus-response mapping switching by asking the participants to respond with other keys if the background colour changed. As in the two first experiments, there was no effect of the task type, but a significant lower switch-cost for the gamers. Thus, this study failed to find any underlying process accounting for the improved results of the action videogame players.

Even though all the previous studies focused on action videogames, these are not the only games that lead to an increased flexibility, as other videogames need players to switch between several important tasks to win. For example, this is the case of RTS games where the players must command several groups of units, switching between different categories of units to command them. In these types of games, players must also construct buildings, manage resources, and engage in a number of other activities. All these tasks are similarly important to win the game because they are all interconnected, and thus require the participants to switch efficiently between them. In a study by Dobrowolski et al. (2015), RTS players, FPS players, and control participants (i.e., having played less than two hours per week on both RTS and FPS, and no more than four hours per week on other games during the past six months) were tested on both a Switching-task and a Multiple Object Tracking Task (MOT). To be included in the study, RTS players had to have played at least seven hours per week on RTS games and less than five hours on FPS games during the past six months, and inversely for the FPS players. This experiment led to significant differences between the three groups with further analyses showing that RTS players significantly outperformed both the FPS players and the control participants. No significant differences were observed between the latter groups, contrary to the previous studies (i.e., as an FPS game is considered an action game). In the switching-task, RTS players had a lower switching-cost without any differences in global reaction-time or accuracy between the groups. In the MOT, RTS players showed a significantly better accuracy than controls, and a near-to-significant difference with the FPS players. This study shows some interesting results on the impact of videogame playing on task-switching. By showing that games other than FPS can lead to further improved flexibility, it implies that other studies comparing cognitive processes on different types of videogames are required.

The last study exploring how task-switching is affected by recurrent gaming assessed the impact of gaming onset (i.e., age when one started gaming) on this executive function (Hartanto, Toh, & Yang, 2016). The participants were classified into three groups based on their onset: (i) non-gamers, (ii) early-onset gamers (i.e., started before 12 years old), and (iii) late-onset gamers (i.e., started after 12 years old). This age was chosen by Hartanto et al. (2016) due to the relevant literature indicating that children reach a fully developed shifting function (i.e., reaching the same performance on switching tasks as adults) around the age of 12 years (Anderson, Anderson, Northam, Jacobs, & Catroppa, 2001; Cepeda, Kramer, & Gonzalez de Sather, 2001). Furthermore, contrary to previous studies, the authors explored both the switching cost and the mixed cost (i.e., slower response in repeated trials in mixed blocks compared to repeated trials in pure blocks—i.e., blocks without any switching), studying a wider range of variables related to the shifting function. The results showed that the onset of gaming had no impact on the number of hours spent on videogames, nor on self-perceived level of expertise. Despite this lack of difference, once all the variables were included in a stepwise regression, only the age of gaming onset significantly predicted the shifting levels, both for the switching and mixed costs. Finally, when using the same categorization as other studies (i.e., comparing gamers who play more than 6 h per week to non-gamers), gamers had a significantly smaller mixed cost and a marginally smaller switching cost (p=0.06).

In summary, most of the included studies found significantly improved performance in switching-task among gamers, implying greater flexibility in comparison to non-gamers (Colzato, 2010; Dobrowolski et al., 2015; Green et al., 2012; Karle et al., 2010; Strobach et al., 2012). One possible explanation for the absence of results from some studies could be the lack of control on game playing. Since other types of games than action videogames can induce an improvement in flexibility (e.g., RTS games – Dobrowolski et al., 2015), it is highly possible that some participants in the control groups were playing such games and truthfully reported that they did not play any action videogames. The study by Dobrowolski et al. (2015) raises an important need to focus on what the different genres of videogames can bring in terms of skill to gamers. Indeed, more than different gameplay, playing different kinds of videogames requires different categories of skill (e.g., strategy, sharpened reflexes, multi-tasking), some games even requiring a combination of these skills. Therefore, more studies are needed to assess the abilities developed by playing specific videogames, and the impact of this training on general cognitive tasks. Despite the lack of control on this variable, the studies still yielded consistent results implying that videogames have an important positive impact on flexibility. Even if it appears that the age of gaming onset is playing an important part on the flexibility levels of the gamers (Hartanto et al., 2016), little is known about the other potential underlying processes in the performance of gamers, apart from an increased difference with non-gamers when stimuli are cued, or when there is more time to prepare a response (Karle et al., 2010). The even greater performance when cues are included in the task could be evidence of a better top-down control of attention, with gamers exhibiting a somewhat better ability to focus their attention on a stimulus when cued beforehand. Further explanation of this is provided below.

2.4.2. Attentional control

Videogames require constant attention from gamers (arguably more in action videogames), as even the slightest lapse in attention can lead to death of the character, or to losing the game. Attentional control can be divided into two different types, top-down and bottom-up control. In top-down control of attention, a person consciously allocates their attention to a chosen stimulus, while in bottom-up control, the more salient stimulus will catch the person's attention (Desimone & Duncan, 1995). Attention has further been defined by the differentiation of three systems according to the Attentional Network Task (ANT; Fan, McCandliss, Sommer, Raz, & Posner, 2002). These are the *alerting system* (i.e., being able to make use of a clue to prepare for a stimulus), the *orienting system* (i.e., being able to orientate one's attention toward a spatial area after a spatial cue), and the *executive control system* (i.e., being able to inhibit the distractors). The first two systems (i.e., alerting and orienting systems) are associated with bottom-up attention selection due to the cue directing attention despite the will of the person. The third system (i.e., executive control system) is linked with the top-down selection as this system requires the person to direct their attention themselves by ignoring the distractors. It would be expected that gamers exhibit better top-down attention since winning a game requires to inhibit the distractors and to focus on the right "stimuli" (e.g., to focus one's attention on important objectives without being distracted). Yet, as important stimuli can appear in a game, requiring a fast relocation of attention, the bottom-up selection could be at stake among action videogame players. Current literature demonstrates that videogames players exhibit better top-down control (Cain & Mitroff, 2011; Cain, Prinzmetal, Shimamura, & Landau, 2014; Chisholm, Hickey, Theeuwes, & Kingstone, 2010; Chisholm & Kingstone, 2012, 2015a; Irons, Remington, & McLean, 2011), some studies showing improved bottom-up processing (Cain & Mitroff, 2011; Castel, Pratt, & Drummond, 2005; Chisholm et al., 2010; Mishra, Zinni, Bavelier, & Hillyard, 2011; Schubert et al., 2015).

Chisholm and Kingstone published three studies on the attentional abilities of gamers (i.e., three hours per week for at least the past six months), mainly testing their top-down control of attention (Chisholm et al., 2010; Chisholm & Kingstone, 2012, 2015a). In these studies, three different tasks were used (i.e., Orientation Perception Task, Oculomotor Capture Task, and Compound Search Task), thus allowing a wide measure of top-down control. All these studies reached the same conclusion that gamers exhibited better top-down control, which was not explained by other variables assessed (e.g., speed to engage in an eye-saccade). Studies by Cain et al. (Cain & Mitroff, 2011; Cain et al., 2014) confirmed these results despite using different tasks (i.e., Change Detection Task, Anti-cue Task, and Attentional Blink Task) and a stricter inclusion criterion for being a participating gamer (i.e., five or six hours per week for the past six months). In addition, their first study demonstrated that gamers exhibited better bottom-up attention selection (Cain & Mitroff, 2011), indicating that gamers would both consciously direct their attention better than non-gamers and be more sensitive to salient stimuli if these were relevant for the ongoing task or activity.

Dye et al., (2009) explored the associations between videogame use and attentional processes via the ANT. As defined earlier, this model divides attention into three core systems, the alerting, orienting, and executive control systems (Fan et al., 2002). In this study, the authors recruited action videogame players (i.e., playing any action videogame during the past 12 months) and non-gamers. Despites the different inclusion criteria from other studies (i.e., younger participants and less rigorous criteria for gamers), the results obtained match previous findings. Gamers were faster in all the conditions (i.e., exhibiting a faster processing speed) and showed a greater improvement than non-gamers when the stimuli were cued, exhibiting better orienting and executive control systems, thus, a better top-down control of attention. The results of this study suggest that playing videogames improves both basic processing speed and conscious control of attention. However, the lack of differences between the two groups in the alerting systems indicates that there is no difference in bottom-up control, thus refuting results from other studies (e.g., Cain & Mitroff, 2011; Mishra et al., 2011).

Other studies have investigated the Theory of Visual Attention (TVA; Bundesen, 1990) recruiting gamers. The TVA measures attention via six parameters: the threshold value (T_0 - i.e., the minimum time of presentation required for participants to process a stimulus), the visual processing speed (C), the short-term storage memory capacity (K – i.e., amount of stimuli storable concurrently in short-term memory), the iconic memory buffer (μ – i.e., the difference in accuracy between masked and unmasked stimuli), the top-down control (α), and the spatial distribution of attention (w_{lat} – i.e., lateral distribution and w_{vert} – i.e., vertical distribution). To assess these parameters, participants must perform both whole and partial report tasks. In the whole report, participants are presented with a set of five coloured letters (i.e., red or green) which are either masked or unmasked. There are three presentation times (i.e., short, medium, and long), and participants are asked to indicate which letters were presented. This version of the task leads to measuring the parameters C, K, t_0, and μ. In the partial condition, one or two letters are presented on the screen, and participants are asked to indicate which letter is presented in a preselected colour. When two letters are presented, the second letter can either be in the preselected colour (participants having to report the two letters), or in another colour (participants having to report only one of the letters). The partial report task leads to measuring the parameters α, w_{lat}, and w_{vert} (Kyllingsbæk, 2006). Using this model of visual attention, Schubert et al. (2015) explored the underlying mechanisms of the outperformance from gamers on attentional tasks. They recruited gamers (i.e., playing 10 hours per week in the past six months) as well as non-gamers, and tested them with the whole and partial report tasks. Gamers needed a shorter presentation time to process the stimuli (t_0), and a greater processing speed (C); no other significant difference being observed. These results confirm other studies examining processing speed because gamers were faster than non-gamers (Cain & Mitroff, 2011; Mishra et al., 2011), but the lack of difference in top-down control goes against the main results of other studies (Cain et al., 2014; Chisholm et al., 2010).

Another study compared two different videogame genres players to test whether game type would impact the performance on attentional task or not. In this study, Krishnan, Kang, Sperling, and Srinivasan (2013) tested either RPGs or FPS gamers. To be included in this experiment, participants had to play one of these two types of game at least four days a week, with a minimum of one hour of gaming on these days. The participants were all tested on the same task (i.e., pressing a button every time a preselected stimulus appeared in a given zone of the screen). Depending upon the types of trial, participants were asked to attend to one, two, or four regions of the screen, thus increasing the difficulty of the task, and the spatial distribution of attention. This experiment led to an overall better performance by the FPS players, the difference reaching its pinnacle when the participants were asked to attend four locations at the same time. Importantly, due to the lack of control group (i.e., participants who did not play any videogames), the only conclusion of this study was that FPS players have a better attentional process than RPG players. Consequently, nothing can be concluded on the direct contribution of RPG to the attentional abilities.

In conclusion, the current literature on attention agrees on several important points. Firstly, gamers appear to exhibit a better global attention level, as their processing speed is increased compared to non-gamers (Cain & Mitroff, 2011; Castel et al., 2005; Chisholm et al., 2010; Mishra et al., 2011; Schubert et al., 2015), even though some studies contest these findings (Cain et al., 2014; Irons et al., 2011). To nuance these results, Krishnan et al. (2013) demonstrated that the improvement in the attentional capacities are greatly influenced by the type of games played with FPS players exhibiting better attentional processing than RPG players. This study, in accordance with Dobrowolski et al.'s study (2015), indicates that more studies exploring the specific impacts of the different types of videogames are greatly needed in the cognitive literature. Secondly, gamers exhibited greater top-down attentional control, i.e., a greater ability to ignore distractors and to stay focused on the main task (Cain & Mitroff, 2011; Cain et al., 2014; Chisholm et al., 2010; Chisholm & Kingstone, 2012; Dye et al., 2009; Irons et al., 2011), although one study's analyses did not reach significance (i.e., Irons et al., 2011) and one study found opposing results (i.e., Schubert et al., 2015).

2.4.3. Sub-second time perception

The research on time perception can be divided into the perception of very short durations (i.e., under the second – sub-second time perception) and longer durations (i.e., over the second – multi-second time perception). Interestingly, the results on both these sections of time perception appear to clash, as one appears to improve (i.e., sub-second), while the other one would deteriorate (multi-second). Since this section explores the positive impact of gaming, only the sub-second studies will be attended to, multi-second time perception being included in the negative impact section of this chapter. This time perception mainly comprises the ability to differentiate concomitant and serial stimuli, and to perceive which stimulus came first in the case of serial stimuli. Indeed, in some videogames, gamers can perform several spells and abilities with their character. Hence, knowing that one of these skills takes less time to be activated than another one is crucial as it allows the gamer to react fast in dangerous situations. Only two studies have explored sub-second time perception among gamers.

In the first study (Donohue, Woldorff, & Mitroff, 2010), multisensory temporal processing was tested, which is the ability to know whether two stimuli are concomitant or not, and if they are not, which one appeared first. In their experiment, gamers (i.e., 2 hours per week on FPS and 4.5 hours per week on any other action game for at least 6 months), non-gamers (i.e., less than 1.5 hours per week on any action game and 0 hours on FPS for at least 6 months), and “other” participants (i.e., fit in none of the two previous groups and were only included in the correlational analysis) were compared. All participants were tested on two different tasks: A simultaneity judgment task (SJT) and a temporal-order judgment task (TOJT). In the two tasks, participants were presented two stimuli (visual and auditory) with random Stimulus Onset Asynchronies (i.e., SOA, duration between the appearance of the two stimuli) varying between 0ms (i.e., simultaneous stimuli) and 300ms. The gamers outperformed the non-gamers on the TOJT, exhibiting better accuracy than non-gamers. In the SJT, gamers also outperformed non-gamers by being able to perceive that two stimuli were not concurrent with a smaller SOA on average. Interestingly, gamers were more biased on both tasks when the visual stimulus came first, which is the opposite from non-gamers who were more biased for auditory ones. This can be explained by the higher importance of visual stimuli compared to auditory ones in videogames.

In the second study (Rivero, Covre, Reyes, & Bueno, 2012), there were two types of time perception: sub-second perception and multi-second perception. This study comprised frequent gamers (i.e., 30 hours per week during the past month) and occasional gamers (less than 5 hours per week during the past month). For sub-second time perception, participants underwent a temporal comparison ask (i.e., TCT – 100-1000ms) and a temporal bisection task (TBT, 200-800ms). For the multi-second duration, participants performed an Estimation Task (ET – 10, 30, and 60s) and a time production task (TPT – 5s and 45s). While there was a significant outperformance by the gamers for both the TCT and the TBT, there was no difference between the two groups for both the multi-second tasks. Even though sub-second time perception was affected by gaming, it was unlikely that short durations above the second would be affected by this activity. In fact, while sub-second perception is important in videogames, being able to perceive duration above five seconds would be important only in specific game genres. For example, in some online games where gamers can fight an opponent, knowing that they will not be able to use a specific ability before five seconds is crucial because they know that they have a clear advantage during this interval. However, as it has been shown that gamers can present severe time loss while playing (Chou & Ting, 2003; Meerkerk, Van Den Eijnden, Vermulst, & Garretsen, 2009), assessing time perception for longer durations (e.g., above 30 minutes) would be interesting.

In conclusion, these two studies suggest that gamers exhibit a better time perception in the sub-second area, but further studies are needed to explore this perception, and its underlying mechanisms. Furthermore, it would be interesting to explore the impact of playing different game genres on time perception, as it is expected that videogames which do not focus on reflexes would not improve sub-second time perception. It is of interest as some games need the players to be attentive on several delays (i.e., delays before using their own abilities, and delays before an opponent can use their own abilities).

2.5. Results: Negative impact

2.5.1. Multi-second time perception

Gamers often experience time loss, that is, playing longer than intended, and not realizing how long it has been since they started playing (Wood & Griffiths, 2007; Wood, Griffiths, & Parke, 2007). As a matter of fact, some questionnaires evaluating excessive use of videogames include questions on time loss due to its importance in excessive use (e.g., Demetrovics et al., 2012). Nevertheless, little is known on the mechanisms behind this impairment among gamers, although it could be a consequence of impaired time perception. As mentioned in the first chapter, time perception literature is currently divided between two retrospective and prospective time perception (Levin & Zakay, 1989). The first is conscious and ad-hoc and the second one is unconscious and post-hoc. The following research on the topic explored both types of time perception and yielded disparate results.

The first study on time perception among gamers explored retrospective time perception (RTP; Rau, Peng, & Yang, 2006). The authors recruited expert gamers and novices who had to play a well-known videogame (i.e., *Diablo II*, a dungeon crawler real-time role-playing game) for one of three different durations (i.e., 30, 60, and 90 minutes). After the game session, participants were asked to stop playing, and the experimenters assessed how much time the participant needed to actually stop playing (delay time), the acceptance of break-off, the satisfaction with the session, and a time estimation of play duration. First, there was no significant difference for the delay time, acceptance, and satisfaction level between the two groups. Second, the experts tended to underestimate the 60-minute-duration while the novices overestimated it (i.e., p=.058). Nonetheless, there were several limitations in this experiment, as the participants were informed that the experiment would last a maximum of 90 minutes, they were able to reach an almost perfect time estimation in the 90-minute-duration group. Besides, when tested, there were 30% of internet-addicted participants in the expert group compared to 35% in the novice group. It is possible that many novices just played other games, thus greatly biasing the results. This would explain why the novices enjoyed playing this game significantly more than the experts.

In another study, Tobin and Grondin (2009) explored the impact of activity type (i.e., reading or playing a videogame) on both prospective and retrospective time perception. For this purpose, they recruited adolescents who were allocated to two groups (i.e., prospective and retrospective) and had to perform three consecutive activities (i.e., playing a game for 8 and 24 minutes, and reading a text for 8 minutes). This distribution highlights the first limitation of this experiment as there was no comparison for the 24-minute-session of videogame play, while there was one for the 8-minute-session. This is the only study exploring videogame use and time perception association without comparing gamers versus non-gamers, as the study used a correlational approach by controlling both videogames use and abuse. Although the 24-minute gaming session was underestimated, it could be due to either the gaming activity or the length itself; the lack of control task for this duration prevented any conclusion. On the other hand, the main objective of this study was fulfilled, the participants underestimated the 8-minute gaming session compared to the reading session. The authors further compared time perception of disordered gamers (n = 14) to the remainder of the sample (n = 102). This comparison led to a significant difference only for the 24-minute-session, with disordered gamers underestimating more greatly the duration of the gaming session than the healthy participants. This comparison could not be generalized due to the small sample of disordered gamers. As a result, they compared participants playing more than seven hours per week (n = 27) and participants playing between one and six hours (n = 58); leading to more balanced group sizes. This comparison replicated the previous analysis, with frequent gamers underestimating the 24-minute-session more than the "casual" gamers.

Another study explored time distortion experienced while gaming (Wood & Griffiths, 2007). In this experiment, participants played one out of two videogames (i.e., to allow participants to play a game on their favourite platform, computer or console) for 45 minutes and were asked to fill in several questionnaires before and after the gaming session. While playing, they were interrupted three times (i.e., after 13, 37, and 45 minutes), being asked how long they had played. The only result related to time distortion came from the questionnaire as two-thirds of the participants (67.5%) reported frequently/always experiencing time loss. No association between videogame play and the duration evaluation was found after each interruption. However, as the authors did not inform the participants before the experiment that time estimation would be evaluated in this study, a methodological issue arose. The first evaluation of time duration fitted the retrospective definition of time perception while the two subsequent evaluations arguably fitted the prospective definition. Indeed, as Grondin and Plourde (2007) stated, as soon as a participant is asked to make an estimation of play duration, the following estimation(s) will systematically become prospective as participants will begin to realize what they are being asked to do.

In brief, despite the frequent time loss reported by gamers (Wood & Griffiths, 2007; Wood et al., 2007), studies exploring multi-second perception abilities among these gamers show no consistent results. Some studies show biased time perception (i.e., without clarifying the paradigm concerned in the results; Tobin & Grondin, 2009) or nearly significantly impaired one (i.e., in a retrospective paradigm; Rau et al., 2006), while other studies show no such association (i.e., in a prospective paradigm; Rivero et al., 2012; Wood & Griffiths, 2007). This lack of significant results could be due to the short durations used (i.e., 60 seconds for Rivero et al., 2012), or the way that time perception was assessed (e.g., not controlling the prospective and retrospective paradigm while measuring time perception; Wood & Griffiths, 2007). The near significant results (i.e., p=.059 for Rau et al., 2006) may be explained by a lack of rigor, as they did not control whether the novice gamers had any expertise in other games than the tested one. Yet, as the novice group included 35% of Internet addicts, it is highly probable that these participants would have spent a fair amount of time on videogames. In conclusion, the current results do not allow any direct conclusion, and little is known on the interaction between gaming and time perception. This interaction will be explored in depth in the third chapter of this thesis, and the potential variables interacting with both gaming and time perception will be analysed thoroughly.

2.5.2. Inhibition

Research on potentially impaired inhibition among disordered gamers has been motivated by the presence of such an impairment in other behavioural addictions (e.g., gambling disorder; Ioannidis, Hook, Wickham, Grant, & Chamberlain, 2019). This would imply that disordered gamers would play because they cannot prevent themselves from doing it. Inhibition in these studies can be defined in two different ways, as either the restraint of a pre-potent motor response (i.e., the ability to inhibit an automatic response) or the cancellation of a pre-potent motor response (i.e., the ability to stop an already engaged response).

The restraint mechanism is often assessed through the Go/NoGo task (i.e., pressing a button for a specific stimulus but not for another one) or the Stroop test (i.e., reading a colour name while ignoring in which hue it is written – interference inhibition). Experiments using the Go/NoGo mostly showed an impaired inhibition level among gamers (Littel et al., 2012; Yao, Wang, et al., 2015). The only study failing to find any result regarding a Go/NoGo task only recruited 30 participants (Chen et al., 2015) compared to other studies with higher numbers of participant (*n* = 52; Little et al., 2012, and *n* = 66; Yao et al., 2015). The Stroop test was only used in two studies explored among gamers yielding contradicting results. While a first one failed to find any significant association between gaming disorder and inhibition (Yao, Wang, et al., 2015), another study found partial support (Bailey, West, & Anderson, 2010). More specifically, Bailey et al. (2010) recruited frequent gamers (i.e., playing 43 hours per week on average) and casual gamers (two hours per week on average). The study used two Response-to-Stimulus Interval (RSI) lengths (i.e., 500ms and 2000ms). Using this manipulation, frequent gamers showed poorer results under the longer RSI condition, implying that these participants were unable to maintain their control during longer durations.

In another study, Colzato, van den Wildenberg, Zmigrod, and Hommel (2013) explored the other type of inhibition, the cancellation of pre-potent motor response, among FPS gamers. This type of inhibition was tested via the Stop-Signal Task (SST) which is similar to the Go/NoGo. The main difference is that the stimulus will always first appear as a "Go" (i.e., initiating a response from the participant) before morphing into a "NoGo" (i.e., forcing the participant to cancel its response). In Colzato and colleague's study (2013), the sample included FPS players (i.e., playing at least five hours per week for a year) and control participants who were all tested on an SST and an N-Back Task (NBT). Not only did the gamers not show any sign of impaired inhibition, they were faster than the non-gamers, contradicting the rest of the literature.

A possible explanation for this unexpected result may be the emotional affect involved in gaming. Indeed, the UPPS [Urgency, Premeditation, Perseverance, Sensation Seeking] Impulsive Behavior Scale (Whiteside & Lynam, 2001) describes the lack of inhibition (i.e., urgency) as a difficulty to inhibit a reaction to an emotional stimulus (e.g., drinking alcohol after a break-up). Two studies included emotional affect through gaming stimuli during the task, with the purpose of impairing the inhibition of the gamers, and both studies produced significant results (Ko et al., 2015; Liu et al., 2014). Liu et al. (2014) added gaming pictures in half of the blocks of a classic Go/NoGo task, testing both disordered gamers (i.e., according to the Diagnostic Criteria for Internet Addiction for College Students [DCIA-C]; Ko et al., 2009) and control participants. The analysis showed that gamers only exhibited an impaired inhibition under the gaming-pictures condition, with no significant differences found in the control condition. In a second study, Ko et al. (2015) used a Directed Forgetting Task (DFT) including gaming words with disordered gamers (i.e., same criteria as the previous study) and control participants. In the DFT, participants were presented a series of words (i.e., either neutral or gaming-related), some of them followed with an instruction to "not remember" these (i.e., in order to inhibit the attentional focus on some words). The results matched those of Liu et al. (2014) with the gamers remembering more gaming-related-words and fewer neutral words than control participants, thus implying worse inhibition in comparison to non-gamers.

In conclusion, the current literature on the inhibition impairment among gamers currently provides contrasting findings. Some studies demonstrated an impairment among disordered gamers (Ko et al., 2015; Littel et al., 2012), or partial support (Bailey et al., 2010; Liu et al., 2014; Yao, Wang, et al., 2015), while other studies show no such association (Chen et al., 2015; Colzato et al., 2013). The differing results may partially be explained by the tasks used, and thus, the type of inhibition tested. For example, Bailey et al. (2010) found that using a Stroop task, gamers showed impaired inhibition only under a long response-to-stimulus interval, while Yao et al. (2015) only found impaired inhibition in the Go/NoGo task, and not in the Stroop Task. This could mean that gamers only show impaired automatic response inhibition and not interference inhibition. This supposition explains the findings of Littel et al. (2012), however, it does not cover the lack of significance in the Go/NoGo task (Chen et al., 2015). It is of interest that when including gaming pictures, two studies found that gamers exhibited poorer inhibition despite measuring two types of inhibition (Ko et al., 2015; Liu et al., 2014). These findings adhere to the concept of urgency developed by Whiteside and Lynam (2001) where under emotional affect, individuals tend to exhibit poorer inhibition. Gaming-related pictures could have elicited emotional affect, and thus may have impaired the gamers' inhibition.

2.5.3. Decision-making

Decision-making can be studied using different paradigms. For instance, it can be assessed through tasks measuring the passage between an unknown situation to a risky one. In such tasks, the participant does not know the rules at the beginning of the task, and learns these through performing the task (e.g., Iowa Gambling Task, IGT; Bechara, Damasio, Damasio, & Anderson, 1994). This type of task is thus based on a learning process, with participants having worse scores failing to understand or perceive these rules. Another way to study such processes is risky decision-making, that is, tasks where the participants clearly know about the rules as they start the task (e.g., Game of Dice Task [GDT]; Brand et al., 2005; Balloon Analogue Risk Task [BART]; Lejuez et al., 2002). Finally, decision-making can be assessed through delay-discounting paradigms, an economist perception of decision-making stating that the more a reward is delayed, the less value will be perceived. In such tasks, participants must make a choice between an immediate and small reward (e.g., £10 now) or a delayed bigger reward (e.g., £100 in a year). While the two first types of tasks lead to differentiating an impaired learning process (i.e., failing to improve in IGT-like tasks), or impaired basic decision-making (i.e., low scores in risky tasks), the delay-discounting paradigm assesses the inability of disordered gamers to postpone a gaming session.

Two studies have compared the Probability Discounting Task (PDT) performance within disorder gaming and control participants in group analysis, thus considering risky decision-making (Lin, Zhou, Dong, & Du, 2015; Wang et al., 2016). In the PDT, participants are presented two choices with a varying reward and probability of receiving it (e.g., 100% chance of receiving £10 against 50% of receiving £15). The two studies found the same results that impaired decision-making with riskier choices was more prevalent among disordered gamers. Lin et al. (2015) showed a significant correlation between the disorder severity and risk-taking. Nonetheless, since Lin et al. (2015) assessed internet addiction rather than gaming disorder (i.e., using the Internet Addiction Test; Young, 1998 and recruiting participants spending more than half their internet time on games), no definitive conclusions can be drawn. These findings on risky decision-making have been replicated with the Cups Task (i.e., another task measuring probability discounting), showing the same findings, that is riskier choices for the disordered gamers (Yao, Chen, et al., 2015; Yao, Wang, et al., 2015). Furthermore, using the GDT among disordered gamers (i.e., according to a modified version of the IAT for *World of Warcraft*) and control participants, Pawlikowski and Brand (2011) reported the same finding. In the GDT, participants have to bet virtual money on the outcome of a dice with pre-programmed choices varying in terms of odds and money wagered (i.e., the less likely the outcome, the more money wagered). The results showed that at the end of the task, disordered gamers had less money than the control participants, indicating riskier choices. There was also a significant and negative correlation between disorder severity and the GDT score. Finally, on top of testing risky decision-making, Yao, Wang, et al. (2015) demonstrated that disordered gamers had a lower improvement in the Iowa Gambling Task than non-gamers. However, given the poor results in the risky decision-making tasks (Pawlikowski & Brand, 2011; Wang et al., 2016) , it is more likely that the disordered gamers have an impaired risk evaluation than an impaired learning process. Consequently, more studies exploring the learning processes involved in IGT-like tasks are needed to confirm such an explanation.

Only two studies have explored the delay discounting abilities of disordered gamers. In the first study, Weinstein, Abu, Timor, and Mama (2016) tested both disordered gamers (i.e., according to the Problematic Online Gaming Questionnaire, POGQ; Demetrovics et al., 2012) and control participants on a BART and a Delay Discounting Task (DDT). The authors replicated the previous results on risk-taking among excessive users with the BART, with disordered gamers showing worse results than the control participants. For the DDT, the disordered gamers discounted the rewards more steeply than the control participants, that is, they preferred immediate and smaller rewards opposed to more important delayed ones. Using another task to measure Delay Discounting (i.e., the Single Key Impulsivity Paradigm, SKIP), Nuyens et al. (2016) replicated these findings. The SKIP is an implicit measure of delay discounting, participants being asked to wait as long as they can before clicking on a picture. The longer they wait, the more they earn points or money. In this experiment, the earliest stages from the SKIP were negatively correlated with the score on the Problem Online Gaming Questionnaire (Demetrovics et al., 2012), while the latest stages were not, implying that even though the disordered gamers had a worse delay-discounting level, they had the same level of learning process.

All studies on decision-making among disordered gamers show similar findings –impaired decision-making (Lin et al., 2015; Pawlikowski & Brand, 2011; Wang et al., 2016; Yao, Chen, et al., 2015; Yao, Wang, et al., 2015). Furthermore, it appears that excessive gamers tend to make riskier choices (Lin et al., 2015; Pawlikowski & Brand, 2011), which could explain their tendency to play videogames more than intended (e.g., playing more despite being more tired the next day). On the other hand, the results on the learning processes at stake in the decision-making are unclear, firstly due to the lack of studies on this specific process (i.e., only two studies; Nuyens et al., 2016; Yao, Wang, et al., 2015), and secondly due to opposite results (i.e., significant results; Nuyens et al., 2016; no significant results; Yao, Wang, et al., 2015). Finally, the two studies using delay-discounting tasks found that disordered gamers had difficulty in delaying rewards (Nuyens et al., 2016; Weinstein et al., 2016), which might explain their tendency to play immediately instead of waiting. In conclusion, more studies are needed in this field, as little is known on either the learning processes and the delay-discounting.

2.6. Discussion

It appears that gaming can impact cognitive processes both positively and negatively. Firstly, gamers appear to have better conscious control of their attention (i.e., top-down attention; Cain & Mitroff, 2011; Chisholm & Kingstone, 2012) and a better processing speed (Castel et al., 2005; Mishra et al., 2011). These performances appear to be differently affected depending on the videogame genre played, FPS gamers showing better results than RPG gamers (Krishnan et al., 2013). Secondly, gamers exhibited better cognitive flexibility (i.e., better task-switching performance; Colzato, 2010; Karle et al., 2010). This improved flexibility may be dependent upon the game genre played because FPS players were significantly outperformed by RTS players (Dobrowolski et al., 2015). Moreover, two studies explored the underlying mechanisms of superior performance by gamers. Nonetheless, these studies failed to find any significant results other than even better results when the gamers were cued or had more time to prepare their response to a stimulus (Karle et al., 2010). These studies match the results from the attentional studies, as better top-down attention led to such results too. Thirdly, gamers showed better multisensory temporal processing (i.e., ability to differentiate simultaneous or consecutive stimuli; Donohue et al., 2010; Rivero et al., 2012). Nonetheless, despite their better overall cognitive performance, gamers exhibited a bias towards visual stimuli compared to auditory ones (i.e., a trend reporting that the visual stimulus came first instead of the auditory one), with the control participants showing the opposite trend (Donohue et al., 2010). In short, gamers outperformed non-gamers on three different cognitive processes: task-switching, sub-second time perception, and attentional processes. Additionally, two studies raised an important issue by comparing different game genres in their experiment, leading to significant differences between these genres (Dobrowolski et al., 2015; Krishnan et al., 2013). Such differences may indicate that all game genres may impact on cognitive processes differently, depending upon their structural characteristics. Additionally, it should be noted that almost all the studies reviewed assessing the positive impacts explored action videogames as a global construct, despite that this is an umbrella designation grouping very different game genres (e.g., FPS, RTS, MOBA, etc.).

Importantly, no causal link can be confirmed regarding the improved cognitive processes among videogame players due to the quasi-experimental design used. Nonetheless, several studies explored the training effect of videogames on several cognitive processes. Even if these were not included in the review, as the researchers did not recruit gamers per se but non-gamers that were asked to play in order to improve specific skills, they are noteworthy. Indeed, these studies tend to support a causal effect of videogames on the improvement observed instead of the possibility that individuals with improved cognitive skills play games due to their higher level on these skills. Concerning the switching costs, several studies found that training non-gamers, or inexperienced gamers, on videogames led to significant improvements, with reduced switching costs (e.g., Glass, Maddox, & Love, 2013; Oei & Patterson, 2014; Strobach et al., 2012). Regarding attention, the same pattern of results was observed in several studies using videogames in order to improve processing speed or visual attention (Belchior et al., 2013; Schubert et al., 2015). To the best of the author's knowledge, there is no study that has explored how videogame training could improve or worsen sub-second time perception. However, it is important to put these results in light of a meta-analysis led by Sala, Tatlidil and Gobet (2018) who explored the effect of videogames on cognition considering the type of study (i.e., comparison of gamers and non-gamers, training studies, and correlational studies). What the authors showed is that while there was a small significant effect for the comparison and correlational studies, there was no significant overall effect in the training studies. These results contrast with Bediou et al.'s (2018) meta-analysis showing how action videogames affect the gamers' cognitive skills. This discrepancy between the two papers may result from the specific focus of Bediou et al. (2018) on the action videogame genre, while Sala et al., (2018) used a broader approach to gaming (i.e., all game genres included). This is of interest when Bediou et al., (2018) mentioned that the type of videogame played may influence the impact on cognition. This implication is based on the fact that intervention studies comparing action videogames to other game genres (e.g., *Tetris,* Real-Time Strategy games) still yielded significant results. In brief, little can be concluded on a possible causal effect of playing videogames on cognition and more research in this domain is required.

Although gamers exhibited better sub-second time perception, it was expected that they would show impaired multi-second time perception, as time loss is a common consequence among those experiencing gaming disorder (Wood & Griffiths, 2007; Wood et al., 2007). Yet, the studies exploring time perception failed to provide any clear conclusion, some studies not finding any significant differences (Rivero et al., 2012; Wood & Griffiths, 2007), while other studies found either significant results (Tobin & Grondin, 2009) or near significant ones (Rau et al., 2006). Nonetheless, taken as a whole, results pointed towards impaired time perception despite some methodological errors (e.g., no separation of RTP and PTP, no verification of the control group's gaming habits) biasing the results. Another cognitive process impaired through gaming disorder is decision-making. Studies have shown that both risky decision-making (e.g., Pawlikowski & Brand, 2011; Yao, Wang, et al., 2015) and delay-discounting (Nuyens et al., 2016; Weinstein et al., 2016) were significantly impaired among disordered gamers. The results regarding the learning process in decision-making are contrasting, as only two studies explored these associations, each leading to opposite results (i.e., an improvement throughout the task, Nuyens et al., 2016; lower score on the IGT, Yao, Wang, et al., 2015). Therefore, more studies on the learning level of disordered gamers in decision-making tasks are needed, even if it is probable that gamers only have impaired risky decision-making with a correct learning process (i.e., ability to learn and apply the rules in a decision-making task) according to the other studies' results. Finally, it has been hypothesized that disordered gamers would engage in this behaviour due to an impaired inhibition. The current literature is not clear on this aspect, with some studies showing an impairment (Ko et al., 2015; Littel et al., 2012), and other studies finding no impairment, or an even better performance among disordered gamers (Colzato et al., 2013). Nevertheless, meeting the urgency definition of Whiteside and Lynam (2001), two studies found that disordered gamers exhibited impaired inhibition only when gaming pictures were included in the task (Ko et al., 2015; Liu et al., 2014). This means that disordered gamers may engage in problematic behaviour despite knowing the possible consequences (e.g., playing videogames late at night despite the risk of being tired in the morning) as the videogame stimuli emotionally aroused them.

Despite some differences found in the results, the studies exploring the improvement among gamers yielded relatively consistent findings including improved (i) sub-second time perception, (ii) switching abilities, and (iii) attentional abilities (mostly the top-down control, and processing abilities). These studies only recruited healthy gamers, and mostly studied the action game genre that comprises numerous game genres (e.g., RTS, FPS, RPGs). The studies yielding a negative impact on the cognitive processes among gamers do not show such consistency, as they revealed contrasting results for both the multi-second time perception and the inhibition studies. The studies exploring decision-making provided consistent results (i.e., impaired decision-making abilities in risky situations). Again, the populations studied may have impacted on the results reported. While the studies exploring the positive consequences of gaming recruited participants from the healthy population, the studies on the negative consequences of gaming solely recruited disordered gamers. To the best of the author's knowledge, only one study explored the difference of attentional control between disordered and healthy gamers, finding no significant difference (Collins & Freeman, 2014). This results in no possible definitive conclusion due to the lack of comparison between disordered and healthy gamers in the studies outlined. Consequently, the current literature examining the effect of gaming on cognitive ability requires further study comparing the two populations.

Future studies investigating the impact of gaming on cognitive processes should also examine executive functions using validated models of cognitive processes. For example, the Miyake model of Executive Functions (Miyake, 2000) includes three different functions: (i) shifting (or task-switching), (ii) inhibition, and (iii) updating. According to this model, several tasks are needed to fully explore each of these functions, and despite the number of studies exploring both inhibition and shifting, only part of the tasks have been used. For example, in the switching task there were no studies examining local-global shifting, which is the ability to identify either a bigger figure (e.g., a triangle or a square) or smaller figures composing the bigger one. Finally, the updating function, (i.e., the ability to encode information in working memory, and gradually delete old any unnecessary information when it becomes useless and replace it with new more important information) have yet to be explored. Gaming may improve this function, as most current videogames require gamers to monitor different stimuli during their session (e.g., objectives, ammunition, and whether the team member is still alive).

In conclusion, the studies reviewed suggest that gaming can have a positive impact on cognitive processes for healthy gamers, contrasting with the negative consequences brought by disordered gaming. However, this field of study needs more rigour because little is known about the (i) different impacts concerning disordered or casual gaming, or (ii) impact regarding different game genres. Such studies may be of use for the videogame industry as the results indicate that videogames can have a positive impact on gamers, as long as gameplay is non-disordered. Indeed, those in the gaming studies field should work in co-operation with game developers to prevent gamers developing addictive behaviours.

Chapter 3: The potential interaction between time perception and gaming

3.1. Chapter overview

In the first chapter of this thesis, time perception was defined and the main cognitive and emotional processes affecting it have been explored. The purpose of that chapter was to understand which types of variable were to be controlled in this thesis. The second chapter, on the other hand, explored which types of cognitive processes were affected by gaming, whether it was healthy or disordered use. The purpose of this chapter was twofold. First it allowed to explore the different types of design used in this field of research, which helped designing the experiments of this thesis. The second aim, directly linked to this chapter, was to explore which cognitive functions were common between the research on gaming and time perception.

This current chapter builds from these two chapters, and examines which processes are different (i.e., either improved or altered) among gamers (i.e., whether healthy or disordered) and could explain time loss observed in this population. The chapter is divided into six parts: (i) an introductive section briefly summing up time perception, gaming, and previous research on their interaction; (ii) the common cognitive processes between gaming and time perception; (iii) the emotional processes in common between time perception and gaming; (iv) the implication of emotion regulation in this interaction; (v) the impact of flow; and (vi) a conclusion.

3.2. Introduction

3.2.1. Gaming

In recent years, videogames have become one of the major leisure activities with more than two billion people playing at differing levels of involvement (Statista, 2018a). In most cases, gaming is non-problematic and associated with positive outcomes (e.g., Colder Carras et al., 2017; Granic, Lobel, & Engels, 2014; Nuyens, Kuss, Lopez-Fernandez, & Griffiths, 2019). It is however recognized that for a minority, excessive videogame playing can result in a number of problems. Indeed, gaming disorder has been associated with deficits affecting specific cognitive processes (e.g., decision-making and inhibitory control; see Nuyens, Kuss, Lopez-Fernandez, & Griffiths [2017] for a systematic review) and with various psychological and health-related negative outcomes (e.g., Achab et al., 2011; Gentile, 2009; Hellström et al., 2012; Männikkö, Ruotsalainen, Miettunen, Pontes, & Kääriäinen, 2020).

Negative consequences of videogame overuse have become a health concern because a small percentage of gamers are impacted by problems emerging as a consequence of gaming disorder (e.g., Gentile, 2009; Rumpf et al., 2018; Taechoyotin, Tongro, & Piyaraj, 2018; Yen et al., 2008). This concern led to the inclusion of Internet Gaming Disorder (IGD) in Section 3 (i.e., disorders requiring further research) of the latest (fifth) edition of the *Diagnostic and Statistical Manual of Mental Disorders* (DSM-5; American Psychiatric Association, 2013), and Gaming Disorder in the eleventh edition of the International Classification of Diseases (ICD-11; World Health Organization, 2016). Based on these recent developments, the present chapter uses the terms 'gaming disorder' and 'disordered gamer' for the sake of consistency.

One factor of interest existing in both disordered and healthy gaming is compromised time control (i.e., time loss) which can be defined as the underestimation of time spent in a gaming session (e.g., Chou & Ting, 2003; Meerkerk et al., 2009). This phenomenon is clinically relevant as time spent playing videogames can directly affect an individual's life if not controlled properly (e.g., compromising sleep quality, occupation and/or education, and/or relationships; Griffiths, Kuss, & King, 2012). Additionally, compromised time control is frequently encountered by clinicians dealing with patients suffering from gaming disorder (Torres-Rodríguez, Griffiths, Carbonell, Farriols-Hernando, & Torres-Jimenez, 2019), but little is known regarding the psychological mechanisms underlying compromised time control. Time loss may potentially be explained by impaired time perception, resulting in difficulty in keeping track of within-session gaming duration. Although the present paper focuses on problem gaming, it is worth noting that impaired time control has been related to a wide range of psychopathological disorders, including Attention Deficit and Hyperactivity Disorder (e.g., Bielefeld et al., 2017), bipolar disorder (e.g., Bolbecker et al., 2014), schizophrenia (e.g., Ciullo et al., 2018), and substance use disorder (e.g., Wittmann, Leland, Churan, & Paulus, 2007). Consequently, compromised time control constitutes a trans-diagnostic etiopathological process (e.g., Dudley, Kuyken, & Padesky, 2011). Importantly, as literature examining the relationship between disordered gaming and time perception is scarce, research on healthy gaming will be explored to delineate the possible associations between time perception and disordered gaming.

3.2.2. Time perception

According to influential models, time perception depends on two separate processes: a conscious and ad-hoc process where attention is directed towards time (i.e., prospective time perception [PTP]), and an unconscious and post-hoc process where attention is diverted away from time (i.e., retrospective time perception [RTP]) (Levin & Zakay, 1989). The prospective process is conceptualized in the Attentional Gate Model (AGM; Zakay & Block, 1995) and the retrospective process is mainly conceptualized within the Contextual Change Model (CCM; Block & Reed, 1978).

3.2.3. Previous exploration of time perception among gamers

From a clinical perspective impaired time perception amongst gamers appears obvious (i.e., compromised time control is often observed in gaming disorder). Still, to date, only four studies have explored impaired time perception among problem gamers, leading to mixed results (i.e., Rau et al., 2006; Rivero et al., 2012; Tobin & Grondin, 2009; Wood & Griffiths, 2007). Since these studies were explored in the previous chapter, they will only be summarized here as a reminder. Rau et al. (2006) asked experts gamers (i.e., on the tested game) and novice gamers to play *Diablo II* (a dungeon crawler real-time role-playing game) for three different time intervals (i.e., 30, 60, and 90 minutes) and asked them to estimate the duration of the session retrospectively. Even though the difference between the two groups was non-significant (p=.059), the expert gamers underestimated the 60-minute-duration while the novice gamers overestimated it. In order to compare the impact of different activities on both PTP and RTP, Tobin and Grondin (2009) made adolescents perform three consecutive activities (i.e., playing a game for 8 and 24 minutes, and reading a text for 8 minutes). The 24-minute-session of video-gaming was underestimated and the 8-min gaming session was more frequently underestimated than the reading session. Furthermore, when comparing disordered gamers (i.e., according to the scale developed by Griffiths & Hunt, 1998) to healthy gamers as well as when comparing frequent (i.e., more than seven hours per week) and casual (i.e., between one and six hours per week) players, the authors showed an underestimating trend among the more 'excessive' gamers.

In another experiment, Wood and Griffiths (2007) asked participants to play one of two videogames (i.e., participants could choose whether they wanted to play a console or computer game) for 45 minutes and were interrupted at three pre-determined moments (i.e., after 13, 37, and 45 minutes), where they were asked to report how long they had played. Results showed that there was no significant association between videogame play and temporal estimation after each pause. The final study exploring time perception among gamers was conducted by Rivero et al. (2012) who examined both sub-second and multi-second time perception. The first one was relative to reflexes and action planning rather than duration estimation and is thus not discussed here. Participants were asked to perform an estimation task (i.e., estimating three different durations of 10, 30, and 60s) and a temporal production task (i.e., pressing a button for 5 or 45s). No significant differences between the occasional and frequent gamers were found which may have been due to the small sample used.

The research on time perception and gaming (i.e., whether disordered or healthy) currently suffers from a lack cohesion, as the aforementioned studies produced very different findings. From a clinical perspective, understanding the underlying mechanisms of compromised time control is important in order to improve and tailor treatment interventions. Accordingly, the purpose of this chapter is to elaborate on the psychological processes and mechanisms susceptible to cause compromised time control while gaming. Two different pathways will be considered, underlain by either cognitive or emotional processes. Indeed, past research has emphasized that problem gaming is associated with specific cognitive (e.g., executive functions) and emotional factors (e.g., emotion regulation strategies) that are postulated to play a pivotal role in time perception (e.g., Baudouin, Vanneste, Isingrini, & Pouthas, 2006; Cain et al., 2014; Colzato et al., 2013; Fayolle et al., 2014).

3.3. Cognitive processes in time perception and gaming

3.3.1. Attentional processes

Attention processes play a crucial role in time perception, even if it is postulated that they affect RTP and PTP in an opposite way (Block & Zakay, 1997). In RTP, performing a task which elicits more selective attention lengthens the perceived duration via the larger number of events happening during the interval (Block & Reed, 1978). In PTP, performing a more cognitively demanding task shortens its perceived duration because participants pay less attention to time (Zakay & Block, 1995). In experimental situations, the first way to assess how attention affects PTP is to divert the participant's attention away from time by using a dual-task paradigm. In doing so, researchers have observed a systematic underestimation of time when participants have had to perform a non-temporal concurrent task while estimating time duration (e.g., Burle & Casini, 2001; Chinchanachokchai et al., 2015). In another attempt to manipulate attention demand, it has been shown that it is possible to consciously divert an individual's attention from time to a different increment (Casini & Macar, 1997; Kladopoulos et al., 2004; Macar et al., 1994). For example, Macar et al. (1994) asked participants to perform both a word categorization task (i.e., counting animals' names) and a temporal task (i.e., estimating a word series' duration). The participants were further told to focus their attention either entirely on one of the two tasks (i.e., 100%/0%), mainly on one of the two tasks (i.e., 75%/25%), or equally between the two tasks (i.e., 50%/50%). Results showed that the more attention was directed to the categorization task, the more errors were made in the temporal task and the fewer errors were made in the categorization task. A final way of testing the attentional effect is by using cues to explore attention orientation. Here, participants received a cue regarding the following stimulus (e.g., its duration, location, modality) which helped them to focus on it due to their preparation. As they were more focused on the stimulus, and as a result less on time perception, an underestimation of time was observed (Mattes & Ulrich, 1998; Osugi et al., 2016).

Many videogames (especially action videogames such as first-person shooter [FPS]) require continuous and flexible attention from players, and even the slightest lapse in attention can lead to losing the game. Attention can be divided into two separate processes, namely top-down attention (i.e., when individuals consciously direct their attention towards a specific stimulus) and bottom-up attention (i.e., when individuals' attention is attracted toward a prominent stimulus). In addition, top-down attention can be 'activated' by either normal cues (i.e., warning the participant that a stimulus is about to appear) or a spatial cue (i.e., directing participants' attention towards a specific spatial area). The current literature demonstrates that videogame players appear to exhibit better top-down control (e.g., Cain et al., 2014; Chisholm & Kingstone, 2015b; Irons et al., 2011) which could be explained by the requirement to focus on the relevant stimuli in-game (e.g., to focus an individual's attention on important objective-related stimuli without being distracted). Furthermore, some studies exhibited improved bottom-up processing (e.g., Castel et al., 2005; Mishra et al., 2011; Schubert et al., 2015), which could be a consequence of important stimuli appearing randomly within a game requiring a fast relocation of attention from the gamers. However, these studies used different tasks and paradigms to measure attention (e.g., Theory of Visual Attention tests, anti-cueing task, and compound search task) and recruited gamers playing different games genres, which complicates their comparison. Another way to explore attentional processes among gamers is to utilize attentional biases. The basic principle is to include game-related stimuli (i.e., either words or pictures) in a previously validated task. The studies using this paradigm among disordered gamers have systematically demonstrated that gamers unintentionally direct their attention towards the gaming stimuli and have difficulty in disengaging from these stimuli (Jeromin, Rief, & Barke, 2016; Lorenz et al., 2013; Metcalf & Pammer, 2011; van Holst et al., 2012).

Interestingly, a study by Krishnan, Kang, Sperling, and Srinivasan (2013) compared players of two different genres of videogames (i.e., role-playing game [RPG] and FPS game players) to assess whether game genre impacts the performance on attentional tasks. Findings demonstrated overall better performance by the FPS players. Due to the lack of control group (i.e., participants who did not play any videogames), the only conclusion that can be drawn from this study was that FPS players have better attentional processes than RPG players. Consequently, nothing can be concluded on the direct contribution of playing RPGs on time perception compared to non-gamers.

3.3.2. Working memory

Another important process in prospective time perception is working memory, especially when an individual compares two different time durations. According to Baddeley (1992), working memory comprises three components (i.e., visuospatial sketchpad, phonological loop, and central executive). The visuospatial sketchpad plays a central role in retaining and manipulating the visuospatial imagery while the phonological loop has the same role concerning auditory information. The central executive facilitates controlled and proactive cognitive processes and coordinates the visuospatial sketchpad and the phonological loop. According to the AGM (Zakay & Block, 1995), working memory plays a central role in the decision-making process of PTP. First, pulses are gathered in an accumulator in working memory, allowing an individual to make a time duration estimation. After the estimation is made, the response is stored in a reference memory which is more durable. This storage allows the comparison of a newly observed time duration estimation with a previous experienced time duration via working memory. Research on the relationship between time perception and working memory has mainly – if not entirely – been conducted in prospective settings, confirming the AGM theory. Indeed, studies have shown that PTP is predicted by both the visuospatial sketch components of working memory (Baudouin, Vanneste, Isingrini, et al., 2006; Bi et al., 2013; Perbal, Droit-Volet, Isingrini, & Pouthas, 2002). In addition, numerous studies have shown that when performing dual-tasks, participants tend to underestimate time (e.g., Brown & Merchant, 2007; Brown & Smith-Petersen, 2014), which is of interest given that divided attention is part of the four executive functions comprising the central executive component of working memory (Baddeley, 1992).

A study conducted among elderly participants showed that poorer temporal performance (i.e., lack of precision when estimating a time duration) was associated with working memory deficits (Baudouin, Vanneste, Pouthas, et al., 2006). On the contrary, when exploring the development of time perception skills among children, Zélanti and Droit-Volet (2011) observed that while short-term memory and attention predicted temporal sensitivity development in the different age groups, working memory did not show such an effect. Additionally, while attentional processes predicted the difference of temporal performance between single and dual tasks among children, working memory did not play such a role (Hallez & Droit-Volet, 2017). To date, the only study showing an effect of working memory on time perception among children did not show any developmental effect, but an overall positive correlation between the two variables (Droit-Volet, Wearden, et al., 2015).

Most of the available research regarding videogame players emphasizes that regular gamers have an improved working memory (e.g., Colzato et al., 2013; McDermott, Bavelier, & Green, 2014; Mishra et al., 2011), some studies showing that these improvements only occur with regards to the visuospatial sketchpad (e.g., Posner Letter Identity Task, Visual Working Memory Task) (Lau-Zhu, Holmes, Butterfield, & Holmes, 2017; Mishra et al., 2011; Seya & Shinoda, 2016). Although this latter finding is theoretically coherent because videogames mainly influence visuospatial skills (Bavelier, Green, Pouget, & Schrater, 2012), studies still demonstrate that healthy gamers do not exhibit any impaired working memory component (e.g., Colzato et al., 2013; Lau-Zhu et al., 2017). Furthermore, Huang, Young, and Fiocco (2017) compared the effects of console and mobile gaming on cognition, including a measure of working memory. First, their results supported previous research (i.e., regular console gaming improves working memory). Second, they found that playing casual games on a mobile device led to similar effects. This study is noteworthy given that increasing numbers of people now own a smartphone (Statista, 2018b), granting them free and easy access to multiple videogames.

3.4. Emotional processes in time perception and gaming

Time is subjective. It appears to drag out when engaged in a boring activity (e.g., waiting for an appointment or queuing in a shop) and to pass by very quickly when engaged in an appealing or joyful activity (e.g., partying or watching a good film). When researchers have tried to explore the effect of emotions on time perception in a laboratory setting, results have not systematically supported the idiom that ‘time flies when you’re having fun’. Indeed, the results mainly show an overestimation of time irrespective of whether the task was prospective or retrospective (e.g., Bisson et al., 2009; Cassidy & Macdonald, 2010; Kellaris & Kent, 1992). It is noteworthy that studies using pictures for a longer duration managed to observe an underestimating effect among participants (Smith et al., 2011). It is then possible that only longer emotional stimuli would manage to lead to an underestimation, while shorter ones would not.

Nevertheless, whether music affects time perception and whether listening to music while performing a laboratory task can be considered as ‘fun’ are two separate issues. For example, a few studies have explored fun in other ways, showing different results. For instance, one study explored time perception among novice tandem skydivers (Campbell & Bryant, 2007). Even though skydiving is inherently different than playing videogames, the way the researchers investigated this may be helpful in understanding how gaming enjoyment could affect time perception. The study assessed participants’ levels of excitement and fearfulness before the jump and after landing, and (retrospectively) asked participants how long the skydive had lasted. The results showed that while their level of fear positively predicted their time estimation (i.e., time slowing down), their level of excitement showed the opposite (i.e., time passing faster).

Another study explored the motivational intensity of the positive state effect on time perception by comparing a low-approach motivation positive state (i.e., feeling calm or peaceful) and a high-approach motivation positive state (i.e., feeling desire) to a neutral state (Gable & Poole, 2012). In this study, participants could either look at pictures of flowers (low-approach), dessert pictures (high-approach), or geometric shapes (neutral). The results showed that there was no difference between the low-approach motivation positive state and the neutral state. On the other hand, the high-approach motivation positive state was significantly underestimated compared to the other two groups. Also, by telling half the participants that they would receive a dessert at the end of the experiment, the authors showed that expectancy was able to strengthen the previous results as the participants expecting to actually eat a dessert ended up underestimating time more than other participants not expecting to eat a dessert.

Concerning gaming, its impact on emotion has been investigated via neuropsychological studies. These studies demonstrate stronger brain reactivity for disordered gamers compared to control participants when confronted with gaming cues, meaning that disordered gamers are more aroused by gaming stimuli (Ahn, Chung, & Kim, 2015; Ko et al., 2013; Liu et al., 2017; Zhang et al., 2016). For instance, two studies using the same paradigm showed that disordered gamers exhibited stronger brain reactions than healthy gamers when confronted with gaming-related cues (Ko et al., 2013; Thalemann, Wölfling, & Grüsser, 2007; Wang et al., 2017), and that these activations were associated with their urge to play videogames (Ko et al., 2013; Wang et al., 2017) . These two studies imply that on top of disordered gamers being more sensitive to gaming cues than non-gamers (which would be normal since non-gamers are not familiar with these), they are more sensitive than healthy gamers too.

Three other studies have explored in-game reactions with either neural activation through an electroencephalogram (EEG, Shin, Heard, Suo, & Chow, 2012) or physiological activation through an electrocardiogram (ECG), facial electromyography (EMG), and skin conductance (Ravaja, Saari, Salminen, Laarni, & Kallinen, 2006; Salminen & Ravaja, 2007). The EEG study showed that even if healthy gamers can experience negative emotions during a gaming session (e.g., their character getting shot or dying), they reported only positive subjective emotions after the gaming session. The physiological activation studies showed that some game events elicited arousal (Salminen & Ravaja, 2007), and that both positive and negative events elicited positively valenced arousal among healthy gamers (Ravaja et al., 2006). Taken together, the findings of these studies tend to support the emotional explanation for compromised time control. Indeed, behavioural and EEG studies have demonstrated that disordered gamers tend to show stronger brain reactivity when confronted with gaming-related stimuli than non-gamers and exhibit stronger neural activity than non-disordered gamers while playing. These findings demonstrate that disordered gamers experience stronger arousal, which can lead to increased time distortion and in turn to experiencing greater compromised time control. Besides, the in-game studies demonstrate that healthy gamers experience positive arousal during their gameplay, whether they are achieving something good or bad in-game.

3.5. Emotion regulation

Even though emotion regulation plays a crucial role in the interaction between cognitive skills and emotion (e.g., working memory; Malagoli & Usai, 2018; executive functions; Marceau, Kelly, & Solowij, 2018), this has rarely been studied in the field of time perception. According to Eisenberg and Spinrad's (2004, p. 338) comments on a paper by Cole, Martin, and Dennis (2004), emotion regulation can be defined as "*the process of initiating, avoiding, inhibiting, maintaining, or modulating the occurrence, form, intensity, or duration of internal feeling states, emotion-related physiological, attentional processes, motivational states, and/or the behavioral concomitants of emotion in the service of accomplishing affect-related biological or social adaptation or achieving individual goals*". The studies on this topic show that good emotion regulation leads to a lower (almost non-existent) interference of emotion on temporal estimation (Tian, Liu, & Huang, 2018; Wittmann, Rudolph, Linares Gutierrez, & Winkler, 2015).

Since emotion regulation can be defined as the reduction of an individual's reaction to an arousing stimulus (e.g., Evren, Evren, Dalbudak, Topcu, & Kutlu, 2018), three studies can be included in this section because they explored the different ways to reduce a stimulus-arousing effect on an individual. The first way to reduce reaction to an arousing stimulus is to divert attention from it. Using this method with aversive sounds, Mella, Conty, and Pouthas (2011) showed that when their participants had to focus on the sounds, there was an effect of the stimulus on their time estimation (i.e., overestimation). However, when participants were asked to focus equally on the task and the sound, or exclusively on the task, this effect was disrupted, supporting previous findings. Using the perceived level of control as a mediating variable, Buetti and Lleras (2012) recruited arachnophobe and non-arachnophobe participants and confronted them with spider pictures. In order to fluctuate their level of perceived control of the situation, and therefore the arousing effect of the pictures, the participants were either told that pressing a button would make less spider pictures appear or did not receive such instruction. The results showed that under a higher perceived control of the situation, the effect of the very arousing pictures was completely nullified, and this was independent of the percentage of spider pictures presented. These results were further replicated in another study using a similar design (Mereu & Lleras, 2013). Accordingly, it can arguably be concluded that emotion regulation would diminish (if not entirely inhibit) the interference of emotional stimuli on time perception. If this was verified, it would mean that better emotion regulation would lead to a lesser impact of emotion on time perception, and as a result a lesser underestimation of duration.

This fact is of interest given that that several studies have shown associations between gaming and emotion regulation. Villani and Colleague's recent review (2018) showed that regular gaming can be a useful tool in regulating emotion (e.g., to relax during a stressful time) and is even used in therapy. Nonetheless, it would appear that this is different among disordered gamers. For instance, Seo, Kang, and Chae (2012) compared regular and disordered gamers on various emotional variables (i.e., emotional competence, positive emotion, emotional expression, and emotional intelligence) and showed that disordered gamers exhibited lower scores on the emotional variables compared to healthy gamers. These results are further supported by studies showing that disordered gamers have impaired emotion regulation (Evren et al., 2018; Wichstrøm, Stenseng, Belsky, von Soest, & Hygen, 2018) as well as abnormal activation in brain areas responsible for emotion regulation (i.e., orbitofrontal cortex, Du et al., 2016, Zhou et al., 2019; dorsal anterior cingulate cortex, Lee et al., 2015; subcortical and cortical regions, Yip et al., 2018). Based on this literature, it would appear that an efficient emotion regulation ability would alter (if not prevent) any emotional interference on time perception. Yet, the fact that the disordered gamers exhibit an impaired regulation of their emotion may explain why they cannot control the emotional affect coming from their gaming sessions. While a healthy gamer could 'inhibit' or at least reduce the arousal arising from their gaming session (and thus diminish the impact on their time perception), disordered gamers would not be able to (or would have more difficulties to) do so, resulting in observed compromised time control.

3.6. Flow

Flow has been defined as a total involvement in a task where the level of the individual's skill is matched by the level of challenge the task poses leading to experiencing a loss of self-consciousness (Csíkszentmihályi, 1975). According to Csíkszentmihályi (1993), it includes four main components (i.e., control, attention, curiosity, and intrinsic interest) and eight elements (i.e., clear goals and immediate feedback, balance between skills and challenge, concentration, sense of control, loss of self-consciousness, awareness and action merging, reward, and time distortion). When an individual experiences a flow state, all attention is focused on the task itself (e.g., playing videogames) to the point of possibly experiencing a momentary self-awareness loss. Csíkszentmihályi (1993) pointed out that one of the flow elements is time distortion, where individuals experience either a lengthening or shortening of time duration while in a flow state (i.e., overestimation or underestimation of lapsed time during the activity). In an opinion paper on the possible effect of boredom on time perception, Zakay (2014) based part of his argument on Csíkszentmihályi's (1990) definition of flow, asserting that boredom was the other end of a pole on the enjoyment continuum.

Therefore, according to Zakay (2014), while boredom leads to an overestimation of duration, flow experience leads to the opposite effect (i.e., a significant underestimation of time due to the almost entire attentional pool resources being allocated to the activity, inducing the flow state). The case of boredom tends to be supported when comparing participants with a high level of boredom-proneness to participants with low levels. Indeed, Watt (1991) and Danckert and Allman (2005) showed that individuals with more boredom-prone tendencies judge time to be longer during a boring task than participants with lower levels of boredom-proneness. Although this is not a direct measure of flow, the findings indicate a possible fluctuation of time depending on flow experience-proneness. Another way to approach the effect of flow on time perception is through attention. Numerous studies on attention (i.e., see section *"1.1.1. Attention"*) tend to support the relationship between flow and time perception due the increased attention on non-temporal activity leading to an underestimation of time.

In a more direct manner, few studies have explored the direct effect of flow on time perception. By solely exploring the effect of immersion in a videogame, Sanders and Cairns (2010) showed that in a prospective setting, the more a videogame player was immersed in a game (through the inclusion or not of music within a short videogame session), the more they underestimated the time spent playing it. This matched the reports of the participants stating that they felt more immersed when they heard in-game music. This result, among other things, may explain the different results obtained in the previously described experiment on compromised time control among disordered gamers. Indeed, different games include different background music which may constitute a confounding variable. The results of studies exploring the effect of flow experience on playing videogames have been inconsistent and could be due to the varying measures used in the different studies (e.g., Game Engagement Questionnaire, Brockmyer et al., 2009; the Flow State Scale-2, Jackson & Eklund, 2002). For example, some studies have found an association between flow experience and disordered gaming (Chou & Ting, 2003; Hull, Williams, & Griffiths, 2013; Khang, Kim, & Kim, 2013), while others have not (Wan & Chiou, 2006). Contrarily, when exploring time spent gaming among healthy gamers, studies showed that the gamers experiencing flow states tended to spend more time playing (Johnson, Gardner, & Sweetser, 2016; Khang et al., 2013). Finally, it has been pointed out that the structural characteristics of videogames (e.g., negative rewards features, narrative), as well as the players' motives (e.g., playing alone or with other gamers, online or offline), can affect how likely gamers are to experience a flow state (Kaye, 2016; Laffan, Greaney, Barton, & Kaye, 2016; Liu & Chang, 2016). A common denominator between the three papers is the importance of social interaction. While Laffan et al. (2016) and Liu and Chang (2016) only reported that the result on a subscale exploring social interaction correlated significantly with the experienced level of flow, Kaye (2016) put this variable to the forefront in her study. It was demonstrated that knowing teammates' skill levels and having efficient communication and teamwork with teammates significantly predicted the level of experienced flow.

The study by Kaye (2016) showed that in online cooperative games (e.g., Massively Multiplayer Online Role-Playing Games [MMORPG], Multiplayer Online Battle Arena games [MOBA]), not only are the gameplay and the players themselves important to achieve a flow experience, but the way the players interact with their teammates plays an important role. These studies further imply that some game genres (e.g., FPS games and real-time strategy games) can facilitate the experience of a flow state. This needs to be explored in future studies as the finding implies that different types of games have different indirect impacts on time perception via the level of flow they induce.

Another way to explore the potential association between time perception, gaming, and flow is through the concept of enjoyment. In a study by Christandl, Mierke and Peifer (2018), participants engaged in a task for ten minutes, and half of them were told that the task lasted five minutes (time-dragging condition), while the other half was told it lasted 15 minutes (time-flying by condition). The participants who were told that the task lasted longer than what they had thought evaluated their recalled level of flow as higher than the participants who were told the task was shorter. This study shares similar results to another study on time perception and task enjoyment (i.e., Sackett, Meyvis, Nelson, Converse, & Sackett, 2010). They showed that by making participants feel like time passed faster (i.e., by deceiving them about the total duration of the task), participants judged the task as more enjoyable. The study also replicated the results with irritating sounds (i.e., using an underestimation' condition, leading to a lower irritating rating) and music (i.e., using an 'underestimation' condition, leading to a higher rating of the song played). These two studies suggest that time perception and flow are highly associated based on their mutual bidirectional association with enjoyment.

Interestingly, by associating the results on the interaction of emotion and time perception and the research exploring flow, it may provide a possible explanation of how retrospective time perception of gamers can be affected. The studies on the emotional interference on time perception showed that emotions, and especially 'having fun', can induce an underestimation of time duration. Based on this, it could be argued that gamers will experience arousal when confronted with gaming stimuli, which would lead to an emotional response which would not be present among non-gamers, even if they were to play once (as there would not be such an association due to the lack of repetitive game play). Furthermore, as disordered gamers exhibit a hypersensitivity to gaming stimuli, this would lead to a stronger emotional effect compared to healthy gamers. This stronger effect may then result in a stronger underestimation of time during the gaming session, leading to the observed compromised time control effect. This hypothesis is once again supported by flow theory as enjoying a game helps in experiencing a flow state while playing, strengthening the aforementioned effect. Additionally, the difficulty to inhibit one's arousal while playing (i.e., emotion dysregulation observed among disordered gamers) could prevent disordered gamers attenuating this effect compared to healthy gamers.

3.7. Discussion

This chapter aimed to collate previously published data on the compromised time control effect and relate it to disordered gaming. The compromised time control effect is a possible direct consequence of impaired time perception, which leads to an underestimation of the time spent on an activity (in this case, gaming).

It is important as underestimating gaming session length significantly can lead to detrimental consequences due to little time remaining for other important activities (e.g., education and/or occupation, spending time with loved ones, and sleep). Even though it would appear that compromised time control is a direct consequence of impaired time perception, the studies on this topic did not show consistent results, implying that this may not be the case (Rau et al., 2006; Tobin & Grondin, 2009; Wood & Griffiths, 2007). Therefore, the present chapter sought to understand how time perception and videogame use can be associated in order to explain the compromised time control effect.

The first explanation provided for this relates to cognitive processes as cognition can be both impaired by disordered gaming (Nuyens et al., 2017) and improved by regular (non-disordered) gaming (Nuyens et al., 2018). When examining cognitive factors relevant in time perception, two common processes are attention and working memory (Gibbon, Church, & Meck, 1984; Zakay & Block, 1995). When evaluating these two processes among non-disordered gamers, it has been shown that they were both improved, especially for visual working memory (e.g., Colzato et al., 2013; McDermott et al., 2014) and top-down attention (e.g., Cain & Mitroff, 2011; Chisholm et al., 2010). Then, from a cognitive perspective, it would appear that non-disordered gamers are more likely to have a more accurate time perception than non-gamers, whereas this is not the common observation. Nevertheless, the studies on the associations between working memory and attention with time perception solely used prospective experimental settings. It is thus possible that the compromised time perception among gamers is not prospective but retrospective, which fits gaming reality, the gamers rarely consciously monitoring time while engaging in the activity they enjoy. This is supported by the concept of flow according to Zakay (2014), who posited that flow and boredom represent opposite ends of the same continuum. While being bored lengthens time duration (i.e., overestimation of time), experiencing flow leads to the opposite effect (i.e., underestimation of time), thus explaining the compromised time control effect. Although this has not been thoroughly researched, the studies on the association between attention and time perception tend to support this since the less attention is focused on time, the shorter the time duration is perceived to be.

Another possible explanation relates to emotional factors rather than cognitive ones, the enjoyment of an activity leading to underestimating its duration. To date, the laboratory studies mainly showed an overestimation of time when adding emotional stimuli to the experimental task (e.g., Bisson et al., 2009; Cassidy & Macdonald, 2010), thus contradicting the idea developed by Zakay (2014). However, there is a difference between observing emotional stimuli in a laboratory setting and actually having fun to the point of forgetting about time. This fact is underlined by the study among novice skydivers, showing that their level of excitement during their very first jump was negatively associated to their duration estimation (i.e., the more they were excited, the shorter they estimated the jump) (Campbell & Bryant, 2007). Interestingly, the opposite trend was observed, with participants estimating a task as more enjoyable when they were tricked into believing that a task lasted longer than they thought (Sackett et al., 2010).

The studies reviewed showed that disordered gamers tend to show more intense reactivity to gaming cues, and to exhibit greater physiological reactions during a gaming session than healthy gamers and control participants (e.g., Ko et al., 2013; Ravaja et al., 2006; Salminen & Ravaja, 2007; Thalemann et al., 2007). On top of the higher reactivity, these studies showed that even 'bad' in-game events could lead to positive arousal reactions (e.g., character getting shot or dying in the game; Ravaja et al., 2006). Again, flow can play a determining role in the relationship between gaming, emotion, and time perception. Using Zakay's (2014) definition of boredom as the opposite to flow on the enjoyment continuum, research has demonstrated that boredom-prone participants tend to overestimate the duration of a boring task more than less boredom-prone participants (Danckert & Allman, 2005; Watt, 1991). Furthermore, when participants were more immersed in a game, they estimated the duration of their gaming session as shorter than when they were less immersed. This result was only significant in a prospective setting (Sanders & Cairns, 2010). Even though there is a lack of studies examining the causal link between enjoyment and time perception, it appears plausible that having fun leads to underestimating time duration. Since disordered gamers exhibit difficulties regulating their emotions, it is possible that it would affect the emotional interference of gaming on time perception. Since it has been shown that an efficient emotion regulation can reduce (if not nullify) the emotional interference on time perception, it is expected that a deficient emotion regulation will lead to a stronger effect of emotion.

Based on the reviewed literature, several hypotheses on the association between time perception and gaming can be formulated. First, based on the improved working memory and attentional focus observed amongst the healthy gamers (e.g., Cain & Mitroff, 2011; Chisholm et al., 2010), it appears that the impaired time perception leading to the time loss effect would not be prospective. Indeed, attention and working memory, according to the Attentional Gate Model (Zakay & Block, 1995) are crucial within prospective time perception and these improved skills would therefore lead to a more accurate time perception prospectively. However, according to Block and Zakay (1997), attention or working memory would not directly affect retrospective time perception as this type of temporal cognition is rather based on short term memory (Block & Reed, 1978). It is then possible that the gamers' time perception would be only affected retrospectively.

Second, it has been shown that having fun can lead to an underestimation of time (Campbell & Bryant, 2007; Gable & Poole, 2012), although the laboratory studies exhibited that emotional stimuli often lead to an overestimation of duration (Gil & Droit-Volet, 2011; Grommet et al., 2011). This is of interest since it has been shown that gamers react more strongly to gaming stimuli, and can associate negative outcomes with pleasure (Ahn et al., 2015; Ravaja et al., 2006; Thalemann et al., 2007). Therefore, it is possible that the reason behind the gamers' underestimation of time while playing result from an exacerbated arousal derived from their gaming session. Furthermore, since the disordered gamers exhibited even stronger reactivity to the same gaming cues than healthy gamers (Ko et al., 2013) it could be hypothesized that the effect of gaming on their time perception would be stronger as well. Finally, emotion regulation could play a crucial role due to the difference observed between healthy and disordered gamers regarding this skill. Indeed, while healthy gamers exhibit normal abilities to regulate their emotions (Villani et al., 2018), it appears that the disordered gamers manifest an impaired emotion regulation (Seo et al., 2012; Wichstrøm et al., 2018). As a result, it can be presumed that while the healthy gamers could manage to limit the effect of their emotional reactivity when confronted to gaming cues, the disordered gamers would end up overwhelmed by their stronger reactivity due to their impaired emotion regulation.

Interestingly, several of the potential associations between time perception and disordered gaming explored in this chapter are included in the Interaction of Person-Affect-Cognition-Execution (I-PACE) model (Brand et al., 2019). According to this model, the development and maintenance of addictive behaviours (including disordered gaming) would rely upon common underlying mechanisms. Each category of process affecting the development is represented by a letter of the model: (p) represents the core characteristics of the **p**erson (e.g., the biopsychosocial constitution, the personality, the motives), (a) and (c) are the **a**ffective and **c**ognitive responses to stimuli (e.g., cognitive biases, cue-reactivity, emotion regulation), and (e) represents the **e**xecutive functions (e.g., inhibition, decision-making). Concerning this thesis, the (a), (c), and (e) sections of this model are of particular interest since they integrate the emotional and cognitive processes explored in the present studies (e.g., attention, working memory).

In conclusion, for the rest of this thesis, it will be hypothesized that the time loss effect among gamers results from impaired retrospective time perception. Nonetheless, it will also be assumed that this impairment results from their hyper-reactivity to gaming cues and will therefore not be observed in normal conditions.

Chapter 4: Methodology

4.1. Chapter overview

The main aim of the present research is to validate the Dual-Process Contingency model (DPCM) with longer durations (i.e., multi-minute time perception) among gamers and non-gamers. This thesis comprises three experiments utilising a quantitative approach because it was decided to explore a continuous variable (i.e., temporal estimation). The first experiment aims at testing the DPCM with a longer duration, thus determining the associations existing between retrospective and prospective time perception. The second experiment's objective is to test the difference in time perception between gamers and non-gamers in view of the DPCM. Finally, the third experiment's aim is to test the interactions between cognitive and emotional factors in the DPCM among gamers and non-gamers. Consequently, the thesis will have important implications at both theoretical and experimental levels by unifying prospective and retrospective time perception under the DPCM and studying its associations with cognitive and emotional factors. In addition, it will have implications at clinical level by determining the role played by impaired time perception in the emergence of time loss. Before exploring the methodology adopted in the three experiments constituting this thesis, this chapter will expound the philosophical assumptions underlying the thinking process behind the thesis as well as a short explanation of the methodological approach chosen to test the hypotheses (i.e., quantitative experimental approach).

4.2. Philosophical assumptions

Underlying philosophical assumptions are important before starting any experimentation. Indeed, a researcher's philosophical assumption shapes their vision of the world and will affect their research design greatly. Although numerous paradigms have been created through time, Candy (1989) has summarised these into three main taxonomies, a fourth one having been added by Tashakkori and Teddlie (2003). These four main paradigms are the pragmatist, positivist, interpretivist, and the critical paradigm. These paradigms are all defined through four axes: (i) epistemology (i.e., the nature of one's knowledge), (ii) ontology (i.e., a belief system on which the interpretation of the data is based), (iii) methodology (i.e., the research design: how the experiment is conducted), and (iv) axiology (i.e., ethical considerations).

Given that this thesis solely comprises quantitative experiments, the most fitting philosophical assumption is positivist pragmatism, which follows the scientific method (see Figure 1, p. 238). Since its first introduction by Auguste Comte (1856), the positivist approach of research postulates that knowledge is only achievable through experimentation and observation. Its epistemology is objectivist (i.e., knowledge is deduced from experimental work), its ontology fits the naïve realism (i.e., material objects and their characteristics are observable), its methodology follows the scientific method, and its axiology is beneficence (i.e., trying to maximize positive results while minimizing any possible risk for the participants).

4.3. The quantitative approach

Given that the variables explored in this thesis are exclusively continuous (e.g., time estimation, scale scores, and reaction time), the most appropriate research approach is quantitative. Indeed, this experimental design particularly fits the natural science method of testing (Bryman, 1984; Howe, 1992) and is core to the positivist approach of social sciences research. The quantitative designs follow the scientific method adapted from the natural sciences and are based on statistical analysis of numeric data (i.e., extracted from the testing such as scale scores or reaction times) (McQueen & Knussen, 2006). Therefore, based on this type of design, a researcher should explore the possible independent variables influencing the level of a dependent variable (e.g., in this thesis, gaming is an independent variable and time estimation is the dependent one), while controlling possible cofounding variables (e.g., in this thesis, gender and age). The main assets of this method compared to a qualitative one are its objectivity (i.e., the discussion is based on objective measures of the behaviour) and its replicability (i.e., using the same measure, another tester could do the same experiment and reach the same results). Furthermore, one of the assets of this method is that the results are generalizable if a representative sample is explored.

This method has been criticized for its lack of flexibility regarding the complexity of human processes, which can sometimes result in disregarding potentially interesting variables. And despite this research attempting to show the associations between different variables, sometimes it will not be able to explain how, or why, these relationships exist with regards to the human mind. In this particular research, the quantitative approach assesses the relationship between gaming and time perception and test two variables underlying this relationship (i.e., cognitive process and emotional interference).

Quantitative research is mainly used in three types of experiments: (i) survey research, (ii) correlational studies, and (iii) experimental research. These experiment types are not exclusive and can be mixed in the design, especially for long-term work such as a thesis. In this thesis, demographic data, as well as personality trait data, and gaming use data will be collected via questionnaires, similar to survey research. Furthermore, the scores on these questionnaires will be compared to the results on the various experimental tasks through the use of correlations. The core of this experiment (i.e., exploring the interaction between gaming and time perception) will be studied via an experimental approach because the scores of the different groups will be compared. Accordingly, this thesis will be based on the three main types of research included in the quantitative approach of social sciences (e.g., psychology, law, and sociology).

4.4. Limitations and advantages of a laboratory-based approach of time perception in gaming disorder

The first limitation of the laboratory-based approach in this experimental thesis is its context and its impact on arousal. Indeed, one of the aims of this experiment is to explore the arousing effect of videogames on time perception, in other words, observing if the distorted time perception of gamers is due to an emotional reaction following the presentation of gaming cues. For this purpose, gaming pictures will be used in the third experiment, with the aim of eliciting an emotional reaction among the gamers even if this experiment's method cannot compare to the many types of stimulation offered by real modern videogames (e.g., visual stimuli, music, and sound effects). Interestingly, within this limitation lies one of the advantages of this method, which is the control of exogenous variables. Indeed, while a real videogame will procure an abundant amount of diverse stimulations (i.e., both visual and auditory), this experiment will be able to maintain its focus on a single type of stimulation (i.e., visual). This will allow a better grasp of this specific stimulation, further studies being able to explore the other types of stimulation. Only when understanding each component on their own will the research be able to integrate them all in a complex model.

The central variable assessed in this thesis is time perception, which is thought to be impaired among gamers due to their observed time loss. In real life, gamers will play for varying durations depending on multiple factors (e.g., the day, time of the day, and the game itself). Testing the participants in a laboratory setting is then not representative of this variation, yet it allows a replication of the duration between and within the different groups tested. Another limitation directly related to the previous one is the duration tested (i.e., between one and six minutes for a total of ten minutes) compared to the duration of a typical gaming session (i.e., more than one hour). Even though the duration used in this thesis is not fully representative of a typical gaming session duration, it represents a viable approximation and a stepping stone for further research using durations and contexts which are more ecologically valid. In addition, using shorter durations gives the ability to make several trials in a retrospective setting where the participants would provide all the estimations at the end of the task. This is possible since less than 10 minutes would pass between the end of the first block and the moment where the participants would provide their estimation (i.e., the end of the task). For longer durations (e.g., three blocks varying between 10 and 30 minutes for a total duration of one hour), almost one hour would lapse between the first block and the end of the task where the participants would provide their estimation. In the second case, it may be hard for the participants to remember how long the first block lasted when they had finished the whole task, while it is much easier in the first case. As a consequence, fewer trials should be included for longer durations, if not a single estimation. Although this would be closer to the reality of gaming sessions, using a multiple shorter duration allows more adjustments (e.g., deletion of multiple outliers for each duration). These possible adjustments represent a security measure which is essential in a first exploration such as this one.

Another limitation lies within the population tested, as most of the participants available at a university campus are students. This limitation does not reside within the young age of the sample which should not be a major problem due to the similar age of the general gamer population (Statista, 2018c), making this sample representative of the real gaming population. Instead, the limitation results from the recruitment of participants through an internal credit system provided by

Nottingham Trent University. Indeed, the students using this system are mostly psychology students aiming to gather enough credits for their third-year thesis. Therefore, the participants may try to work out the aim of the experiment, affecting the result both by a lack of focus on the task itself and by adapting their behaviour based on their own hypothesis. However, the main aim of this thesis is the exploration of time perception (i.e., both prospective and retrospective), which may prevent such a bias. Indeed, in the case of retrospective time perception, the participant does not know the real aim of the experiments since they are performing a recall task. The participants may indeed try to understand how they are expected to perform the distraction task, rather than considering time perception as a variable. In the opposite case, when performing a prospective time estimation, it is expected that the participant will perform as well as they can regarding the time estimation, despite having to perform a cognitively challenging task. In brief, this bias can be viewed to be in favour of this experiment.

4.5. Variables explored in the thesis

4.5.1. Time perception

In this section, the most adequate measure of time perception for this thesis will be discussed. Numerous tasks exist in the literature to measure time perception which can be reduced to six main tasks, which have been adapted into multiple variations. First, in the Estimation Task (ET), participants are presented a stimulus (e.g., a picture or a video), or asked to perform a task for a random duration and then are being asked to tell the experimenter how long that stimulus/task was presented for/lasted. Second, in the Temporal Reproduction Task (TRT), participants are asked to observe a duration (i.e., similar to the ET), and to reproduce this duration with an action (e.g., pressing a button for the same duration, or telling the experimenter when that duration has elapsed again). The third task, the Temporal Production Task (TPT) is highly similar to the TRT task, with the exception that instead of having to observe a stimulus and reproducing its duration, the experimenter will simply tell a duration to the participants, who are being asked to reproduce it in the same manner as for the TRT. Fourth, in the Temporal Comparison Task (TCT), participants are presented two durations (i.e., either identical or different) and are asked to decide which one is the longer one. The fifth task, the Temporal Bisection Task (TBT), requires the experimenter to present two durations (i.e., called anchors) repeatedly to the participants until they manage to differentiate them. Afterwards, participants are presented durations between these two anchors and are asked to decide to which of the anchors it is the closest. Finally, the sixth task, the Temporal Generalization Task (TGT), is similar to the TBT. Participants are asked to familiarize themselves with a single duration at the beginning (i.e., instead of two durations), and in the following blocks of the task, they are asked to indicate whether the following durations are shorter or longer in comparison to the first one.

All these tasks have their strength and weakness, and not all are suitable for specific research purposes. For example, while the temporal production, generalization, and bisection tasks do not allow the researcher to perform testing in a retrospective setting, the estimation, reproduction, and comparison tasks allow testing retrospectively. It is noteworthy that the TCT only allows a single retrospective testing since, after the first comparison, the participant will be aware of the temporal aspect of the experiment, leading them to make any further judgment prospectively. Nonetheless, when it comes to quantitative experiments, some of the previous tasks represent an important interest as they allow testing a myriad of durations (i.e., the TGT and TBT). Since the participant simply needs to remember up to two durations, and to compare it to other random durations, it allows the experiment to present dozens of these durations and achieve precise estimations of their temporal perception. The other tasks also allow the testing of multiple durations, but the way they were created greatly limits the number of testing.

In this thesis, both retrospective and prospective time perception are measured, the first aim of the thesis being to validate the Dual-Process Contingency Model of time perception (i.e., see the first chapter on time perception for an exploration of the model). Therefore, the temporal reproduction, bisection, and generalization tasks were not viable tasks to explore time perception in the present thesis since they are not fit to test retrospective time perception. Additionally, both the temporal comparison and production tasks only allow for testing once because participants make a first trial retrospectively, and then have to perform the other trials prospectively. The ET on the other hand allows the experimenter to avoid this issue by simply asking the participants to estimate the duration after all the trials have been presented. Unfortunately, this prevents the experiment from including numerous trials (i.e., it may be arduous to estimate more than 2-3 durations accurately retrospectively), yet, this is still the best possibility. Furthermore, this task is particularly suitable to evaluate the time loss effect among gamers. Indeed, when gamers observe such a temporal distortion (i.e., underestimating the time spent on a game), it is more likely that they estimate the duration, instead of any other means offered by the other tasks (e.g., reproducing the duration). In conclusion, this task is not only more suitable in regard to the experimental setting, it is also more ecologically valid than any other task.

4.5.2. Gaming disorder

Given that gaming disorder was defined in the second chapter of this thesis, its definition will not be further discussed in this section. It is still worth mentioning that in this thesis, two approaches to gaming disorder will be used to cover a wider aspect of this construct. First, the definition and criteria provided by the DSM-5 (i.e., IGD, American Psychiatric Association, 2013) and second, the problematic use of videogames provided by Demetrovics et al. (2012). Indeed, King, Haagsma, Delfabbro, Gradisar, and Griffiths (2013) reviewed all the different gaming disorder scales existing at the time (i.e., 19 scales) which assessed different conceptualisations of this construct. In evaluating these scales, the authors extracted 16 different facets of this disorder (e.g., preoccupation, control loss, and deception), and the Problematic Online Gaming Questionnaire (i.e., POGQ, Demetrovics et al., 2012) used in the present research assesses nine of these criteria. When adding the nine criteria of the IGD to the POGQ, a total of 13 criteria from King et al.' 16 criteria (2013) are assessed. The only non-explored criteria according to King et al.' study (2013) not studied using these two psychometric scales are "*dependency on others*", "*illegal acts*", and "*financial conflicts*".

4.5.3. Attentional focus

The interaction between attention and both time perception and gaming has been widely explored in the three first chapters of this thesis and will not be further explored in this section. In summary, it appears that attention is a crucial variable in time perception (Lejeune, 2000; Zakay & Block, 1995) and appears to be more efficient among regular gamers (Cain & Mitroff, 2011; Chisholm et al., 2010). For this reason, it appeared judicious to include a measure of attentional focus in this thesis in order to control a potential effect of the improved attention of gamers on their perception of time. For this purpose, the model of the Attention Network Task (ANT) was adopted (Fan et al., 2002). According to the ANT, attention is divided into three different systems: (i) the alerting system (i.e., being able to make use of a clue to prepare for a stimulus), (ii) the orienting system (i.e., being able to orient attention towards a spatial area after a spatial cue), and (iii) the executive control system (i.e., being able to inhibit the distractors). The first two systems (i.e., alerting and orienting systems) are associated with bottom-up attention selection (i.e., external stimuli catching one's attention) due to attention being directed despite the will of the individual. The third system (i.e., executive control system) is associated with top-down selection (i.e., conscious direction of one's attention) as this system requires the individual to direct their attention themselves by ignoring distractors.

4.5.4. Working memory

As for the attentional focus, working memory has been explored in regards with time perception and gaming in the third chapter of this thesis and will not be further explored in this section. Similar to the section on 'attention', it has been explained that working memory is a very important process in temporal cognition (Gibbon et al., 1984) and appears to be improved among regular gamers (Colzato et al., 2013; Mishra et al., 2011). In this experiment, the Digit Span Test (DST), one of the sections of the fourth edition of the Wechsler Adult Intelligence Scale (i.e., WAIS-IV, Weschler, 2008), was chosen to assess working memory. Even though this task may not be entirely accurate because it is only a specific part from the entire battery, this task had the advantage of being short, given that the whole testing session lasted over 40 minutes.

4.5.5. Impulsiveness

Impulsiveness has first been defined as a tendency to act spontaneously in an unplanned and excessive fashion, and this unidimensional construct was the second mostly cited diagnostic criterion in the DSM-IV-TR (American Psychiatric Association, 2000). Although the root of impulsiveness lies in antiquity with Hippocrates' work, this section will explore the evolution of this construct, starting with the inclusion of impulsiveness within Eysenck's three-factor model of personality (i.e., neuroticism, extraversion/introversion, and psychoticism) (Eysenck, 1967). According to Eysenck, impulsivity is mainly related to psychoticism and is defined as a tendency to not think before acting. It was still observed that impulsivity-related items were present in all the sections of the questionnaire Eysenck created to assess this model of personality (i.e., Eysenck's Personality Questionnaire; Eysenck & Eysenck, 1975). Impulsiveness is included in the Five-Factor Model of personality (i.e., FFM, Costa & MacCrae, 1992) which includes four facets, or subcategories, directly related to impulsiveness: (i) impulsiveness–neuroticism, (ii) self-discipline and deliberation–Conscientiousness, and (iii) excitement-seeking–extraversion).

The first multidimensional model of impulsivity was proposed by Barratt (1985). According to him, there are three main types of impulsiveness, subdivided into six factors: *attentional impulsiveness* (including attention and cognitive instability; difficulty to remain focused on a task), *non-planning impulsiveness* (including self-control and cognitive complexity; not thinking ahead about the possible consequences of an action), and *motor impulsiveness* (including motor and perseverance; acting on the spur of the moment). Based on these three concepts, Patton, Stanford, and Barratt (1995) created the Barratt Impulsiveness Scale 11 (BIS-11).

Basing their thoughts on the aforementioned measures of impulsivity, Whiteside and Lynam (2005) created a test battery which they administered to 437 university students. The battery included the NEO-PI-R (Costa & MacCrae, 1992), the BIS-11 (Patton et al., 1995), the sensation-seeking scale (Zuckerman, 1993), the Temperament and Character Inventory (Cloninger, Svrakic, & Przybeck, 1993), the EASI-III Impulsivity Scales (Buss & Plomin, 1975), the Personality Research Form Impulsivity Scale (Jackson, 1984), the Multidimensional Personality Questionnaire Control Scale (Tellegen, 1982), Dickman's Functional and Dysfunctional Impulsivity Scales (Dickman, 1990), and the I-7 Impulsiveness questionnaire (S. Eysenck, Pearson, Easting, & Allsopp, 1985), and 14 items created to assess impulsivity occurring in negative emotional states (e.g., "*When I feel bad I will often do things I later regret in order to make myself feel better now*", "*I only act rashly when I am upset*"). Collating the data from all the questions and performing factor analyses, Whiteside and Lynam (2005) developed a four-factor model of impulsivity. These four factors were named **u**rgency, lack of **p**remeditation, lack of **p**erseverance, and **s**ensation seeking, giving its name to this model: the UPPS model of impulsivity.

Urgency is the tendency to react rashly when experiencing a negative emotion (e.g., drinking lots of alcohol after receiving bad news). According to Cyders and Smith (2008), there exists the positive equivalent of negative urgency (i.e., positive urgency), which posits that the same type of rash reaction to emotion can occur when the situation is positive (e.g., spending a lot of money after receiving good news). This positive urgency later led to the creation of an integrative model of impulsivity, namely the UPPS-P (Lynam et al., 2006). Furthermore, it has been shown that both types of urgency are subcomponents of a key mechanism conveniently named "urgency" (Lynam et al., 2006). This factor is closely related to the neuroticism facet of the FFM, and individuals with high urgency tend to be more anxious or dysphoric (d'Acremont & Van der Linden, 2007). Compared to 'motor impulsiveness' elaborated by Barratt (1985) which held a similar definition, this concept has the important advantage of including emotion in impulsiveness. This is interesting given that it has been shown numerous times that emotion can alter inhibition (e.g., Rebetez, Rochat, Billieux, Gay, & Van der Linden, 2015; Verbruggen & De Houwer, 2007) while urgency has been associated with the inhibition of pre-potent response (Bechara & Van Der Linden, 2005).

Premeditation is the ability to think about the potential (negative) consequences of an act before acting; the lack of premeditation being the difficulty to foresee these consequences. This is close to the deliberation facet of the FFM, the lack of planning ability from the BIS, or the definition of impulsivity from Eysenck. Individuals with a lack of premeditation simply act without care for (or thought of) the consequences of their actions (e.g., drinking heavily the day before an important job interview). According to Bechara and Van der Linden (2005), premeditation is linked to decision-making.

Perseverance is the ability to remain focused on a hard or boring task and the lack of perseverance refers to the difficulty to remain focused on such a task. This construct is close to the self-discipline facet of the FFM, as well as the cognitive impulsivity and cognitive complexity of the BIS. Individuals with a lack of perseverance tend to present attentional deficits, have more mind drift (Bechara

& Van Der Linden, 2005), and find it harder to lead their project to completion (Gay, Schmidt, & Linden, 2011).

Sensation seeking is openness to new experiences and the tendency to seek exciting activities and new adventures. This facet is related to the motivational systems defined by Gray (1981; i.e., Behavioural Inhibition System and Behavioural Activation System) and the excitement facet of the FFM. Individuals with higher levels of sensation seeking tend to take more risks, and to engage in more dangerous activities.

As mentioned earlier, both types of urgency are part of a higher global Urgency factor. And, according to a structural modelling of the UPPS-P, premeditation and perseverance depend on a global component named the conscience deficit factor (Billieux, Rochat, & Van der Linden, 2014). This conscience deficit factor and urgency are both part of a higher-order factor, self-control, which relates to executive functions (e.g., inhibition, and decision-making). On the other hand, sensation seeking is more related to the motivational systems and is thus a separate motivational factor. Even though these two higher-order factors (i.e., motivational and self-control) are separate, they still show important interaction, which impacts an individual's behaviour (Billieux et al., 2012).

When thinking about the interaction of impulsivity and time perception, the first thing that comes to mind is the delay discounting (DD) paradigm. The DD paradigm is based on an economist perspective of decision-making, where the longer an individual has to wait before receiving a reward, the less subjective value they will attribute to this reward (Ainslie, 1993). Therefore, in a DD task, a participant is presented with varying reward values and delays before getting it, allowing the researcher to determine a function of their temporal decision-making (Rachlin, Brown, & Cross, 2000). Interestingly, the research examining the DD function of gamers exhibits a steeper function (i.e., a faster devaluation of reward over time) for pathological gamers compared to healthy or non-gamers (i.e., a difficulty to delay rewards, Buono et al., 2017). Furthermore, this relationship has been further supported by a study using a more implicit method to explore this association (i.e., the Single Key Impulsivity Paradigm, Nuyens et al., 2016). Unfortunately, despite the importance of time perception in DD (i.e., overestimating duration makes it harder to postpone a reward), no study clearly explored the associations between these two variables. However, several studies have shown that groups exhibiting an impaired DD also showed impaired time perception (e.g., Baumann & Odum, 2012; Brocas, Carrillo, & Tarrasó, 2018). Still, this is not a pure measure of the association between impulsivity and time perception since other factors come into play (e.g., reward sensitivity).

When it comes to directly comparing impulsivity and time perception, the results and methods differ between the few experiments available (i.e., multiple definitions of impulsivity, and different temporal tasks). According to tapping studies (i.e., asking participants to tap in a repetitive rhythm of one tap per second), impulsive individuals tend to tap faster, indicating a faster cognitive tempo (Barratt, Patton, Greger Olsson, & Zuker, 1981; Wittmann et al., 2007). When comparing these results to the current main prospective time perception model (i.e., the attentional gate model, see first chapter for more details), this refers to a faster pulse rate from the pacemaker, leading impulsive individuals to overestimate duration.

This assumption is supported by case studies showing that populations marked by stronger impulsivity (e.g., individuals with Attention Deficit/Hyperactivity Disorder, borderline disorder, and addiction disorder) tend to overestimate duration (Stanford & Barratt, 1996). This relationship is of interest when juxtaposed with studies exploring impulsivity among gamers where, despite a few inconsistencies, gamers appear to exhibit increased impulsivity (e.g., Billieux et al., 2015b; Ryu et al., 2018). In addition, studies demonstrate that the level of impulsivity experienced by gamers predict their level of addiction (e.g., Billieux et al., 2011; Ko et al., 2017), and could even trigger the development of disordered use (Gentile et al., 2011). Moreover, this last study showed in their longitudinal exploration of disordered gaming that developing disordered use leads to increased impulsivity.

4.5.6. Depression

According to the DSM-5 (American Psychiatric Association, 2013), depressive disorder is an umbrella concept including different mental disorders (i.e., disruptive mood dysregulation disorder, major depressive disorder, persistent depressive disorder, premenstrual dysphoric disorder, substance/medication-induced depressive disorder, and depressive disorder due to another medical condition). These disorders have been regrouped into a single section due to their shared presence of mood modification (i.e., presence of sadness/emptiness feeling, sleep disturbance, and thoughts of death). Among these specific disorders, the most common one is major depressive disorders, which is outlined by a succession of depressive episodes of at least two weeks (i.e., changes in cognition, affect, and neurovegetative functions) and remission episodes. The ICD-11 (World Health Organization, 2016) shares a similar definition of the umbrella construct of depressive disorders, the specific disorders inside this umbrella term slightly differing from the DSM-5 (i.e., single episode depressive disorder, recurrent depressive disorder, dysthymic disorder, and mixed depressive and anxiety disorder). The equivalent of major depressive disorders in the ICD-11 is recurrent depressive disorder, which is characterized by the presence of at least two depressive episodes (i.e., similar to the ones presented in the DSM-5), separated by a remission period.

Regarding time perception, depressed individuals often report that the perception of time was lengthened, or that time was slowed down (Gallagher, 2012; Msetfi, Murphy, & Kornbrot, 2012). For example, Vincent Van Gogh in one of his letters to his brother mentioned that “days seem like weeks” to him (Van Gogh, 1890). However, it can be argued that it refers to the time experience construct (i.e., the subjective feeling of time passing by). Even if these two constructs are theoretically very similar, several authors pointed out that the processes at stake can be drastically different (Kent, van Doorn, Hohwy, & Klein, 2019; Msetfi et al., 2012).

Concerning the time perception measures in research, the association with depression is inconclusive. Some current research has found that depressed participants (i.e., whether clinical or non-clinical) tend to overestimate durations (Biermann et al., 2011; Bschor et al., 2004), while other research has either failed to find any significant difference (Oberfeld, Thönes, Palayoor, & Hecht, 2014; Thönes & Oberfeld, 2015) or, occasionally, the opposite result (i.e., an underestimation of duration; Gil & Droit-Volet, 2009; Mioni, Stablum, Prunetti, & Grondin, 2016). This could be due to two main factors related to the methodology used. First, it has been shown in several experiments that depressed patients exhibit dulled motor responses. Therefore, the experiments using either a production or reproduction task exhibit a clear limitation because of the importance of the motor input in these tasks. Second, most of the studies exploring time perception use short durations to allow multiple measurements of time estimation. Although this is ecologically relevant, the way the depressed participants express their time experience tends to imply that they refer to long, meaningful durations, which is not represented by the studies exploring durations smaller than a minute.

This is of particular importance when it is known that depressed individuals appear to exhibit impaired sustained and selective attention (Gualtieri, Johnson, & Benedict, 2006) which is crucial for longer durations, but of lower importance in the shorter durations (Zakay & Block, 1995). When taking these two points into consideration, there is unfortunately not enough evidence to reach a definitive conclusion regarding the importance of depression in time perception, even though the association between depression and time experience has systematically been shown in research (Oberfeld et al., 2014; Thönes & Oberfeld, 2015).

Concerning gaming, the results are more straightforward and most of the research including a measure of depression alongside a measure of gaming addiction has found an association between the two variables (e.g., Bargeron & Hormes, 2017; Männikkö et al., 2020; van Rooij et al., 2014). The only question still under debate is whether disordered gaming leads to depression, or if depressed individuals escape through gaming and develop disordered use afterwards. A few studies have attempted to resolve this debate by performing longitudinal research, showing disparate results. For example, Brunborg et al. (2014) showed that the amount of gaming at the first time point in the longitudinal study significantly predicted depression levels (among other variables) at the second time point (i.e., two years later). This study therefore implied that gaming is the predictor, or the antecedent, of depression. Gentile et al. (2011) supported these results with a stronger exploration of this interaction, and showed that someone with more gaming disorder symptoms at the first time point of the longitudinal study exhibited higher levels of depression at the second time point of the study (i.e., one year later). And, if the symptoms of gaming disorder increased for the second measurement time point of the study, levels of depression became even stronger at the third time point of the study (i.e., one year after the second measurement, and two years after the first one).

Interestingly, another longitudinal study highlighted the possibility of a vicious circle, or a bidirectional interaction between the two variables (Krossbakken et al., 2018). This research first supported the two previous longitudinal studies by showing that disordered gaming predicted levels of depression after one and two years. Second, it showed the opposite trend where depression predicted the development of disordered gaming after one year (i.e., not after two years). Despite the lack of support regarding the associations between time perception and depression, it was decided to include a measure of this variable in the present research in order to control for its potential impact. This is of particular importance because it has been shown that disordered gaming is closely related to depression.

4.5.7. Anxiety and stress

According to the DSM-5 (American Psychiatric Association, 2013), anxiety disorders are characterized by an excessive fear (i.e., a response to a real or perceive threat) and anxiety (i.e., anticipation of a threat). Anxiety disorders include several subtypes (i.e., separation anxiety disorder, selective mutism, specific phobia, social anxiety disorder, panic disorder, agoraphobia, and generalized anxiety disorder), the most common disorders being Specific Phobias and Social Anxiety Disorder (i.e., social phobia) according to the DSM-5. The first one is defined by fear/anxiety immediately triggered by a specific object/situation, which is avoided by the individual (or endured with intense discomfort) for at least six months. The second one, a specific phobia, shares commonalities with the previous disorder. This phobia is directed towards social situations, especially in situations when individuals can be observed and "judged" negatively by other individuals (e.g., due to their anxiety symptoms). It differs from Specific Phobias by the fact that the fear/anxiety is disproportionate compared to the actual threat of the situation. The ICD-11 offers a similar definition of Anxiety Disorders but since the ICD-11 does not include prevalence rates, there is no predominant type of Anxiety Disorder in this reference book (World Health Organization, 2016).

The literature on anxiety and time perception is scarce compared to depression, yet, the global results appear more straightforward. The literature on this interaction shows that anxious individuals tend to overestimate duration (e.g., Bagana & Raciu, 2012; Campbell & Bryant, 2007; Droit-Volet, Mermillod, et al., 2010). The most common effect observed concerns Social Anxiety Disorder, where individuals suffering from social phobia overestimate the duration of angry and fearful faces compared to non-anxious faces (Ishikawa & Okubo, 2016; Yoo & Lee, 2015). According to Bar-haim, Kerem, Lamy, and Zakay (2010), this difference between anxious and non-anxious individuals only occurs within very short durations (i.e., in this experiment, the results were significant only for 2s, and not for 4s and 8s). Interestingly, studies on one of the most widespread phobias, arachnophobia, showed that when confronted with their fear (i.e., spiders), arachnophobes overestimated time in the same manner that social phobic participants did when observing angry faces (Buetti & Lleras, 2012; Watts & Sharrock, 1984). Furthermore, the target of this phobia (i.e., spiders) was easily manipulated in experimental settings (i.e., compared to social situations), and allowed for more flexibility in the testing of the phobia. For example, Watts and Sharrock (1984) approached a spider as close as the participant could withstand it and made them estimate a 45s duration, showing that there was no difference in the estimation between the phobic and non-phobic individuals. Afterwards, they placed the spider closer to the participants, asking them to signal when it was starting to be unbearable and then again asked them to estimate a 45s duration. They showed that phobic participants overestimated the duration compared to the non-phobic ones. In another study, Buetti and Lleras (2012) explored the effect of perceived control on the interaction between anxiety (or stress) on time perception. For this purpose, they manipulated the perceived control of arachnophobes (and non-arachnophobes) on the appearance of a spider (or other high-arousing negative pictures) in a task. They showed that when participants believed that they had no control over the appearance of the spider pictures, they tended to overestimate the duration of these, while the effect completely disappeared when participants thought that they were controlling their appearance.

To the best of the author’s knowledge, only one study found a result that potentially contradicts the previous research in this section. In a study comparing anxious and depressed patients with control participants, Mioni et al., (2016) showed that while depressed participants under-reproduced durations (500, 1000, and 1500ms), anxious participants over-reproduced them. This could be interpreted as an overestimation of time for the depressed participants versus an underestimation for the anxious (as they estimated their production as shorter than its real duration). Even though this first interpretation may be true, it could be due to anxious participants overestimating the duration of the stimuli which they had to reproduce. Indeed, if the participants overestimated the first duration, they would in turn produce a longer one, contradicting the underestimation hypothesis.

Regarding gaming, the results follow the same trend as for depression, with disordered use (i.e., irrespective of the terminology and/or measure used) having been associated with higher anxiety scores (e.g., Bargeron & Hormes, 2017; Hyun et al., 2015; Wartberg, Kriston, & Thomasius, 2017). All of the studies showing this association used surveys, and most of them used the general population, showing the same type of results, and will not be further discussed. On the other hand, some of the research on this interaction explored it among clinical populations, or observed potential variables altering this association, and will be discussed in the following paragraphs.

Using a clinical sample, Vadlin, Åslund, Hellström, and Nilsson (2016) compared the levels of different psychopathologies between non-disordered gamers and disordered gamers within a clinical population, and observed whether the same observations could be made between disordered gamers and control participants from the non-clinical population. Interestingly, while presenting symptoms of depression, ADHD or anxiety raised the likelihood of developing disordered use in the non-clinical population, there was no difference in terms of psychiatric symptoms among the clinical population.

Two factors appear to influence the relationship between disordered gaming and anxiety levels. First, Bonnaire and Baptista (2019) showed that while disordered Massively Multiplayer Online Role-Playing Game (MMORPG) players exhibited higher levels of anxiety (and depression) compared to healthy gamers, disordered Multiplayer Online Battle Arena (MOBA) gamers only showed higher scores of depression and alexithymia. Therefore, it appears that the game genre preferred by the disordered gamers may influence the impact of their disordered use on their mental health. In another study, Király et al. (2015) explored the gamers' motives as well as their disordered use, showing that the motives of escape (i.e., playing games to avoid real-life struggles) and competition (i.e., playing to compete with other players) directly influenced the interaction between gaming disorder and psychological distress. The escape motive interaction is of particular interest because it has been hypothesized that disordered gaming may develop as result of the gamer playing games to escape negative affect (Kardefelt-Winther, 2014).

The following studies investigated stress rather than anxiety which are included in this section due to the similarities in these constructs' definitions. The results are similar to the ones from anxiety studies due to the disordered gamers overall higher level of stress (Achab et al., 2011; Che et al., 2017; Kaess et al., 2017). This relationship has mainly been studied among disordered gamers, one study (Canale et al., 2019) exploring both gaming disorder and time spent gaming in relation with the perceived stress (i.e., perceiving stress as uncontrollable). Although this study showed the same association found in previous literature between stress and disordered gaming, the researchers observed that there was an interaction effect between psychological resilience and stress on gaming. When analysing this effect, they showed that when the level of psychological resilience was low, the level of perceived stress was positively correlated to time spent gaming, while this correlation was non-significant when the level of psychological resilience was high.

As with anxiety, gaming disorder variables appear to influence its interaction with stress (i.e., motives and mindfulness). Similar to anxiety, the escapism motive appears to play a key role in the relationship between stress and gaming disorder (Snodgrass et al., 2014). To summarize this research, it appears that perceived stress is related to the escapism motive and that this same motive is associated with disordered gaming. This makes sense as the escapism motive concerns gamers playing to escape real-life problems or negative emotional states (i.e., here perceived stress). Accordingly, a stressed gamer could play more to escape their negative state and would be more at risk in developing disordered use. It is worth noting that all types of stress are not necessarily related to gaming disorder. For example, Hong, You, Kim, and No (2014) showed that academic stress was negatively associated with disordered gaming, indicating that the more stressed their participants were about their academic achievement, the less likely they were to developing gaming disorder. This is interesting, once coupled with the observed negative correlation between academic motivation and gaming disorder, as it could mean that when students want to perform at school and are stressed about it, they would simply spend more time working instead of escaping this stress while gaming. Finally, while motives appear to promote the association between gaming disorder and stress, it would appear that mindfulness, on the other hand, shows the opposite effect (Yu, Mao, & Wu, 2018). Indeed, while the researchers observed an overall significant association between stress and gaming disorder, this association was only existent among participants with lower levels of mindfulness, while it entirely disappeared when they had higher levels of mindfulness. It could mean that when gamers are able to cope with stress in another way than gaming, they would not need to escape from their negative state which would reduce the risk of developing disordered gaming.

This section has shown that gaming disorder shares important associations with both anxiety and stress, different variables being able to reinforce or diminish that interaction. In addition, it appears that anxiety and stress can directly affect time perception, leading to a quasi-systematic overestimation of time. Furthermore, it was shown that the lack of control of stress (i.e., one of the two components of perceived stress) is closely related to gaming disorder (Che et al., 2017). Finally, it was shown that not having control over a stressor systematically leads to an overestimation of time (Buetti & Lleras, 2012; Watts & Sharrock, 1984). Therefore, it appears that some of the reinforcement of stress both increases its impact on gaming and time perception. This information made it crucial for this thesis to have a measure of both stress and anxiety in order to control its potential influence on the participants' time perception.

4.5.8. Emotion reactivity

This measure is unrelated to both gaming and time perception and was used as a control variable in the third experiment; its relevance will be briefly explained. In the third experiment of this thesis, emotional stimuli (i.e., gaming pictures) will be introduced in order to observe if they affect the gamers' time perception. Since emotional reactivity differs between individuals, it may directly influence the relationship between the arousal created by the gaming pictures and the gamers' time perception. As a result, it was decided to include such a measure.

4.6. Conclusion

Based on these previous considerations, three experiments studied the underlying mechanisms of time loss through a careful inspection of the gamers' time perception. The first experiment aimed to validate the explored Dual-Process Contingency Model of time perception combining both retrospective and prospective time perception with longer duration (i.e., longer than one minute). This first experiment already included the control variables aforementioned (i.e., depression, anxiety, stress, attention, working memory, impulsiveness, and emotion reactivity) in order to prevent any confounding variable biasing the results. The second study explored the baseline retrospective time perception of the gamers, which meant testing their time perception without any additional variable. This study was also adapted on the basis of the first experiment's results. Finally, the third and final study of this thesis explored how attention, through an increased difficulty of the task, and emotion (i.e., gaming pictures) affects the interaction between gaming use and time perception. In the second and third experiments, controlling the extraneous variables was important due to the interaction of these with both gaming use and time perception.

Chapter 5: Experiment 1 – Validation of the Dual-Process Contingency Model

5.1. Experiment 1 background

In the first chapter of this thesis, it was outlined that time perception was theoretically split between the prospective time perception (PTP, i.e. – conscious perception of time) and retrospective time perception (RTP, i.e. – unconscious perception of time; Block & Zakay, 1997). While PTP is supposed to rely on a model based on attentional process at its core (i.e., the attentional gate model, AGM - see Chapter 1; Zakay & Block, 1995), RTP appears to rely on a memory-based model (i.e., the contextual change model, CCM - see Chapter 1; Block & Reed, 1978).

However, according to Thomas and Weaver (1975), both timing process aforementioned would be tightly related through two core cognitive variables, namely time processing (i.e., focusing more or less on time, comparable to the AGM) and information processing (i.e., estimating time through the changes in the environment, comparable to the CCM). While the first variable would be predominant and the second one would be secondary in the PTP, the opposite trend should be observed in the RTP. (For more details on the functioning of this model, see Chapter 1). In their research piece, Thomas and Weaver (1975) named this model the Dual-Process Contingency Model (DPCM) and showed that the model exhibited significant results for duration shorter than 100ms. Later on, Zakay (1993) validated this model for duration between 12 and 15 seconds.

5.2. Aim and hypotheses

In the previous section, a model unifying PTP and RTP was outlined which currently suffers from a lack of validation as only two studies explored and validated the model, and this for short durations (i.e., less than 15s). Nevertheless, one of this thesis' objectives is to explore time perception among gamers to help understanding why they tend to underestimate greatly the time they spend gaming (i.e., time loss effect). Consequently, the previous validation of maximum 15s is not suited for this thesis, as a gaming session will always exceed this duration considerably.

Therefore, the first and main aim of this experiment is to validate the DPCM with a longer duration. And, as the following experiments will explore time perception among gamers as well as the variables affecting this association, this study will already include measurement of gaming use and abuse within a survey. This first exploration of gaming in this study will allow a first look at the potential impact of gaming on time perception. Additionally, the impact of potentially confounding variables (i.e., attention, working memory, depression, stress, anxiety, and impulsiveness) has been included either through questionnaires or tasks (i.e., see *"Section 5.3.3. Materials"*).

According to previous research on the DPCM, there should be a significant triple interaction between the time perception paradigm (i.e., PTP and RTP), time processing, and information processing. After analysis, time processing should exhibit an important effect in the PTP contrasting with a less pronounced effect in the RTP and the opposite trend should be observed in the RTP.

Concerning gaming, it was hypothesized in Chapter 3 that gamers' impaired time estimation would lie within the RTP and not PTP. It was also mentioned that their RTP would be impaired only when confronted to emotional affect, and that their time perception should remain unaffected under normal circumstances. As a result, no association between the gaming variables and time perception, whether retrospectively or prospectively, should be observed in this study.

5.3. Method

5.3.1. Design

A between-group comparison design has been used in this experiment. The independent variables were the segmentation (i.e., separation of the stimuli in multiple groups, two or four subgroups), the difficulty of the task (i.e., easy or hard), and the time perception paradigm (i.e., prospective or retrospective). These three dichotomous variables led to a 2x2x2 design creating eight different groups. The dependent variable was the temporal estimation of the participants. In addition, this between-group design was coupled with a correlational exploration of several variables which may affect time perception (i.e., attentional process, working memory, gaming use/abuse, impulsiveness, depression, stress, anxiety, and demographic data).

5.3.2. *Participants*

A sample of 98 participants (13 males) were included in this experiment (M_{age} = 20.98 years, SD = 4.71). They were recruited mainly through an internal credit system provided by Nottingham Trent University in which the psychology students could participate to diverse experiment in exchange for credits. In order to recruit more participants, the students from the research methods classes at NTU were asked to participate in exchange for research credits. Of these 98 participants, 23 mentioned that they played videogames between 1 and 30 hours per week (M = 10.67, SD = 8.62).

5.3.3. *Materials*

5.3.3.1. Self-reported measures

Demographic data: Demographic data were collected to have a better overview of the population recruited for the experiments. Furthermore, it allowed control of any possible cofounding variables. The data collected were the participants' age, gender, highest achieved educational level, and whether they were currently suffering from a mental health problem.

Gaming use: The first experiment's goal was not to compare gamers and non-gamers (i.e., whether disordered or healthy), yet these questions were included to allow a first approach between time perception and videogame use. Therefore, participants were first asked if they played videogames. If they did, gaming questionnaires were administered, if they did not, these questionnaires were not completed. First, they were asked about favourite game genre(s) among the following options (i.e., allowing them to pick as many as they wanted to): Multiplayer Online Battle Arena (MOBA) games, Massively Multiplayer Online Roleplaying Games (MMORPGs), First-Person Shooter (FPS) games, Role-Playing Games (RPGs), Real-Time Strategy (RTS) games, race games, sport games, and other genres (i.e., allowing them to write down their favourite genres). Afterwards, they were asked about the title(s) of their favourite game(s), the average hours per week they spent playing videogames, whether they preferred playing on weekdays or the weekend (or both), and whether they played in the morning, afternoon, evening, or at night (on weekdays and the weekend).

UPPS-P, short behavioural scale (s-UPPS-P; Khazaal & Nuyens, 2020): The s-UPPS-P is a multidimensional measure of impulsiveness which comprises 20 four-point Likert items equally distributed on the five UPPS-P subscales (i.e., positive/negative urgency, lack of premeditation, lack of perseverance, and sensation seeking). Although this specific scale has not been validated yet, other short versions of the UPPS-P have been rigorously validated previously in several languages such as in Arabic (Bteich, Berbiche, & Khazaal, 2017; alphas between .58 and .72) and Swedish (Claréus, Daukantaitė, Wångby-Lundh, & Lundh, 2017; alphas between .61 and .79). It is worth noting that this English short version of the UPPS-P is adapted from the French short version created by Billieux et al. (2012). The UPPS-P is not the only multidimensional construct of impulsiveness (e.g., the Barratt Impulsiveness Scale, Patton et al., 1995), but, contrary to the other well-validated scales, the UPPS-P includes an emotional construct (i.e., positive and negative urgency). This emotional aspect is essential in this thesis because the last experiment aims at exploring the emotional interference on time perception among gamers, which means that analysing an emotional aspect of impulsivity is relevant.

Problematic Online Game Questionnaire (POGQ, Demetrovics et al., 2012): The POGQ is a multidimensional tool assessing the problematic use of online videogames including 18 five-point Likert items divided into five different subscales. The first subscale, preoccupation, comprises two questions and is defined as the constant thinking about the game when one is not playing. The second subscale, immersion, includes four questions and is defined through different concepts associated with time loss (i.e., losing track of time while playing and forgetting to eat due to the game). The third subscale, social isolation, refers to the neglect of other activities or of one's friends in favour of gaming and comprises three questions. Interpersonal conflicts, the fourth subscale, comprises two questions exploring how gaming impacts the participants' life negatively. The fifth subscale, overuse, defines abuse of the game (i.e., spending too much time on the game) via three items. Finally, the last subscale, withdrawal, includes four items exploring negative emotions emerging when one cannot play videogames for a prolonged period of time. This scale has high Cronbach's alphas (e.g., between .90 and .95 in its first validation, Demetrovics et al., 2012). Furthermore, the scale's scores showed interesting interactions with various variables, such as risky decision-making (Weinstein et al., 2016), delay discounting (Nuyens et al., 2016; Weinstein et al., 2016), and other types of problematic use (Bőthe, Tóth-Király, & Orosz, 2015). Finally, it has been shown that this scale's validity did not vary between the online and offline gamers, which is of interest as this thesis will include both types of gamers (Smohai et al., 2017).

Internet Gaming Disorder (IGD) criteria (American Psychiatric Association, 2013): The IGD criteria comprise nine dichotomous questions exploring the different symptoms according to the DSM-5 (American Psychiatric Association, 2013), namely: (i) preoccupation (i.e., thinking constantly about Internet games), (ii) withdrawal (i.e., negative feelings when the Internet game has been taken away), (iii) tolerance (i.e., the need to increase the gaming time or to play more exciting games to achieve the same level of satisfaction), (iv) unsuccessful attempts to stop playing, (v) loss of interest in other activities, (vi) gaming despite harm, (vii) deception (i.e., lying about one's gaming habits), (viii) escape (i.e., playing to avoid negative feelings), and (ix) interpersonal conflicts. According to the DSM-5, in order to be considered as disordered gamer, an individual has to present five of these nine criteria during the past 12 months.

Depression Anxiety and Stress Scale – Short-form DASS-21 (Lovibond & Lovibond, 1995): The short version of the DASS comprises 21 four-point Likert items equally distributed between three subscales exploring depression, anxiety, and stress symptoms for non-clinical population. The first validation showed high Cronbach's alphas (i.e., between .87 and .94, Antony et al., 1998) and the scale has been validated in Vietnamese (i.e., alpha between .70 and .77, Tran, Tran, & Fisher, 2013), Spanish (i.e., alphas between .71 and .88, Antúnez & Vinet, 2012) and in Portuguese (i.e., alphas between .86 and .92, Vignola & Tucci, 2014). This scale was of interest due to the measures of three separate important concepts using a single brief instrument, avoiding the inclusion of multiple scales, which could have affected the results due to survey fatigue.

Emotion Reactivity Scale (i.e., ERS, Nock, Wedig, Holmberg, & Hooley, 2008): This scale assesses a multidimensional definition of emotion reactivity: (i) emotion intensity (i.e., how strongly an individual reacts), (ii) sensitivity (i.e., individual's reaction to a stimulus or an array of stimuli), and (iii) persistence (i.e., the time taken to return to the baseline level of arousal) across 21 five-point Likert items. This scale showed high reliability in its validation study for every single subscale (i.e., Cronbach's alphas ranged between .81 and .88). As for the other scales, this construct has been validated in other languages, such as French (Lannoy, Heeren, et al., 2014) or Dutch (Claes, Smits, & Bijttebier, 2014), exhibiting the same type of reliability scores (Cronbach's alphas respectively between .75 and .88 and between .77 and .89).

5.3.3.2. Behavioural measures

Temporal task: In order to test the DPCM with longer durations (i.e., around one, three, and six minutes), a distraction task was needed because making time perception core to the task would have rendered impossible a switch between prospective and retrospective time perception, this latter one being an unconscious process. This task needed to include stimuli allowing an easy fluctuation of the DPCM's two main variables, namely segmentation and attention. These stimuli also needed to be able to fluctuate in terms of emotional valence (i.e., neutral stimuli versus emotional ones) as the plan was to test emotional processes in further studies. These facts led to the selection of words allowing the fluctuation of both the DPCM variables and of a word recalling task (WRT), which was a non-temporal distraction task. In order to modify the attention brought upon the task, and indirectly to time itself, half the participants were presented with simple, familiar, words (e.g., "cat", and "night"), while the other half had to remember more complex and non-familiar words (e.g., "belligerent", and "plenipotentiary"). Normally, having more complicated/unfamiliar words to retain requires more cognitive resources than remembering simple/familiar words. Concerning segmentation, celebrity names were included at regular intervals between the common words (with a single name in the low segmentation groups and three in the high segmentation groups).

The purpose of the celebrity names was to divide the sequence of stimuli into several subgroups, allowing the participants to have one or three markers in order to provide a time estimation. The names changed depending on the level of difficulty as well (e.g., "Zlatan Ibrahimovic" vs. "Rihanna"). Finally, half the participants were told beforehand that they would have to estimate the length of each block at the end of the task (i.e., prospective time perception), while the other half only learned about this aspect of the task at the end of the trial, making this estimation unconscious (i.e., retrospective time perception). These three dichotomous variables led to a 2x2x2 design and the creation of eight different experimental conditions.

The words were selected on the *MRC Psycholinguistic Database from the University of Western Australia* (Coltheart, 1981). Among the diverse variables offered by the website, the familiarity rating (i.e., ranging from 100 to 700, with an average of 488 and a standard deviation of 99) and the number of syllables were chosen to create the word list. For the complex words, they could not score higher than 325 on the familiarity score (i.e., about 1.65 standard deviation under the average familiarity score) and needed to include at least three syllables (i.e., in order to produce "complex" words). For the simple words, they required a minimum of 587 in the familiarity score (i.e., one standard deviation over the average familiarity score, as 1.65 did not yield enough words), and to include a maximum of three syllables (i.e., to produce simple, "easy to remember" words). Furthermore, each word needed to include at least three letters to allow the removal of numerous conjunctions or pronouns, the remaining words (e.g., she, they, and for) being manually removed afterwards. The task structure comprised a succession of a fixation cross (1000ms), a word (3000ms), and a blank screen (1000ms) for a total of 5s per trial. The short block included 11 trials (i.e., 55s), the medium-length block included 31 trials (i.e., 155s), and the long block included 71 trials (i.e., 355s). In order to avoid the participants guessing the exact duration of each block by rounding up their estimation to the minute, each block lasted slightly shorter than the aimed duration (i.e., 55s vs. 60s, 155s vs. 180s, 355s vs. 360s). The blocks were randomized, and the participants had two minutes to recall as many words as they could. At the end of the task, the participants were asked to estimate the duration of each block as accurately as they could, excluding the two-minute recall parts.

Digit Span Test (Weschler, 2008): The Digit Span Test is a well-validated measure of working memory (Jung, 2018; Torgesen & Griffith, 1980). In this test, the experimenter reads a series of digits in which the participant has to either repeat in the exact same order (i.e., forward test) or in the opposite order (i.e., backward test). Starting with three numbers in the forward test and two in the backward test, the number of digits is increased by one with every correct answer. When participants answered wrongly, they had another chance with the same number of digits, a second mistake led to the end of the test.

Attentional Network Task – Revised (ANT-R, Fan et al., 2002): The ANT-R explores three different components of attention, namely the alerting system, the orienting system, and the executive control system. In this task, the participant first sees a fixation cross (between 1000 and 2200ms) during which a cue appears for 150ms. This is followed by a set of either one or five arrows (until the participant answers or for a maximum of 1500ms), and the cross reappears 1000ms after the arrows disappeared. The participant has to decide which direction the central arrow is heading. The cue can appear above or below the cross, indicating where the arrows will appear. Also, the cues can be multiple and appear at both these locations at the same time, or simply be juxtaposed on the fixation cross. In these two last cases, the cue does not indicate where the arrow(s) will appear but lets participants know that its/their apparition was imminent. Whether the cue indicates where the arrows are going to appear or not helps to assess the alerting and orienting system. In order to assess the executive control system, the trial can either include a single arrow or multiple arrows; in the second case, the arrows surrounding the central one (i.e., the target) can either be congruent (i.e., heading in the same direction) or incongruent (i.e., heading in the opposite direction).

5.3.4. Procedure

Participants could either subscribe through the University recruitment system to a specific date and time when they would participate in the experiment, or on a piece of paper with the same options if recruited in a research methods class. When coming to the laboratory, they were given a code name to ensure their anonymity based on the first letter of their first name, the first letter of their mother maiden name, and the two last digits of their birth year (e.g., FD92, AA94). The mother's maiden name was preferred to the participants' second name because the use of their initials would allow the experimenter, or any other researcher involved in the study, to find the participants' real identity when they were recruited in classes (i.e., through the University database).

After reading the information sheet and giving their fully informed consent, the participants were introduced to the first task, the WRT. The participants were first randomly allocated to one of the eight possible groups varying in terms of the three independent variables (i.e., segmentation, work load, and temporal paradigm). Afterward, the participants were introduced to the functioning of the task. First, the participants would be presented a series of words which would appear automatically one after another and would need to read the words passively until the following message appeared: *"All the words have been presented, please press the space bar and try recalling as many words as you can for two minutes".* After seeing that message, they were asked to press the space bar and start writing down as many words as they could until the screen message changed to *"The recalling time is over, please press the space bar as soon as you are ready for the next block".* The only difference in terms of instructions between the different groups depended on the time perception paradigm; the participants in the PTP were warned that they would have to estimate the duration of the three blocks, while the other participants did not know about time perception until the end of the task (RTP). After completing the three different blocks (i.e., in a fully random order), the participants were asked to provide their time estimation for each of the three blocks. They were allowed to use any time measure they preferred (i.e., minutes or seconds) and were told that they could be as accurate as they wanted (e.g., one minute and thirty seconds, three minutes and ten seconds).

After completing the WRT, the participants were introduced to the DST. This order was chosen to allow the participants to stop fixating the computer screen and rest their eyes for a few minutes. It was explained that they would first have to repeat the digits dictated by the experimenter in the exact same order (i.e., forward test) with increasing difficulty until they could not do it anymore. Secondly, they were asked to repeat the digits recited by the experimenter in the opposite order (i.e., backward test) with increasing difficulty until they could not do it anymore. Finally, the participants were reassured that the task was virtually limitless, and that getting stuck did not mean that they failed the test in order to prevent as many negative feelings as possible.

Once the participants were done with the DST, they were introduced to the ANT-R. Since the task was quite complex, participants were offered examples on top of the text instructions. In these examples, each type of cues and arrow were shown to the participants and the researcher took some time to explain what these types of cues and arrows implicated in the task. Once the participants confirmed that they understood the functioning of the ANT-R, they completed a first short training blocks including 16 trials with at least one representation of each clue and arrow. While completing this training block, the participants were monitored by the experimenter to ensure a proper completion of the task afterward. The experimenter let the participants know that they would be monitored for the training block and that they would not be observed for the testing blocks. Afterwards, the participants completed three different testing blocks with 48 trials each. In order to assure that the participants would not try to estimate the duration of the task, and get distracted, the duration of the task was revealed at the beginning of the testing blocks.

Finally, after completion of the ANT-R, the participants completed the survey in the following order: demographic data, DASS-21, gaming use[1], UPPS-P, POGQ[1], ERS, and the IGD criteria[1]. The participants were told that they could ask any question to the experimenter in case they did not understand any part of it. At the end of the survey, they were given the option to share an email address to participate in further studies organised by the experimenter. Afterward, they were fully debriefed, especially when they were deceived about the time perception aspect of this study and thanked.

5.3.5. Ethics

This research was approved by the College Research Ethics Committee (CREC) prior to data collection. Furthermore, this study's design and procedure is consistent with the Declaration of Helsinki. Only two parts of this experiment could have caused minor harms to the psychological wellbeing of the participants. The first one is the disappointment of the participants in their own performance in the DST which was compensated with the experimenter reassuring each participant with their own score. The second one lies within the method of this experiment, as half the participants were in the RTP condition, thus not knowing about the time perception aspect of this study. Therefore, as the participants were deceived on the true purpose of this experiments (i.e., they were told that the variable of interest was the number of words they could properly remember), they were properly debriefed at the end of the experiments, explaining the reason behind the deception. The other participants were also fully debriefed, although they were not deceived in any way.

[1] These questionnaires were not included if the participants reported not playing videogames.

5.4. Results

5.4.1. Preliminary statistics

Time perception: The time estimation in seconds of the participants had a relatively important fluctuation which increased depending on the duration estimated (i.e., SD = 54.92, SD = 85.97 SD = 120.36 for the short, medium, and long estimation respectively). Therefore, it was decided that every estimation twice as long as the real duration (i.e., 55s, 155s, or 355s) would be removed from the sample. This reduced the variance of both the short and medium blocks (i.e., SD = 21.72 and SD = 68.34 respectively) but did not affect the long block variation as none of the estimation was removed. These standard deviations fit the Scalar Expectancy Theory (SET), as according to this theory, the longer the duration, the longer the estimation variation. The mean and standard deviation of these estimations, including the total estimation, are provided in Table 5.1.

Table 5.1. Descriptive statistics of the time estimations

	Real duration (s)	Mean estimation provided (s)	Standard deviation (s)
Short estimation	55	49.62	21.72
Medium estimation	155	137.07	68.34
Long estimation	355	244.95	120.36
Total estimation	565	459.51	217.06

ANT-R: When calculating the average RT of each participant, two factors were taken into account. First, none of the trials where the participants answered wrongly were included in the calculation. From this modification, a first average and SD were calculated and used to further sort the RT of the participants. Any RT differing from more than two SD from the mean (i.e., either above or below) were excluded. Afterward, the real RT means of the participants were calculated (i.e., global RT, RT based on the different cues, and RT based on the number and congruence of the arrows). The descriptive statistics of both the RT and the accuracy of the ANT-R can be seen in Table 5.2.

Table 5.2. Descriptive statistics of the ANT-R

	Mean[1]	SD
Global RT	434.80	52.91
Single arrow RT	410.53	47.35
Multiple arrows RT	460.82	60.95
Multiple congruent arrows RT	436.61	56.67
Multiple incongruent arrows RT	487.96	66.10
Informative cue[2] RT	417.32	54.66
Dual cue[3] RT	455.22	54.34
Central cue[4] RT	450.47	54.57
Global accuracy	94.02	1.58
Single arrow accuracy	94.86	1.65
Multiple arrows accuracy	93.48	2.16
Multiple congruent arrows accuracy	96.75	1.28
Multiple incongruent arrows accuracy	95.09	4.05
Informative cue[1] accuracy	94.55	1.51
Dual cue[2] accuracy	97.47	2.82
Central cue[3] accuracy	89.81	2.75

Note. [1]The RT value are in ms and the accuracy values in percentages; [2] Single cue appearing either below or above the fixation cross; [3]Two cues appearing both below and above the fixation cross; [4]Cue appearing at the same location as the fixation cross.

DST: The DST does not need any real prior modification before its analysis, as the result analysed is simply the maximum number remembered by the participants either forward (i.e., short-term memory) or backward (i.e., working memory). However, two extra variables were created to attain a deeper exploration of working memory. First, the number of digits recalled backward by the participants was subtracted to the number of digits recalled forward by the participants. The purpose of this modification was to take into account the basic short-term memory of the participant in the calculus of the working memory score (i.e., the bigger the difference, the worse the working memory). The limitation of this calculation is that a participant with two low scores could end up with the same global score as a participant with two higher scores (e.g., five digits forward and three backward – Score of 2; ten digits forward and eight backward – Score of 2). To overcome to this limitation, a second calculation was performed, and the previous results were multiplied by the total number of digits recalled by the participants (i.e., the sum of the backward and forward results). Interestingly, this calculation can be summarised as the square score on the forward task subtracted by the squared score on the backward task. With this method, a participant repeating more digits overall would have a better global score (e.g., to take back the previous example; 16 vs. 36). The descriptive statistics of the DST, including the newly calculated variables, are available in the Table 5.3.

Table 5.3. Descriptive statistics of the DST

	Mean	SD
Forward score (F)	7.61	1.23
Backward score (B)	5.87	0.97
Subtraction score (F-B)	1.74	1.36
Multiplication score (F-B) * (F+B)	24.09	20.25

Questionnaires: For clarity's sake, the results from the gaming questionnaires are separated from the questionnaires not related to gaming. Apart from this fact, no modification has been brought upon the survey results and the guidelines offered by the authors of the scales have been followed. The descriptive statistics of the global questionnaires can be found in Table 5.4 (n = 97) and the gaming questionnaires in Table 5.5 (n = 23).

Table 5.4. Descriptive statistics of the questionnaires not related to gaming

	Minimum	Maximum	Mean	SD
Stress (DASS)	7	27	13.46	4.09
Anxiety (DASS)	7	27	11.45	3.79
Depression (DASS)	7	25	11.39	4.06
Negative urgency (UPPS-P)	4	16	9.95	3.21
Positive urgency (UPPS-P)	6	14	10.63	2.18
Premeditation (UPPS-P)[1]	4	12	7.48	2.19
Perseverance (UPPS-P)[1]	4	13	7.56	1.90
Sensation seeking (UPPS-P)	5	16	10.87	2.64
Emotional reactivity (ERS)	15	101	56.32	19.28

Note. [1]Lack of perseverance/premeditation

Table 5.5. Descriptive statistics of the questionnaires related to gaming

	Minimum	Maximum	Mean	SD
IGD criteria	0	7	1.78	1.88
Preoccupation (POGQ)	2	8	4.13	1.69
Overuse (POGQ)	3	12	5.96	3.36
Immersion (POGQ)	4	18	11.52	3.62
Social isolation (POGQ)	2	8	4.13	1.87
Interpersonal conflicts (POGQ)	2	6	2.91	1.41
Withdrawal (POGQ)	4	14	6.65	3.21
Total POGQ score	20	62	35.30	12.27

5.4.2. Time perception

A first analysis performed on the temporal estimation was to compare the error of estimation between all the participants. For this purpose, the estimation of each participant was first divided by the real duration of the block, giving a number theoretically varying between 0 and 2 (i.e., the estimation over twice the real duration being removed previously). This calculation was still not sufficient because the overestimation (i.e., scores above 1) and underestimation (i.e., score below 1) errors were separated. To get rid of this issue, the scores were first subtracted by 1 (i.e., varying between -1 and 1) and then squared (i.e., varying between 0 and 1). Afterward, to achieve the real error rate, rather than its squared value, the squared root of the previous score was used (i.e., still varying between 0 and 1). The short block had an error rate of .34 (SD = .23), the medium-length block of .39 (SD = .23), and the long block of .40 (SD = .23). Interestingly, when comparing these variables through a repeated measures ANOVA, there was a significant difference, F(2) = 8.579, *p*=.005. Once applying the Bonferroni correction, it appeared that this significant difference was due to a significantly higher error rate in the longest block, compared to the medium and short blocks. It is important to mention that only the data from the participants who did not provide a single outlying estimation remained in the repeated measures ANOVA, leading to a sample of 71 participants. Therefore, for the specific analysis, the mean of the sample changed to .34 for the short block (SD = .23), .37 for the medium block (SD = .22), and .44 for the long block (SD = .23).

Concerning the control variables included in this experiment which could affect time perception of participants (e.g., depression and attention), their effect on the temporal estimation in this experiment were explored through a correlational analysis. As Tables 5.6, 5.7, and 5.8 show, none of the correlations explored affected the estimation of the participants.

Table 5.6. Correlation between the DST variable and time estimation

	DST forward score	DST backward score	DST subtraction	DST global score
Short estimation (n = 73)	.045	-.094	.104	.105
Medium estimation (n = 98	.015	-.085	.074	.071
Long estimation (n = 98)	-.135	-.041	-.093	-.089
Total estimation (n = 98)	-.060	-.097	-.060	-.097

Note. * Correlation is significant at the *p*<.05 level (2-tailed).

Table 5.7. Correlation r between the ANT-R variables and time estimation

	Short estimation (n = 14)	Medium estimation (n = 38)	Long estimation (n = 44)	Total estimation (n = 43)
Global RT	-.039	-.005	-.070	-.133
Single arrow RT	-.021	-.001	-.065	-.128
Multiple arrows RT	-.054	-.008	-.072	-.131
Multiple congruent arrows RT	-.034	-.027	-.077	-.151
Multiple incongruent arrows RT	-.082	.011	-.065	-.108
Informative cue[1] RT	-.015	-.002	-.059	-.121
Dual cue[2] RT	-.084	-.002	-.050	-.130
Central cue[3] RT	-.045	-.015	-.099	-.139
Global accuracy	.020	-.130	-.034	-.053
Single arrow accuracy	.009	-.193	-.091	-.130
Multiple arrows accuracy	.099	-.089	-.026	-.030
Multiple congruent arrows accuracy	.363	.091	.099	.126
Multiple incongruent arrows accuracy	.020	-.119	-.057	-.067
Informative cue[1] accuracy	-.040	-.112	.083	.047
Dual cue[2] accuracy	.283	-.151	-.095	-.102
Central cue[3] accuracy	-.040	-.090	-.138	-.142

Note. *Correlation is significant at the p<.05 level (2-tailed). RT = Reaction time; [1]Single cue appearing either below or above the fixation cross; [2]Two cues appearing both below and above the fixation cross; [3]Cue appearing at the same location than the fixation cross.

Table 5.8. Correlations between stress, anxiety, depression, and impulsiveness with time estimations

	Short estimation (n = 73)	Medium estimation (n = 97)	Long estimation (n = 97)	Total estimation (n = 97)
Stress (DASS)	-.017	.002	.045	.052
Anxiety (DASS)	.200	.545	.666	.420
Depression (DASS)	-.060	.006	-.027	-.022
Positive urgency (UPPS-P)	.005	-.054	-.149	-.141
Negative urgency (UPPS-P)	-.122	-.107	.019	-.118
Premeditation (UPPS-P)[1]	-.032	-.088	-.049	-.212
Perseverance (UPPS-P)[1]	.100	-.074	-.025	-.052
Sensation seeking (UPPS-P)	.037	.072	.116	.057

Note. * Correlation is significant at the *p*<.05 level (2-tailed). [1]Lack of perseverance or premeditation.

5.4.3. Validation of the DPCM

In order to verify the validity of the DPCM for the longer duration explored in this thesis, a General Linear Model Multivariate was used with the three dichotomic variables (i.e., segmentation, difficulty, and temporal paradigm) as predictors and the three durations as well as the total duration for the dependent variables. The order of the block and the participants' ages were further included as a covariate in the analysis to control its impact on the participant's estimation. The results were not significant for all the tested variables, F(8) = .733, *p*=.66 for the short duration, F(8) = .769, *p*=.63 for the medium duration, F(8) = .936, *p*=.50 for the long duration, and F(8) = .967, *p*=.47 for the total duration. Furthermore, when exploring the error rate (i.e., see 'Section 5.4.2. Time perception' for the calculation process), these results were replicated for all durations, the *p*-value varying between .48 and .52.

A variable of interest within the WRT used to test the DPCM is the number of words recalled by the participants. First, the number of words was compared between the easy and complicated versions of the task, the participants recalling more words in the easy setting for all the blocks, $p<.001$. None of the correlations between time perception and the number of words recalled exhibited a significant effect post-correction (i.e., Benjamin-Hochberg correction).

5.4.4. Gamers' time perception

The small sample of gamers who participated allowed a first exploration of their time perception. However, it is important to bear in mind that any results described within this section are to be taken cautiously due to the difference of sample size between the gamers (n = 23) and the non-gamers (n = 74). Unfortunately, the number of participants scoring above 5 on the IGD (i.e., 2 participants) being too low, no group analysis was led based on this variable. The results showed that the long duration and the total duration were significantly different (i.e., the total duration difference probably resulting from the long duration difference). In the long duration, the gamers estimated the duration to be about 71.72s longer than the non-gamers', $t(95) = 2.55$, $p=.012$. For the total duration, this difference was of 112.92s, $t(95) = 2.186$, $p=.031$. However, this difference was observed without separating prospective and retrospective time perception. When splitting the estimation between these two paradigms, the estimations of the gamers did not differ significantly from the non-gamers' estimations retrospectively. Nonetheless, when comparing the prospective estimation provided by the gamers (358.18s) and the non-gamers (240.00s), a significant difference was observed ($p=.01$). Although it appears unexpected for the gamers to overestimate time compared to the non-gamers, a careful observation changed this interpretation. Indeed, when knowing that the real duration of the longer block was of 355s, it appears that the estimation provided by the gamers was simply more accurate than the non-gamers'. This tends to support that gamers have an improved PTP.

Regarding the gaming variables explored in the survey, their effect on time perception was tested through Pearson correlations which can be seen in Table 5.9. Although six of these correlations were significant at first, after the Benjamin-Hochberg correction, they systematically became non-significant. It is still worth mentioning that most of these correlations that were significant at first were systematically negative, indicating that gaming disorder could lead to an underestimation of time.

Table 5.9. Correlation between the disordered use of gaming and time perception

	Short estimation (n = 16)	Medium estimation (n = 23)	Long estimation (n = 23)	Total estimation (n = 23)
IGD criteria	-.175	-.152	.115	.076
Total score (POGQ)	-.478	-.492*	-.071	-.224
Preoccupation (POGQ)	-.195	-.197	-.211	-.353
Overuse (POGQ)	-.225	-.427*	-.064	-.181
Immersion (POGQ)	-.513*	-.424*	.123	.037
Social isolation (PGQ)	-.448	-.328	-.009	.046
Interpersonal conflicts (POGQ)	-.337	-.399	-.020	-.411
Withdrawal	-.509*	-.484*	-.217	-.369

Note. *Correlation significant at p<.05 before Benjamin-Hochberg correction.

5.5. Discussion

The main aim of this study was to explore the validity of the DPCM for longer durations since it was only tested for durations up to 15s. When testing the impact of the three dichotomous variables of the model on the estimations provided by the participants, the model was non-significant, and this for all the variables. Consequently, it is possible that while this specific model of time perception is accurate in describing short durations, it would be inefficient in predicting longer estimations. It is noteworthy that there was no difference in the estimation provided by the participants in the prospective and retrospective settings. This could be due to the lack of difference observed based on the difficulty of the task. This could indicate that the easy task was already too complicated for the participants to be able to focus properly on time. According to the AGM, if participants could not focus at all on the task, the attentional gate would be fully closed, leading the participants to estimate the time retrospectively rather than prospectively. Therefore, for the rest of this thesis, a simpler task than the recalling task should be preferred to allow an effect of the cognitive load. Furthermore, it is worth mentioning that none of the control variables explored within this study correlated significantly with the time estimations of the participants.

Concerning the gamers, they significantly overestimated time compared to non-gamers, a result which is to be considered cautiously due to the small number of gamers (n = 23) compared to non-gamers (n = 74). Interestingly, since the estimation of the gamers was actually closer to the real duration compared to the non-gamers, this could be interpreted as an improved estimation instead of an overestimation. This could be a direct consequence of the previously discussed improved attentional focus and working memory (i.e., see the third chapter on the interaction of gaming and time perception). Consequently, it further implies that RTP would be the key concept when exploring time perception of gamers while PTP would not be implicated. The variables measuring disordered use of videogames among these gamers were correlated with the temporal estimations provided by these same gamers. Nonetheless, the only few significant correlations appeared to not be significant anymore after the Benjamin-Hochberg correction. It appeared that all these correlations were negative, which could indicate that the more disorder use symptoms present in an individual, the more they underestimated time even though these were not significant post-correction.

Chapter 6: Experiment 2 – Gamers' baseline retrospective time perception

6.1. Experiment 2 background

In Chapter 3 of this thesis, the potential associations between time perception and gaming were explored. It has been noted that due to their improved attentional focus (e.g., Cain et al., 2014; Castel et al., 2005) and working memory (e.g., Colzato et al., 2013; Mishra et al., 2011), gamers should exhibit a more precise prospective time perception (PTP) than non-gamers. The results observed in the first experiments tended to support this hypothesis, as gamers produced a more accurate estimation of the longer block compared to the non-gamers (results to be taken cautiously due to the sample difference). This possibility does not match the observed time loss among gamers (Wood et al., 2007) which would exclude that the gamers' impaired time perception would be prospective but rather indicate that they would potentially exhibit an impaired retrospective time perception (RTP). Consequently, this impacted the second study because prospective time perception (PTP) would no longer be explored.

Furthermore, the first experiment's results were non-significant regarding the Dual-Process Contingency Model (DPCM) of time perception, indicating that this model was not fit for longer durations and for this thesis. Accordingly, the following experiments will be based on the Attentional Gate Model (AGM) of time perception and a continuum of attention linking both RTP and PTP (i.e., see discussion of previous experiment). The first study also exhibited that there was no difference between the duration estimation under the easy and the hard settings of the task, meaning that the easy task was potentially already too hard for the participants to focus on time. Thus, the following experiments will include an easier task.

6.2. Aim and hypotheses

As mentioned in the previous section, the aim of this study is to compare the baseline time perception of gamers and non-gamers in a retrospective setting. What baseline means in this study is that no external variable will be explored in the temporal task, all the participants will be confronted with an easy task, including neutral stimuli, without any prior mention of its temporal aspect. The point of this manipulation is to observe whether the gamers exhibit a globally impaired time perception, or if a specific process impairs their time perception while gaming. In addition, the performances of the gamers and non-gamers will be compared on their non-temporal scores for the Lexical Decision Task (i.e., reaction time and accuracy).

Based on the literature outlined in the third chapter, and the lack of coherence in the previous studies exploring time perception among gamers (Rau et al., 2006; Wood et al., 2007), it is expected that no difference will be observed between the two groups. Concerning the performance of the gamers on the non-temporal tasks, it is expected that they will outperform the non-gamers on reaction-time (RT) of the LDT. However, as the LDT is a simple task in term of input (i.e., deciding whether the string of letters represents a word or a string of consonants), accuracy should suffer from a ceiling effect and it is possible that no difference will be observed.

6.3. Method

6.3.1. Design

A between-group comparison design has been used in this experiment. The independent variable was the gaming habits of the participants where gamers were compared to non-gamers. The dependent variable was the temporal estimation of the participants as well as their RT and accuracy. This between-group design was coupled with a correlational exploration of several variables which may affect time perception (i.e., attentional process, working memory, gaming use/abuse, impulsiveness, depression, stress, anxiety, and demographic data).

6.3.2. Participants

A sample of 44 participants (6 males) were included in this experiment, their average age was 19.55 years (SD = 1.25) ranging between 18 and 23 years. They were recruited mainly through an internal credit system provided by Nottingham Trent University in which the psychology students could participate to diverse experiment in exchange for credits. Furthermore, in order to recruit more participants, students from research methods classes at NTU were asked to participate in exchange for research credits. Of these 44 participants, 22 mentioned that they were playing videogames for 8.48 hours per week on average (SD =9.14, range = 1-35).

6.3.3. Materials

6.3.3.1. Self-reported measures

The self-reported measures in Experiment 2 were identical to those in Experiment 1.

6.3.3.2. Behavioural measures

Both the ANT-R and the DST remained unchanged as they brought the desired results in the previous experiment. The DPCM model of time perception, on the other hand, is no longer fit for this thesis and the Word Recalling Task was deemed too hard to generate the expected results. Therefore, it was decided to change the whole temporal task for an easier task which would not include the DPCM segmentation variable (i.e., this variable not being part of the AGM).

When creating the new task for the second experiment, several factors were considered. First, the task required to use the same type of stimuli, in order to control its neutrality, so that the second task still had to include words. Furthermore, the simple task had to be easier, without getting boring, a state that would also affect time perception (Danckert & Allman, 2005; Zakay, 2014). This led to the selection of a lexical decision task (LDT) where the participants are presented either words or non-words and are asked to decide whether the stimulus is a word or not. Although the second experiment did not aim to explore the impact of emotion and cognition on time perception, the task was created to allow these variables' inclusion in another stage of the thesis. As a consequence, it was decided that in the easy task, the non-words would be strings of consonants (e.g., "XGHR") while in the complicated task, they would be non-words resembling real words (e.g., "CORI", Rastle, Harrington, & Coltheart, 2002). In order to fluctuate the level of emotional activation, a priming effect was used, a picture being shortly presented before each stimulus, the picture being either neutral (e.g., a lamp, a book) or gaming-related (i.e., pictures extracted from popular videogames). For more details on the selection of the non-words resembling real words and the emotional pictures, see 'Chapter 7: Experiment 3 – Effect of cognition and emotion on the gamers' time perception'.

The LDT was a succession of a fixation cross (250ms), a blank screen (250ms), a priming picture (750ms), the target stimulus (until the participant responded or a maximum 1500ms), and another blank screen (1750ms minus the target reaction time). The last blank screen had an adaptive duration in order to make sure that every single trial lasted exactly the same duration (i.e., 3s) because the participants were required to estimate the blocks' durations. This task included three blocks with varying durations which were entirely randomised. The short block included 24 trials (i.e., 72s), the medium block included 64 trials (i.e., 192s), and the long block included 112 trials (i.e., 336s) for a total of exactly ten minutes. As aforementioned, half the trials were non-words while the other half were real words (i.e., selected from the simple list used in the first experiment). These trials were further pseudo-randomised to avoid having more than three words or non-words in a row. As this second experiment did not aim to explore emotion, only neutral pictures from the International Affective Picture System (IAPS, Lang et al., 1999) were selected (i.e., between 4.74 and 5.26 in valence, under 4 in arousal, and over 6 in dominance – each variable scaling between 1 and 9). Twenty-four pictures were selected (i.e., eight per block) as every single block number of trials was dividable by eight, avoiding another confounding variable.

6.3.4. Procedure

Participants could either subscribe through the University recruitment system to a specific date and time, or on a piece of paper with the same options if recruited in a research methods class. When coming to the laboratory, they were given a code name to ensure their anonymity based on the first letter of their first name, the first letter of their mother's maiden name, and the two last digits of their birth year (e.g., FD92, AA94). The mother's maiden name was preferred to the participants' family name because the use of their initials would allow the experimenter, or any other researcher involved in the study, to find the participants' real identity when they were recruited in classes (i.e., through the University database).

After reading the information sheet and giving their fully informed consent, the participants were introduced to the first task, the LDT. The participants were first introduced to the functioning of the task. They were told that words or string of consonants would appear in the centre of the screen and that they would have to press the right key (i.e., “n”) if it was a word, and the left key (i.e., “z”) if it was not a word. After confirming that they understood the functioning of the task, the participants were asked to perform a first training block which was monitored by the experimenter to ensure a proper completion of the task afterward. The experimenter let the participants know that they would be monitored for the training block, but that they would not be observed for the testing blocks. Once the training block was completed, the participants could start the real task composed of three separate blocks. After completing the testing blocks (i.e., in a fully random order), the participants were asked to provide their time estimation for each of the three blocks. They were allowed to use any time measure they preferred (i.e., minutes or seconds) and were told that they could be as accurate as they wanted (e.g., one minute and thirty seconds, three minutes and ten seconds).

After completing the LDT, the participants were introduced to the Digit Span Test (DST). This order was chosen to allow the participants to stop fixating the computer screen and rest their eyes for a few minutes. It was explained that they would first be asked to repeat the digits dictated by the experimenter in the exact same order (i.e., forward test) with increasing difficulty until they could not do it anymore. Secondly, they were asked to repeat the digits recited by the experimenter in the opposite order (i.e., backward test) with increasing difficulty until they could not do it anymore. Finally, the participants were reassured that the task was virtually limitless, and that getting stuck did not mean that they failed the test in order to prevent as many negative feelings as possible.

Once the participants completed the DST, they were introduced to the ANT-R. Since the task was quite complex, participants were offered examples on top of the text instructions. In these examples, each type of cue and arrow were shown to the participants and the researcher took some time to explain what these types of cues and arrows implicated in the task. Once the participants confirmed that they understood the functioning of the ANT-R, they completed a first short training blocks including 16 trials with at least one representation of each clue and arrow. As for the LDT, the participants were warned about the monitoring of this specific block and that the experimenter would not monitor the whole task. Afterwards, the participants completed three different testing blocks with 48 trials each. In order to assure that the participants would not try to estimate the duration of the task, and get distracted, the duration of the task was revealed at the beginning of the testing blocks.

Finally, after completion of the ANT-R, the participants completed the survey in the following order: demographic data, DASS-21, gaming use[2], UPPS-P, POGQ[1], ERS, and the IGD criteria[1]. The participants were told that they could ask any question to the experimenter in case they did not understand any part of the survey. At the end of the survey, they were also given the option to share an email address to participate in further studies organised by the experimenter. Afterward, they were fully debriefed, especially concerning the deception about the time perception aspect of this study and thanked.

6.3.5. Ethics

This research was approved by the College Research Ethics Committee (CREC) prior to the data collection. Furthermore, this study design and procedure is consistent with the Declaration of Helsinki. Only two parts of this experiment could have caused minor harms to the psychological wellbeing of the participants. The first one is the disappointment of the participants in their own performance in the DST which was compensated by the experimenter reassuring each participant with their own score. The second one lies within the method of this experiment, as the participants did not know about the time perception aspect of this study (i.e., RTP). Therefore, as the participants were deceived about the true purpose of this experiments (i.e., they were told that the variable of interest was their lexical decision-making abilities), they were properly debriefed at the end of the experiments, explaining the reason behind the deception.

6.4. Results

6.4.1. Preliminary statistics

Time perception: The time estimation of the participants in seconds greatly fluctuated (i.e., SD = 134.94s, SD = 162.76s, SD = 147.49s for the short, medium, and long estimation respectively). It was then decided that every estimation twice as long as the real duration (i.e., 72s, 192s, or 338s) would be removed from the sample. This greatly reduced the variance of both the short and medium blocks (i.e.,

[2] These questionnaires were not included if the participants reported not playing videogames.

SD = 42.92 and SD = 82.27 respectively) but barely affected the long block variation (i.e., SD = 149.90). The mean and standard deviation of these estimations are provided in Table 6.1. Since only 14 participants' estimations remained for the shortest block, the total duration will be the sum of the medium and long block rather than the sum of the three estimations.

Table 6.1. Descriptive statistics of the duration estimation

	Remaining sample	Mean	SD
Short block	14	74.29	42.92
Medium block	38	179.61	82.27
Long block	44	226.71	149.90

ANT-R: When calculating the average RT of each participant, two factors were taken into account. First, none of the trials where the participants answered wrongly were included in the calculation. From this modification, a first average and SD were calculated and used to further sort the RT of the participants. Any RT differing from more than two SD from the mean (i.e., either above or below) were excluded. Afterward, the real RT means of the participants were calculated (i.e., global RT, RT based on the different cues, and RT based on the number and congruence of the arrows). The descriptive statistics of both the RT and the accuracy of the ANT-R can be seen in Table 6.2.

Table 6.2. Descriptive statistics of the ANT-R

	Mean[1]	SD
Global RT	449.90	55.89
Single arrow RT	425.70	51.80
Multiple arrows RT	475.54	61.41
Multiple congruent arrows RT	450.66	58.11
Multiple incongruent arrows RT	503.66	69.12
Informative cue[2] RT	432.19	53.37
Dual cue[3] RT	465.36	58.17
Central cue[4] RT	470.25	63.01
Global accuracy	94.22	1.18
Single arrow accuracy	94.69	2.26
Multiple arrows accuracy	93.61	2.37
Multiple congruent arrows accuracy	96.36	2.19
Multiple incongruent arrows accuracy	95.46	3.46
Informative cue[1] accuracy	94.48	2.10
Dual cue[2] accuracy	90.06	2.77
Central cue[3] accuracy	97.29	2.89

Note. [1]The RT value are in ms and the accuracy values in percentages; [2]Single cue appearing either below or above the fixation cross'; [3]Two cues appearing both below and above the fixation cross; [4]Cue appearing at the same location than the fixation cross.

LDT: The participants RT in the LDT went through the same type of process as for the ANT-R. First, all the RT occurring after a wrong answer was deleted from the calculation. From this first series of RT was calculated and average and SD, and all the value differing more than two SD from the average were suppressed. Afterward, an average RT was calculated for each participant and separated as well between the word and the non-word trials. The descriptive statistics can be observed in the Table 6.3.

Table 6.3. Descriptive statistics of the LDT

	Mean[1]	SD
Global RT	556.99	60.85
Real word RT	551.90	60.63
Non-word RT	562.38	63.13
Global accuracy	97.38	2.91
Real word accuracy	97.91	2.00
Non-word accuracy	96.84	4.94

Note. [1]The RT value are in ms and the accuracy values in percentage.

DST: The DST does not need any prior modification before its analysis, as the result analysed is simply the maximum number of remembered by the participants either forward (i.e., short-term memory) or backward (i.e., working memory). Nonetheless, two extra variables were created to attain a deeper exploration of working memory. First, the number of digits recalled backward by the participants was subtracted from the number of digits recalled forward by the participants. The purpose of this modification was to take into account the basic short-term memory of the participant in the calculation of the working memory score (i.e., the bigger the difference, the worse the working memory). The limitation of this calculation is that a participant with two low scores could end up with the same global score as a participant with two higher scores (e.g., five digits forward and three backward – Score of 2; ten digits forward and eight backward – Score of 2). To overcome to this limitation, a second calculation was added, the previous results were multiplied by the total number of digits recalled by the participants (i.e., the sum of the backward and forward results). Interestingly, this calculation can be summarised as the square score on the forward task subtracted by the squared score on the backward task. With this method, a participant repeating more digits overall would have a better global score (e.g., to take back the previous example; 16 vs. 36). The descriptive statistics of the DST, including the newly calculated variables, are available in Table 6.4.

Table 6.4. Descriptive statistics of the DST

	Mean	SD
Forward score (F)	7.73	0.96
Backward score (B)	5.73	0.92
Subtraction score (F-B)	2.00	1.05
Multiplication score (F-B) * (F+B)	27.02	15.08

Questionnaires: For clarity's sake, the results from the gaming questionnaires will be separated from the questionnaires not related to gaming. Apart from this fact, no modification has been brought upon the survey results and the guidelines offered by the authors of the scales have been followed. The descriptive statistics of the global questionnaires can be found in Table 6.5 (n = 44) and the gaming questionnaires in the Table 6.6 (n = 20).

Table 6.5. Descriptive statistics of the questionnaires not related to gaming

	Minimum	Maximum	Mean	SD
Stress (DASS)	7	22	13.96	3.96
Anxiety (DASS)	7	22	12.00	3.72
Depression (DASS)	7	21	11.89	3.94
Negative urgency (UPPS-P)	4	16	9.64	3.39
Positive urgency (UPPS-P)	7	15	10.18	2.09
Premeditation (UPPS-P)[1]	4	12	7.50	2.06
Perseverance (UPPS-P)[1]	4	13	8.11	2.33
Sensation seeking (UPPS-P)	4	16	10.84	2.65
Emotional reactivity (ERS)	12	95	38.80	19.34

Note. [1]Lack of perseverance/premeditation)

Table 6.6. Descriptive statistics of the questionnaires related to gaming

	Minimum	Maximum	Mean	SD
IGD criteria	0	5	1.80	1.64
Preoccupation (POGQ)	2	8	4.55	1.67
Overuse (POGQ)	3	8	5.10	1.62
Immersion (POGQ)	4	18	10.90	3.66
Social isolation (POGQ)	2	8	4.25	1.68
Interpersonal conflicts (POGQ)	2	5	2.65	1.04
Withdrawal (POGQ)	4	14	6.75	2.83
Total POGQ score	19	56	34.20	10.30

6.4.2. Time perception

A first analysis performed on the temporal estimation was to compare the error of estimation between all the participants. For this purpose, the estimation of each participant was first divided by the real duration of the block, giving a number theoretically varying between 0 and 2 (i.e., the estimation over twice the real duration being removed previously). However, since this calculation was not sufficient because the overestimation (i.e., scores above 1) and underestimation (i.e., score below 1) errors were separated. To overcome this issue, the scores were first subtracted by 1 (i.e., varying between -1 and 1) and then squared (i.e., varying between 0 and 1). Afterward, to achieve the real error rate, rather than its squared value, the squared root of the previous score was used (i.e., still varying between 0 and 1). The short block had an error rate of .52 (SD = .27), the medium-length block of .35 (SD = .24), and the long block of .48 (SD = .28). None of the comparisons using a repeated measures ANOVA were significant, $F(2) = 1.20$, $p=.32$.

Interestingly, using the provided estimation divided by the real duration, without any further modification, it showed that the participants tended to underestimate long block (M = .66, SD = .43) while they had an accurate estimation of the short and medium blocks (respectively, M = 1.04, SD = .60 and M = .92, SD = .42). When comparing these results through the same analysis as the error rate, the results were significant $F(2) = 14.44$, $p<.001$. The Bonferroni correction showed that the long block was significantly more underestimated than the short and medium blocks (p=.002 and p<.001 respectively) while there was no significant difference between these two blocks (p=1.00).

Concerning the control variables included in this experiment which could affect the time perception of the participants (e.g., depression and attention), their effects on the temporal estimation in this experiment were explored through a correlational analysis. As Tables 6.7, 6.8, and 6.9 show, none of the correlations explored affected the estimations of the participants.

Table 6.7. Correlation between the DST variable and the time estimation

	DST forward score	DST backward score	DST subtraction	DST global score
Short estimation (n = 11)	.326	.371	-.029	.028
Medium estimation (n = 35)	.268	.319	-.021	.038
Long estimation (n = 41)	.027	.018	.009	.001
Total estimation (n = 40)	.166	.277	-.094	-.031

Note. *Correlation is significant at the p<.05 level (2-tailed).

Table 6.8. Correlations between stress, anxiety, depression, and impulsiveness with time estimations

	Short estimation (n = 14)	Medium estimation (n = 38)	Long estimation (n = 44)	Total estimation (n = 43)
Stress (DASS)	-.255	-.155	.002	-.245
Anxiety (DASS)	-.114	.043	-.098	-.013
Depression (DASS)	-.155	.037	-.153	-.069
Positive urgency (UPPS-P)	-.364	.042	.002	-.024
Negative urgency (UPPS-P)	-.293	-.110	.007	.037
Premeditation (UPPS-P)[1]	-.284	.006	-.146	.193
Perseverance (UPPS-P)[1]	-.064	-.082	-.157	-.158
Sensation seeking (UPPS-P)	-.090	-.105	.076	.008

*Correlation is significant at the 0.05 level (2-tailed). [1]Lack of perseverance/premeditation

Table 6.9. Correlation between the ANT-R variables and time estimation

	Short estimation (n = 14)	Medium estimation (n = 38)	Long estimation (n = 44)	Total estimation (n = 43)
Global RT	-.009	.042	-.012	-.055
Single arrow RT	.051	..095	-.004	-.024
Multiple arrows RT	-.053	-.002	-.021	-.079
Multiple congruent arrows RT	-.010	.062	-.007	-.055
Multiple incongruent arrows RT	-.076	-.060	-.028	-.111
Informative cue[1] RT	-.037	-.010	-.037	-.089
Dual cue[2] RT	.069	.078	-.013	-.005
Central cue[3] RT	-.031	.089	.030	-.043
Global accuracy	-.346	-.012	.068	.045
Single arrow accuracy	.057	-.024	-.145	-.092
Multiple arrows accuracy	-.479	-.188	-.056	-.001
Multiple congruent arrows accuracy	-.283	-.131	-.196	-.189
Multiple incongruent arrows accuracy	-.457	-.144	.104	.179
Informative cue[1] accuracy	.064	-.136	-.133	-.227
Dual cue[2] accuracy	-.432	.060	-.019	.181
Central cue[3] accuracy	-.430	-.196	-.108	.006

Note. *Correlation is significant at the p<.05 level (2-tailed). RT = Reaction time; [1]Single cue appearing either below or above the fixation cross; [2]Two cues appearing both below and above the fixation cross; [3]Cue appearing at the same location than the fixation cross.

6.4.3. Gamers' time perception

To analyse the difference in terms of baseline time perception between the gamers and non-gamers, the corrected estimations (i.e., without the outliers – see the preliminary statistics section for more details) provided by the participants were compared between the two groups using a *t*-test. None of the comparisons violated the homogeneity of variances assumption ($p>.30$) and the participants' age was controlled in the following analyses. The gamers estimated the short block to last 62.86s (SD = 18.35) compared to 85.71s (SD = 13.78), the difference being non-significant, $t(12) = 1.00$, $p=.34$. Similarly the duration estimation of the medium block by the gamers (M = 173.68s, SD = 88.64) did not significantly differ from the estimation provided by the non-gamers (M = 185.53s, SD = 77.33), $t(36) = .44$, $p=.66$. Finally, the same trend was observed for long block as there was no significant difference between the gamers' estimation (M = 228.41, SD = 160.08) and the non-gamers' one (M = 225.00, SD = 142.75), $t(42) = -.08$, $p=.94$.

In addition, the gaming variables explored in the survey have been compared to the time estimation provided by the gamers. Since the number of participants presenting at least five IGD criteria was too low (i.e., two participants), no *t*-test was conducted on this population. However, the two continuous variables (i.e., POGQ scores and IGD criteria) have been analysed through a correlational approach (see Table 6.10 for details), no significant results being found.

Table 6.10. Correlations between time perception and gaming questionnaires

	Short estimation	Medium estimation	Long estimation	Total estimation
Total score (POGQ)	-.260	-.093	.177	.054
Preoccupation (POGQ)	.096	.274	.149	-.111
Overuse (POGQ)	.046	-.105	.060	.070
Immersion (POGQ)	-.359	-.175	.288	.170
Social isolation (POGQ)	-.695	-.119	-.068	.073
Interpersonal conflicts (POGQ)	.114	-.039	.251	.069
Withdrawal (POGQ)	-.241	-.148	.099	-.068
IGD criteria	-.566	-.259	-.124	.152
Time spent gaming (weekly)	-.350	-.024	.099	-.005

*Correlation is significant at the p<.05 level (2-tailed).

Furthermore, the impact of the favoured genres by the gamers on their time perception has been observed. Since some genres were underrepresented, a preliminary frequency analysis has been led to find out which games' genres would allow a *t*-test. One of the gamers played real-time strategy (RTS) games, three first-person shooters (FPS) games, two massively multiplayer online role-playing games (MMORPG), seven role-playing games, one multiplayer online battle arena (MOBA) games, three race games, and four sport games. Therefore, only the RPG allowed the performing of a *t*-test which was inconclusive for the three durations (p>.24 for all the durations).

6.4.4. Comparison of the gamers' and non-gamers' scores on the LDT

The two main variables compared for the LDT are the RT and the accuracy, which both are subdivided into the global mean, the score for real words, and the score for non-words. For clarity's sake, RT and accuracy will be explored in separate tables. Table 6.11 exhibits the descriptive statistics compared between the gamers and non-gamers and Table 6.12 shows the *t*-test details for these comparisons.

Table 6.11. Mean and SD of the LDT reaction times in ms.

	Gaming	N	Mean	SD
Global RT	Non-gamers	22	584.04	54.67
	Gamers	22	529.94	55.31
Word RT	Non-gamers	22	575.70	56.16
	Gamers	22	528.09	56.45
Non-word RT	Non-gamers	22	592.94	55.61
	Gamers	22	531.83	55.78

Table 6.12. *t*-test on the LDT reaction times in ms

	t	*Df*	*p*-value	Mean difference
Global RT[1]	3.26	42	.002	54.11
Word RT[1]	2.80	42	.008	47.61
Non-word RT[1]	3.64	42	.001	61.11

Note. [1]Equal variances assumed

Concerning reaction times, the gamers exhibited a systematic faster RT than the non-gamers for both words and non-words, which is directly reflected by a global faster RT. In order to observe whether their processing speed affected the RT difference between the word and non-word conditions, a repeated measures ANOVA has been conducted to observe the interaction between gaming and the task conditions. The ANOVA showed a main effect of words, the participants having a slower RT for the non-words (M = 551.38, SD = 63.13) than the word (M = 551.90, SD = 60.63), F(1) = 10.37, *p*=.002. The ANOVA also showed a significant interaction between the type of stimuli and the gaming use, F(1) = 4.30, *p*=.04. To further explore this interaction, the difference of RT between words and non-words was observed separately between the gamers and non-gamers. While the non-gamers exhibited a slower reaction time for the non-words (M = 592.94, SD = 55.61) than the words (M = 575.70, SD = 56.16), *t*(21) = 3.30, *p*=.003; the gamers showed no such difference between the non-words RT (M = 531.83, SD = 55.78) and words RT (M = 528.09, SD = 56.45), *t*(21) = .96, *p*=.347.

Table 6.13 exhibits the descriptive statistics for the accuracy of the gamers and non-gamers in the LDT based on the different conditions while Table 6.14 shows the *t*-test results for the comparisons between gamers and non-gamers. The only difference observed in terms of error rate concerns global accuracy where the gamers exhibited a slightly inferior accuracy compared to the non-gamers.

Table 6.13. Mean and SD of the LDT accuracy in percentage.

	Gaming	N	Mean	SD
Global accuracy	Non-gamers	22	98.59	1.14
	Gamers	22	97.23	2.45
Word accuracy	Non-gamers	22	96.05	6.64
	Gamers	22	97.64	2.13
Non-word accuracy	Non-gamers	22	97.32	3.63
	Gamers	22	97.43	2.04

Table 6.14. *t*-test on the LDT accuracy in percentage

	t	*df*	*p*-value	Mean difference
Global accuracy[2]	2.37	29.71	.025	1.36
Word accuracy[1]	-1.01	42	.29	-1.59
Non-word accuracy[1]	-.128	42	.90	-.11

Note. [1]Equal variances assumed. [2]Equal variances not assumed.

6.5. Discussion

It was hypothesized that the gamers would not exhibit globally impaired time perception, but rather an impairment solely occurring in front of gaming cue – or of course while gaming. The purpose of this experiment was to observe the baseline temporal abilities of gamers compared to non-gamers and showed that there was no difference between these two groups. Additionally, correlational analyses showed that there was no association between the POGQ scores, or the IGD criteria, and the time estimations provided by the gamers. Neither was there any difference in terms of time perception between the RPG gamers and the other gamers of this sample. In conclusion, Experiment 2 validated the first half of the hypothesis and further justified the third and final experiment in this thesis (i.e., observing the impact of gaming cues and attention on time perception among gamers). Additionally, correlations were led between the non-temporal variables explored in this study (i.e., impulsiveness, depression, stress, anxiety, attention, and working memory) and the time estimation provided by the participants. These analyses systematically exhibited the same trend of results, that is, no significant correlation.

Regarding the lexical abilities, several differences were observed between the gamers and the non-gamers. First, in the LDT, a trade-off was observed between reaction time and accuracy, showing that the gamers sacrificed part of their accuracy in order to answer faster. However, while the non-gamers were slower to answer when it came to non-words compared to words, the gamers did not exhibit such a speed reduction between the two conditions. This, coupled with their overall faster reduction, shows that the gamers had a higher lexical decision ability than the non-gamers. These results support one of the hypotheses that gamers would have faster RTs on the LDT.

Chapter 7: Experiment 3 – Effect of cognition and emotion on gamers' time perception

7.1. Experiment 3 background

In Chapter 3, it was noted that since gamers had a better attentional focus and an improved working memory, they should have a better prospective time perception. This hypothesis was partially supported by the preliminary results observed within Experiment 1 (i.e., more accurate prospective estimation of the gamers). Consequently, it was decided to only explore retrospective time perception (RTP) in Experiments 2 and 3. It was also noted that the gamers would exhibit an impaired RTP due to their enhanced reactivity to the gaming cues, rather than a globally impaired RTP. In the second experiment, the RTP of gamers and non-gamers was compared, without any influence of either emotional or cognitive processes, showing that there was no difference in their baseline time perception. These results further supported the hypothesis that the gamers were not suffering from a globally impaired time perception, their time loss resulting from another factor. Accordingly, Experiment 3 explored whether the observed impaired time perception of the gamers was due to a cognitive process (i.e., difficulty of the task), an emotional one (i.e., gaming cues), or an interaction of both these factors.

7.2. Aim and hypotheses

As mentioned in the previous section, the main aim of this thesis is to explore the interactive effect of cognition and emotion on the gamers' time perception. In this experiment, half the participants saw neutral pictures (i.e., the same pictures than the first experiment) and the other half saw gaming pictures (i.e., pictures from popular videogames at the time of the experiment). Furthermore, for half the participants, the non-words were simply strings of consonants (e.g., "GKJF") while for the other half, the non-words looked like real words (e.g., "CORI").

The first hypothesis is that under the emotional condition, the gamers would underestimate the duration of the temporal task compared to the non-emotional one, while this effect would not be observed among the non-gamers. Second, there would be no main effect of cognition for both groups because attention should only affect prospective time perception, this experiment focusing on the retrospective one. Nevertheless, it was hypothesized that there would be a joint effect of cognition and emotion because the complicated version of the task should force the gamers to focus more on it. An increased focus on the task should result in more attention to the gaming pictures, therefore, enhancing its deleterious effect. Finally, it was expected that the same trend of results as the two previous experiments would be observed, that is an improved RT for the Lexical Decision Task (LDT) among the gamers.

7.3. Method

7.3.1. Design

A between-group comparison design was used in this experiment. The three independent variables were the gaming habits of the participants (i.e., gamers vs. non-gamers), the complexity of the task (i.e., strings of consonants vs. non-words), and emotional factors (i.e., neutral vs. gaming pictures). These three dichotomous variables led to eight groups, although two of these groups were already tested in the second experiment (i.e., easy non-emotional condition, gamers and non-gamers). The dependent variable was the temporal estimation of the participants. This between-group design was coupled with a correlational exploration of several variables which may affect time perception (i.e., attentional process, working memory, gaming use/abuse, impulsiveness, depression, stress, anxiety, and demographic data).

7.3.2. Participants

A sample of 94 participants (19 males) was included in this experiment. Their average age was 20.98 years (SD = 4.71) and was between 18 and 47 years. They were recruited mainly through the recruitment system offered by Nottingham Trent University (NTU) in which the psychology students could participate in diverse experiments in exchange for credits. In order to recruit more participants, students from the research methods classes at NTU were asked to participate in exchange for research credits. Finally, as the recruitment of the gamers through these conventional systems was not progressing, a chance to win one of five ten-pounds *Amazon* or *Steam* (depending on the gamers' preference) vouchers was offered. It is important to note that for most of the analyses, the participants from the second experiment will be integrated in this sample. The reason behind it is that one of the conditions of this study (i.e., the easy non-emotional one) used exactly the same protocol and task than the second experiment. Out of the whole sample (i.e., n = 138), 56 mentioned that they were playing videogames for 10.63 hours per week on average (SD = 8.55, range = 0.5-35).

7.3.3. Materials

7.3.3.1. Self-reported measures

The self-reported measures in Experiment 3 were identical to those in Experiments 1 and 2.

7.3.3.2. Behavioural measures

Both the Attentional Network Task – Revised (ANT-R) and the Digit Span Test (DST) remained unchanged as they provided the desired results in the previous experiments. Due to the exploration of emotional and cognitive processes, the LDT stimuli for two of the conditions were modified. The selection of the emotional stimuli was achieved in two principal steps. First, the most popular games at the time of the research were identified (i.e., *Assassin Creeds Odyssey, Fortnite, God of War, Player Unknown Battleground, Detroit Becomes Human, Red Dead Redemption II, Marvel's Spider-Man,* and *Fallout*), also, the main genres played worldwide were identified through different scientific papers (i.e., First-Person Shooter – FPS, Sport games, Real-Time Strategy – RTS, Role-Playing Game – RPG, Massively Multiplayer Online Role-Playing Game – MMORPG, Race games, Multiplayer Online Battle Arena – MOBA, Gestion games, and Fighting games). Through an extensive search, the most popular games were selected for each of the categories, even if they were not part of the most popular games at the time of the research. Finally, a series of at least three pictures by specific game were selected which led to a total of 137 pictures.

In order to select the most suited pictures for the experiment, gamers from the researcher’s personal acquaintances were contacted and all given the pictures and an Excel sheet. The Excel sheet contained a table with the code name of all the pictures in the first column, as well as three extra columns named respectively “Arousal” (i.e., how excited they were feeling about the pictures), “Valence” (i.e., how positive did they feel about the pictures), “Gaming” (i.e., how related to gaming were the pictures), and “Play” (i.e., how much did the pictures make them want to play). The gamers were provided with the definitions of the columns’ titles and were asked to provide a score varying between 1 (i.e., not at all) to 9 (i.e., totally). After two weeks, the answers provided by the gamers who responded (n = 9) were collated, summed, and averaged. On average, the pictures had an arousal score of 4.86 (SD = 1.04), a valence score of 4.89 (SD = 0.97), were judged as related to gaming (M = 6.36, SD = 1.03), and showed a central tendency for the playing desire (M = 4.70, SD = 1.14). To select the pictures, only the ones exhibiting one SD above the average in each of the four measures were selected, leading to 40 potential pictures. As this total was still higher than the number of pictures desired (i.e., 24 as the number of neutral pictures), pictures from the overrepresented genres (i.e., eight pictures for the fighting games, eight for the FPS, four for the MMORPG, and nine for the RPG) were removed. Basically, the pictures differing the most from the average on the four scales compared to the other pictures in the same category were selected. At the end of the selection process, the following pictures were retained: *Assassin's Creed: Odyssey* (1), *Detroit Becomes Human* (1), *Fallout* (3), *Red Dead Redemption II* (1), Fighting games (4), FPS (3), Simulation games (3), MMORPG (3), RPG (3), RTS games (1), and race games (1).

Regarding the complicated version of the LDT, only the non-words were changed as mentioned earlier. For this purpose, instead of strings of consonants (e.g., "XKGJ"), the non-words needed to look like potential real words in order to confuse the participants (e.g., "CORI"). For the creation of the non-words, the *ARC Nonword Database* from the *Macquarie University* (Sydney, Australia; Rastle et al. [2002]) was used. The words had to be constituted of only orthographically existing onsets and bodies (i.e., to create words following the grammar rules of the English language), they could be both monomorphemic or polymorphemic (i.e., be constituted from one or several meaningful morphemes), and had to match real words in term of number of letters and vowel/consonant organisation (e.g., "CORI" vs. "COZY" – four letters; Consonant, vowel, consonant, vowel). A total of 100 non-words matching the real words were created using this method varying between three and seven letters. The words and non-words were split between the three blocks to ensure that they would all share the same average number of letters per block (Short block = 4.92, mid-length block = 4.84, long block = 4.68, $p > .05$).

7.3.4. Procedure

Participants could either subscribe through the university system to a specific date and time, or on a piece of paper with the same options if recruited in a research method class. When coming to the laboratory, they were given a code name to ensure their anonymity based on the first letter of their first name, the first letter of their mother's maiden name, and the two last digits of their birth year (e.g., FD92, AA94). The mother's maiden name was preferred to the participants' second name because the use of their initials would allow the experimenter, or any other researcher implicated in the study, to find the participants' real identity when they were recruited in classes (i.e., through the university database).

After reading the information sheet and giving their fully informed consent, the participants were introduced to the first task, the LDT. The participants were first introduced to the functioning of the task which only varied depending on its difficulty. The instruction for the easier version remained identical from the second experiment; they were told that words or string of consonants would appear in the centre of the screen and that they would be asked to press the right key (i.e., "n") if it was a word, and the left key (i.e., "z") if it was not a word. Concerning the complex version, the only difference is that instead of mentioning the string of consonants, the participants were told that they would be asked to decide whether the string of letters appearing in the middle of the screen were a word (by pressing "n" – e.g., "COZY") or a non-word (by pressing "z" – e.g., "CORI"). After confirming that they understood the functioning of the task, the participants were asked to perform a first training block which was monitored by the experimenter to ensure a proper completion of the task afterward.

The experimenter let the participants know that they would be monitored for the training block and that they would not be observed for the testing blocks. Once the training block completed, the participants could start the real task composed of three separate blocks. After completing the three testing blocks (i.e., in a fully random order), the participants were asked to provide their time estimation for each of the three blocks. They were allowed to use any time measure they preferred (i.e., minutes or seconds) and were told that they could be as accurate as they wanted (e.g., one minute and thirty seconds, three minutes and ten seconds).

After completing the LDT, the participants were introduced to the DST. This order was chosen to allow the participants to stop fixating the computer screen and rest their eyes for a few minutes. They were told that they would first be asked to repeat the digits dictated by the experimenter in the exact same order (i.e., forward test) with increasing difficulty until they could not do it anymore. Secondly, they would be asked to repeat the digits recited by the experimenter in the opposite order (i.e., backward test) with increasing difficulty until they could not do it anymore. Furthermore, the participants were reassured that the task was virtually limitless, and that getting stuck did not mean that they failed the test in order to prevent as many negative feelings as possible.

Once the participants were done with the DST, they were introduced to the ANT-R. Since the task was quite complex, participants were offered examples on top of the text instructions. In these examples, each type of cues and arrow were shown to the participants and the researcher took some time to explain what these types of cues and arrows meant in the task. Once the participants confirmed that they understood the functioning of the ANT-R, they completed a first short training blocks including 16 trials with at least one representation of each clue and arrow. As for the LDT, the participants were warned about the monitoring of this specific block and that the experimenter would not monitor the whole task. Afterwards, the participants completed three different testing blocks with 48 trials each. In order to assure that the participants would not try to estimate the duration of the task, and get distracted, the duration of the task was revealed at the beginning of the testing blocks.

Finally, after completion of the ANT-R, the participants fulfilled the survey in the following order: demographic data, DASS-21, gaming use[3], UPPS-P, POGQ[1], ERS, and the IGD criteria[1]. The participants were told that they could ask any question to the experimenter in case they did not understand any part of the survey. At the end of the survey, they were also given the option to share an email address to participate to further studies organised by the experimenter. Afterwards, they were fully debriefed, especially when they were deceived about the time perception aspect of this study and thanked.

[3] These questionnaires were not included if the participants reported not playing videogames.

7.3.5. Ethics

This research was approved by the College Research Ethics Committee (CREC) prior to the data collection and this study design and procedure is consistent with the Declaration of Helsinki. Only two parts of this experiment could have caused minor harms to the psychological wellbeing of the participants. The first one is the disappointment of the participants in their own performance in the DST which was compensated by the experimenter reassuring each participant with their own score. The second one lies within the method of this experiment, as the participants did not know about the time perception aspect of this study (i.e., RTP). Since the participants were deceived on the true purpose of this experiments (i.e., they were told that the variable of interest was their lexical decision-making abilities), they were properly debriefed at the end of the experiments, explaining the reason behind the deception.

7.4. Results

7.4.1. Preliminary statistics

Time perception: Regarding the participants from this specific experiment, their time estimation in seconds greatly fluctuated, similarly to the previous experiment (i.e., SD = 104.12, SD = 103.51, SD = 151.93 for the short, medium, and long estimation respectively). Therefore, the same exclusion criteria were applied to their estimations (i.e., deletion of the estimation greater than twice the real duration – 72s, 192s, and 338s). This greatly reduced the variance of both the short and medium blocks (i.e., SD = 33.89 and SD = 74.00 respectively) but had a lesser impact on the long block variation (i.e., SD = 121.20).

Concerning the entirety of the participants (i.e., including the samples of both the second and third experiments), the mean and standard deviation of these estimations (i.e., with the same outliers' rules) are provided in Table 7.1. However, since only 59 participants' estimations remained for the shortest block (i.e., against 124 for the medium and 134 for the longest), the total duration will be the sum of the medium and long block rather than the sum of the three estimations.

Table 7.1. Descriptive statistics of the duration estimation for the whole sample

	Remaining sample	Mean	SD
Short block	59	85.17	36.31
Medium block	124	206.17	78.50
Long block	134	283.73	137.03

ANT-R: When calculating the average RT of each participant, two factors were taken into account. First, none of the trials where the participants answered wrongly were included in the calculation. From this modification, a first average and SD were calculated and used to further sort the RT of the participants. Any RT differing from more than two SD from the mean (i.e., either above or below) were excluded. Afterward, the real RT means of the participants were calculated (i.e., global RT, RT based on the different cues, and RT based on the number and congruence of the arrows). The descriptive statistics of both the RT and the accuracy of the ANT-R for the whole sample can be seen in Table 7.2.

Table 7.2. Descriptive statistics of the ANT-R

	Mean[1]	SD
Global RT	449.76	63.18
Single arrow RT	426.08	58.34
Multiple arrows RT	474.77	69.88
Multiple congruent arrows RT	448.33	66.74
Multiple incongruent arrows RT	503.76	74.98
Informative cue[2] RT	434.63	62.87
Dual cue[3] RT	467.27	67.93
Central cue[4] RT	463.07	64.86
Global accuracy	93.87	2.65
Single arrow accuracy	94.49	2.64
Multiple arrows accuracy	93.56	3.44
Multiple congruent arrows accuracy	96.54	2.97
Multiple incongruent arrows accuracy	95.17	5.35
Informative cue[1] accuracy	94.42	2.51
Dual cue[2] accuracy	97.16	3.86
Central cue[3] accuracy	89.80	3.85

Note. [1]The RT value are in ms and the accuracy values in percentage; [2]Single cue appearing either below or above the fixation cross; [3]Two cues appearing both below and above the fixation cross; [4]Cue appearing at the same location than the fixation cross.

LDT: The participants RT in the LDT went through the same type of process as for the ANT-R. First, all the RTs occurring after a wrong answer were deleted from the calculation. From this first series of RT an average and SD were calculated, and all the values differing more than two SD from the average were suppressed. Afterward, an average RT was calculated for each participant and separated as well between the word and the non-word trials. The descriptive statistics of the whole sample can be observed in the Table 7.3.

Table 7.3. Descriptive statistics of the LDT

	Mean[1]	SD
Global RT	596.36	87.86
Real word RT	574.27	78.29
Non-word RT	620.79	105.44
Global accuracy	95.32	8.68
Real word accuracy	97.01	8.49
Non-word accuracy	93.63	10.20

Note. [1]The RT value are in ms and the accuracy values in percentage

DST: The DST does not need any real prior modification before its analysis because the result analysed is simply the maximum number of digits remembered by the participants either forward (i.e., short-term memory) or backward (i.e., working memory). However, two extra variables were created to attain a deeper exploration of the working memory. First, the number of digits recalled backward by the participants was subtracted to the number of digits recalled forward by the participants. The purpose of this modification was to take into account the basic short-term memory of the participant in the calculation of the working memory score (i.e., the bigger the difference, the worse the working memory). The limitation of this calculation is that a participant with two low score could end up with the same global score than a participant with two higher scores (e.g., five digits forward and three backward – Score of 2; ten digits forward and eight backward – Score of 2). To overcome to this limitation, a second calculation was added, the previous results were multiplied by the total number of digits recalled by the participants (i.e., the sum of the backward and forward results). Interestingly, this calculation can be summarised as the square score on the forward task subtracted by the squared score on the backward task. With this method, a participant repeating more digits overall would have a better global score (e.g., to take back the previous example; 16 vs. 36). The descriptive statistics of the DST, including the newly calculated variables, is available in Table 7.4.

Table 7.4. Descriptive statistics of the DST

	Mean	SD
Forward score (F)	7.84	1.18
Backward score (B)	5.75	1.17
Subtraction score (F-B)	2.08	1.21
Multiplication score (F-B) * (F+B)	28.31	17.20

Questionnaire: For clarity's sake, the results from the gaming questionnaires were separated from the questionnaires not related to gaming. Apart from this fact, no modification has been brought upon the survey results and the guidelines offered by the authors of the scales have been followed. The descriptive statistics of the global questionnaires can be found in Table 7.5 (n = 137) and the gaming questionnaires in Table 7.6 (n = 55).

Table 7.5. Descriptive statistics of the questionnaires not related to gaming

	Minimum	Maximum	Mean	SD
Stress (DASS)	7	27	13.56	4.10
Anxiety (DASS)	7	22	11.44	3.65
Depression (DASS)	7	26	12.15	4.25
Negative urgency (UPPS-P)	4	16	9.75	3.33
Positive urgency (UPPS-P)	7	15	10.69	1.82
Premeditation (UPPS-P)[1]	4	13	7.45	2.21
Perseverance (UPPS-P)[1]	4	14	8.07	2.37
Sensation seeking (UPPS-P)	4	16	10.83	1.97
Emotional reactivity (ERS)	12	95	49.79	19.71

Note. [1]Lack of perseverance/premeditation.

Table 7.6. Descriptive statistics of the questionnaires related to gaming

	Minimum	Maximum	Mean	SD
IGD criteria	0	6	1.73	1.51
Preoccupation (POGQ)	2	8	4.65	1.70
Overuse (POGQ)	3	9	4.98	1.75
Immersion (POGQ)	4	19	11.11	3.45
Social isolation (POGQ)	2	8	4.00	1.45
Interpersonal conflicts (POGQ)	2	9	2.76	1.40
Withdrawal (POGQ)	4	14	6.33	2.53
Total POGQ score	19	63	33.84	9.55

7.4.2. Time perception

A first analysis performed on the temporal estimation was to compare the error of estimations between all the participants. For this purpose, the estimation of each participant was first divided by the real duration of the block, giving a number theoretically varying between 0 and 2 (i.e., the estimation over twice the real duration being removed previously). Since this calculation was not sufficient because the overestimation (i.e., scores above 1) and underestimation (i.e., score below 1) errors were separated. To get rid of this issue, the scores were first subtracted by 1 (i.e., varying between -1 and 1) and then squared (i.e., varying between 0 and 1). Afterward, to achieve the real error rate, rather than its squared value, the squared root of the previous score was used (i.e., still varying between 0 and 1). The short block had an error rate of .48 (SD = .23), the medium-length block of .34 (SD = .20), and the long block of .35 (SD = .24). The repeated measures ANOVA between these three variables was significant, $F(1) = 4.661$, p=.035. According to the Bonferroni post-hoc analysis, this significance was due to a significant difference between the short and medium block’s error rates (p=.002), no other difference being significant.

Interestingly, using the provided estimation divided by the real duration, without any further modification, it showed that the participants tended to underestimate long block (M = .83, SD = .39), had an accurate estimation of the medium block (M = 1.06, SD = .39), and tended to overestimate the short block (M

= 1.21, SD = .49). When comparing these results through the same analysis as the error rate, the results were significant F(2) = 55.357, *p*<.001. The Bonferroni correction showed that the long block was significantly more underestimated than the short and medium blocks (*p*<.001 for both comparisons) while the short block was significantly overestimated compared to the medium block (*p*=.003). Concerning the control variables included in this experiment which could affect the time perception of the participants (e.g., depression and attention), their effects on the temporal estimation in this experiment were explored through a correlational analysis. As Tables 7.7, 7.8, and 7.9 show, none of the correlations explored affected the estimation of the participants.

Table 7.7. Correlation between the DST variable and the time estimation

	DST forward score	DST backward score	DST subtraction	DST global score
Short estimation (n = 55)	-.035	-.055	.022	-.011
Medium estimation (n =120)	.154	.025	.127	.146
Long estimation (n = 129)	-.018	-.082	.062	.036
Total estimation (n = 129)	.046	-.080	.122	.110

Note. *Correlation is significant at the p<.05 level (2-tailed).

Table 7.8. Correlations between stress, anxiety, depression, and impulsiveness with time estimations

	Short estimation (n = 58)	Medium estimation (n = 123)	Long estimation (n = 133)	Total estimation (n = 133)
Stress (DASS)	-.086	-.028	.071	.000
Anxiety (DASS)	.010	.024	.028	.091
Depression (DASS)	.050	-.021	.085	.003
Positive urgency (UPPS-P)	-.103	.078	.061	-.034
Negative urgency (UPPS-P)	.166	.054	.052	.069
Premeditation (UPPS-P)[1]	-.188	.054	.075	.078
Perseverance (UPPS-P)[1]	-.235	-.068	.011	-.073
Sensation seeking (UPPS-P)	-.120	-.095	-.004	-.101
Emotion reactivity (ERS)	.003	.042	.109	-.098

*Correlation is significant at the p<.05 level (2-tailed), [1]Lack of perseverance/premeditation.

Table 7.9. Correlation r between the ANT-R variables and time estimation

	Short estimation (n = 57)	Medium estimation (n = 122)	Long estimation (n = 131)	Total estimation (n = 131)
Global RT	-.111	-.041	-.089	-.026
Single arrow RT	-.083	-.026	-.082	-.024
Multiple arrows RT	-.131	-.052	-.09	-.026
Multiple congruent arrows RT	-.115	-.020	-.087	-.009
Multiple incongruent arrows RT	-.145	-.086	-.105	-.049
Informative cue[1] RT	-.085	-.044	-.082	-.034
Dual cue[2] RT	-.139	-.032	-.083	-.018
Central cue[3] RT	-.130	-.043	-.101	-.017
Global accuracy	-.077	.081	.051	.027
Single arrow accuracy	.006	.083	-.009	.011
Multiple arrows accuracy	-.119	.049	.044	-.015
Multiple congruent arrows accuracy	-.053	.080	.061	-.004
Multiple incongruent arrows accuracy	-.116	.052	.047	.008
Informative cue[1] accuracy	-.067	.031	.007	-.029
Dual cue[2] accuracy	-.052	.071	.070	.053
Central cue[3] accuracy	-.064	.090	-.018	-.030

Note. *Correlation is significant at the p<.05 level (2-tailed). RT = Reaction time. [1]Single cue appearing either below or above the fixation cross; [2]Two cues appearing both below and above the fixation cross; [3]Cue appearing at the same location than the fixation cross.

7.4.3. Comparison of the gamers' and non-gamers' scores on the LDT

Compared to the previous experiment, the LDT results (i.e., both the RT and accuracy) cannot be explored through a simple *t*-test. This is due to the multiple conditions in this experiment compared to the single condition in the previous one. In this study, the gamers and non-gamers were split equally into four different conditions differing in terms of emotional levels (i.e., gaming pictures vs. neutral pictures) and difficulty (i.e., easy vs. hard task). To analyse the different interactions between these three variables, a general linear model multivariate was run with the gaming habits, difficulty, and pictures types as independent factors. The dependent factors were the RT and accuracy for the words, the non-words, as well as the entirety of the trials. The model was significant for the words RT (F[7] = 2.212, *p*=.037, $\eta 2$ = .106), the non-words RT (F[7] = 10.745, *p*<.001, $\eta 2$ = .367), and the global RT (F[7] = 5.830, *p*<.001, $\eta 2$ = .239). Concerning the accuracy levels, the model was only significant for the non-word accuracy (F[7] = 3.321, *p*=.003, $\eta 2$ = .152), the other variables not being significant (*p*=.515 for the words accuracy and *p*=.075 for the global accuracy).

There was a main effect of gaming on the global RT (F[7] = 6.303, *p*=.013, $\eta 2$ = .046) although this would probably be due to the effect on the non-words RT (F[7] = 10.943, *p*=.001, $\eta 2$ = .078), the effect for the words RT being non-significant (*p*=.127). Regarding the non-words RT, the gamers were faster than the non-gamers (647.28 vs. 595.51), the same trend being observed for the global RT (614.93 vs. 579.74). There was an expected main effect of cognition on almost all the variables, to the exception of the word accuracy (*p*=.369), these results being described in Table 7.10 for clarity's sake. There was no other significant main effect or any significant interaction between any of the other variables.

Table 7.10. Task difficulty effect on the LDT variables

	Mean difference[1]	F(7)	*p*
Global RT	71.02ms	25.66	<.001
Words RT	37.90ms	7.840	.006
Non-words RT	108.26ms	49.756	<.001
Global accuracy	3.93%	6.705	.011
Words accuracy	1.37%	.814	.369
Non-words accuracy	6.49%	14.286	<.001

7.4.4. Gamers' time perception

To analyse the difference in time perception between the gamers and non-gamers, the corrected estimations (i.e., without the outliers – see 'Section 7.4.1. Preliminary statistics' for more details) provided by the participants were compared using a General Linear Model. It is important to note that the number of participants presenting five or more IGD criteria was too low to be included in this model (i.e., two participants). These analyses were run separately between the gamers and non-gamers for clarity's sake. The two independent variables were the difficulty of the task (i.e., easy vs. hard) and the type of pictures (i.e., gaming vs. neutral). The dependent variables included were the short, medium, long, and total durations. Furthermore, the age of the participants was controlled in both models.

First, the model was explored for the non-gamers with a sample of 35 participants (i.e., the remaining being excluded due to some data missing), showing no significant prediction on any of the variable (i.e. *p*-value varying between .156 and .447). Second, the gamers were explored separately with 22 participants (i.e., due to the deletion of the outlying data), showing significant effect of the model on both the medium and long duration (i.e., $F[3] = 4.122$, $p=.022$, $\eta 2 = .407$ and $F[3] = 6.801$, $p=.003$, $\eta 2 = .531$, respectively), a near-significant effect on the total duration (i.e., $F[3] = 2.715$, $p=.075$, $\eta 2 = .312$), and no significant effect on the short duration (i.e., $F[3] = .465$, $p=.711$).

When exploring the model among gamers, it appeared that there was a main effect of emotion on both the medium and total duration (i.e., $p=.005$, $\eta 2 = .367$ and $p=.023$, $\eta 2 = .256$; respectively) with no other significant effect (i.e., $p=.939$ for short duration and $p=.216$ for long). According to the Bonferroni correction, the gamers underestimated the medium duration by 93.07s and the total duration by 91.85s when gaming pictures were included compared to neutral pictures. Finally, there was also a significant interaction between cognition and emotion on the long duration ($p=.001$) and a near-significant one for the medium duration ($p=.068$), and both the short and total duration were not significant ($p=.769$ and $p=.117$ respectively). When exploring this interaction for the long duration (i.e., the only really significant one), it appeared that when performing the easy task, the participants tended to overestimate the duration when emotional pictures were included (i.e., 228.41s vs. 295.83s), the opposite trend being observed while performing the complicated task (i.e., 360.00s vs. 267.00s). It is noteworthy that none of these comparisons was significant after correction.

7.5. Discussion

It was hypothesized that the gamers would underestimate time when exposed to gaming pictures, this effect being strengthened when more attention was brought upon the task (i.e., complicated version). For this purpose, half the participants undertook an LDT with gaming pictures and the other half with neutral pictures. On top of that, half the participants performed a simple version of the task (i.e., consonants strings) while the other half were asked to take on a complicated version (i.e., non-words). To explore the isolated effect of emotion and attention, as well as its interaction, a general linear model multivariate was conducted using the difficulty of the task and the type of pictures as predictors. For the non-gamers, the model was not significant for any of the duration, while it was significant for the medium and long duration among the gamers. This significance was explained by a main effect of emotion for the medium duration (i.e., underestimation of about 90s in front of gaming pictures) and the total duration (i.e., underestimation of about 90s in front of gaming pictures). Furthermore, despite the lack of effect of the task difficulty, there was an interaction between the difficulty and type of pictures. This interaction showed that in the easy setting, the gamers tended to give longer estimation when confronted with gaming pictures compared to neutral pictures; the opposite trend being observed for the complicated setting. This could indicate that flow plays a crucial role in the interaction between emotion, time perception, and gaming even if these comparisons were not significant post-correction. Indeed, in the complicated task, the gamers would find a challenge fitting their skills, which would require their full attentional focus. In this case, the gamer would fully process the pictures and underestimate time. In the easy setting, the gamers would be bored due to the task being too easy, and the gaming pictures would then distract them even more from the task, enhancing the boring effect (i.e., overestimation of time).

In brief, it appears that gamers can exhibit an impaired time perception when exposed to gaming cues. The hypothesis postulating that emotion would disrupt the gamers' time perception is thus confirmed, although it was hypothesized that attention would strengthen this effect which was not observed. In addition, correlations were calculated between the non-temporal variables explored in this study (i.e., impulsiveness, depression, stress, anxiety, attention, and working memory) and the time estimation provided by the participants. These analyses systematically exhibited the same trend of results, that is no significant correlation.

Concerning the LDT, a general linear model multivariate was run to explore how the different factors (i.e., gaming habits, difficulty, pictures type) would affect the different variables (i.e., RT and accuracy for the words and non-words) assessed. The model was significant for the RT of the words, the non-words, and the average RT. It was also significant for the non-word accuracy, the other effects being non-significant. Regarding the RT, there was a main effect of gaming for the global RT probably due to the strong effect of gaming on the non-words RT as there was no effect on the words RT. Basically, the gamers were faster by more than 100ms when they were processing non-words compared to non-gamers. Finally, there was an expected main effect of difficulty on the task, all the variables, to the exception of the words' accuracy, were worse in the complicated task than the easy task, with no interaction with any other variable.

Chapter 8: Inter-experimental study results

8.1. Chapter overview

This chapter separately explores the common data which were collected in the three different experiments of this thesis. These data comprise the survey which was identical in all the experiments as well as the Attentional Network Task–Revised (ANT-R) and the Digit Span Test (DST). These two tasks are included in this section to compare the results of the gamers and non-gamers.

The chapter is divided based upon the measures explored. First, the subscales from the Depression, Anxiety, and Stress scale 21 items (DASS-21) are studied in comparison to the other scales from the survey. Second, the subscales from the UPPS-P short version (s-UPPS-P) go through the same analyses (i.e., excluding the associations with the DASS-21 already explored). Third, the effect of gaming on all the survey scales as well as the ANT-R and DST are discussed. Finally, the demographic data (i.e., education levels, age, and gender) is examined in relation with the survey results.

Although the survey analysis was mainly exploratory, some hypotheses were formulated. First, it was hypothesized that the level of gaming disorder, whether assessed by the Problematic Online Game Questionnaire (POGQ) or defined by the Internet Gaming Disorder (IGD) criteria, would be directly associated with higher levels of stress, anxiety, and depression. It was also hypothesised that higher scores on the POGQ or IGD criteria would lead to higher scores on the short UPPS-P Impulsive Behavior Scale (s-UPPS-P). Finally, it was hypothesized that the impulsivity measure (s-UPPS-P) would correlate with the depression, anxiety, and stress scale variables on the DASS-21. Concerning the comparisons between the gamers and non-gamers, it was expected that the gamers would exhibit better performance on both the DST and the ANT-R.

8.2. Participants

Due the promotion of the survey on social media and online forums (i.e., dedicated to gaming), 437 individuals started the survey (i.e., 226 of these completed the survey as part of the three previously described experiments). From these data, 94 participants were deleted due to non-completion of it. After deleting these incomplete data, a total of 343 participants remained. This sample included 113 males and was on average 22.50 years (SD = 5.92). Furthermore, 170 of these

343 participants said that they played videogames for 13.89 hours per week on average (SD = 11.77).

8.3. Depression, anxiety, and stress

Descriptive statistics

The DASS-21 (Antony et al., 1998) includes three subscales assessing depression, anxiety, and stress levels within a non-clinical population. On top of providing a continuous score for each of these variables, the DASS-21 includes cut-off scores designating different levels of depression, stress, and anxiety. For all the subscales, the participants can be categorized in normal levels (i.e., under 9 for depression, 7 for anxiety, and 14 for stress), mild levels (i.e., between 10 and 13 for depression, 8 and 9 for anxiety, and 15 and 18 for stress), moderate levels (i.e., between 14 and 20 for depression, 10 and 14 for anxiety, and 19 and 25 for stress), severe levels (i.e., between 21 and 27 for depression, 15 and 19 for anxiety, and 26 and 33 for stress), and finally extremely severe levels (28 or above for depression, 20 or above for anxiety, and 34 or above for stress). Within the sample, participants on average showed normal levels of stress (M = 13.47, SD = 3.99), mild levels of depression (M = 12.37, SD = 4.60), and moderate levels of anxiety (M = 11.21, SD = 3.58). According to the cut-off scores, the participants were mostly categorized as mildly or moderately stressed and anxious, and normally depressed (i.e., see Table 8.1 for details).

Table 8.1. Frequency table of the depression, stress, and anxiety levels

	Normal	Mild	Moderate	Severe	Extremely severe
Depression	252	49	38	3	0
Anxiety	31	100	151	52	8
Stress	51	141	128	22	0

Consequently, this scale allowed two types of analysis: (i) correlational analysis (i.e., when using the continuous score, the sum of all the questions) and (ii) ANOVA (i.e., when using the groups formed by the cut-off scores). While the correlational approach gives a rough idea of how these disorders are associated with other variables, the ANOVA allows an in-depth exploration of these associations. For example, an ANOVA could show that only participants with the highest level of depression exhibit higher levels of anxiety, while the others would not exhibit any difference. In this case, the correlation could be significant, but would lack this level of precision. Importantly, since only eight of the participants reported extremely severe anxiety levels and three reported severe levels of depression, their results will not be included in the analysis due to their outlying nature.

Correlations

First, the scores of the DASS-21 subscales were correlated with the impulsivity levels from the s-UPPS-P questionnaire, showing numerous significant correlations which were then verified through the Benjamin-Hochberg correction. Of all the significant correlations, only the ones between the positive urgency and both the anxiety and depression levels lost their significance. For more details see Table 8.2.

Table 8.2. Correlations between the DASS-21 and the UPPS-P-s subscales

	Stress	Anxiety	Depression
Negative urgency	.348*	.239*	.228*
Positive urgency	.172*	.113[a]	.115[a]
Global urgency	.316*	.214*	.208*
Lack of premeditation	.070	.064	.105
Lack of perseverance	.203*	.261*	.355*
Sensation seeking	-.221*	-.289 *	-.278*

Note. [a]Significant pre-correction, *significant post-correction

Second, the DASS-21 scores were correlated with the Problematic Online Game Questionnaire (POGQ) measures which, similarly to the UPPS-P measures, showed several significant correlations. After the Benjamin-Hochberg correction, only two correlations lost their significance levels (i.e., between interpersonal conflicts and both stress and anxiety levels). See Table 8.3 for detailed correlations.

Table 8.3. Correlations between the POGQ and DASS-21 subscales

	Stress	Anxiety	Depression
Total POGQ score	.269*	.287*	.339*
Preoccupation	.143	.215*	.237*
Overuse	.219*	.202*	.306*
Immersion	.142	.165[a]	.126
Social isolation	.194*	.217*	.283*
Interpersonal conflicts	.154[a]	.166[a]	.279*
Withdrawal	.320*	.310*	.330*

Note. [a]Significant pre-correction, *significant post-correction

ANOVA

Concerning the ANOVAs, the same variables have been explored and, for clarity's sake, only the significant results are discussed in this section. Additionally, the results are divided based on the DASS-21 subscales. First, the ANOVA based on the depression scores is explored, followed by the ones based on anxiety, and finally, the ones based on stress levels. Depression levels were associated with significantly different levels of impulsivity (i.e., negative urgency, lack of perseverance and sensation seeking) and problematic gaming (i.e., total score, preoccupation, overuse, social isolation, interpersonal conflicts, and withdrawal). Overall, these associations showed that with a higher level of depression came a higher level of impulsivity or more problematic gaming. The opposite trend of results was shown for the sensation seeking scores which were lower when the participants exhibited signs of depression. For more details on these analyses, see Table 8.4.

Table 8.4. ANOVA on the impulsivity and problematic gaming based on the depression levels

	Normal level (i)	Mild level (j)	Moderate level (k)	(i-j) *p*-value	(i-k) *p*-value	(j-k) *p*-value
Negative urgency**	9.21	10.33	10.84	.076	.011	1.000
Lack of perseverance***	7.56	8.92	9.47	<.001	<.001	.787
Sensation seeking**	10.91	9.86	9.32	.041	.003	1.000
POGQ total score***	33.68	37.55	42.79	.214	<.001	.199
Preoccupation**	4.50	5.10	5.67	.261	.007	.685
Overuse**	5.15	6.31	7.04	.086	.003	.894
Social isolation***	4.14	4.24	5.88	1.000	<.001	.003
Interpersonal conflicts**	2.93	3.14	4.17	1.000	.006	.103
Withdrawal**	6.31	7.24	8.71	.343	.001	.185

Note. *p<.05, **p<.01, ***p<.001

Anxiety levels were also associated with significant different levels of impulsivity (i.e., positive urgency, negative urgency, lack of perseverance, and sensation seeking) and problematic gaming (i.e., total score, overuse, and withdrawal). Overall, these associations showed that with a higher level of anxiety the higher the level of impulsivity and increased problematic gaming. The opposite trend was shown for the sensation seeking scores. For more details on these analyses, see Table 8.5. Stress levels led to significant different levels of impulsivity (i.e. negative urgency and sensation seeking) and problematic gaming (i.e., total score, interpersonal conflicts, and withdrawal). Overall, these associations showed that with a higher level of anxiety came a higher level of impulsivity or increased problematic gaming. For more details on these analyses, see Table 8.6.

Table 8.5. ANOVA on the impulsivity and problematic gaming based on the anxiety levels

	Normal level (i)	Mild level (j)	Moderate level (k)	Severe level (l)	(i-j) *p*-value	(i-k) *p*-value	(i-l) *p*-value	(j-k) *p*-value	(j-l) *p*-value	(l-k) *p*-value
Negative urgency **	8.00	9.15	9.69	10.54	.474	.044	.003	1.000	.066	.582
Positive urgency **	9.00	10.29	10.32	11.00	.048	.028	.001	1.000	.468	.431
Lack of perseverance **	7.00	7.39	8.21	8.63	1.000	.050	.012	.037	.011	1.000
Sensation seeking ***	11.39	11.32	10.46	9.29	1.000	.488	.004	.082	< .001	.040
POGQ total score **	30.33	33.10	36.64	41.68	1.000	.127	.004	.357	.008	.272
Overuse *	4.28	5.25	5.80	6.68	.973	.142	.019	1.000	.165	.913
Withdrawal **	5.50	6.31	6.80	8.91	1.000	.490	.001	1.000	.002	.014

Note. *p<.05, **p<.01, ***p<.001

Table 8.6. ANOVA on the impulsivity and problematic gaming based on the stress levels

	Normal level (i)	Mild level (j)	Moderate level (k)	Severe level (l)	(i-j) *p*-value	(i-k) *p*-value	(i-l) *p*-value	(j-k) *p*-value	(j-l) *p*-value	(l-k) *p*-value
Negative urgency ***	7.90	8.84	10.79	11.23	.365	<.001	<.001	<.001	.005	1.000
Sensation seeking **	10.88	10.96	10.29	8.73	1.000	1.000	.014	.287	.003	.088
POGQ total score **	30.41	35.18	37.42	41.92	.204	.014	.005	1.000	.201	.939
Interpersonal conflicts *	2.38	3.18	3.30	4.00	.201	.101	.032	1.000	.761	1.000
Withdrawal ***	5.34	6.63	7.30	9.00	.208	.010	.001	1.000	.036	.292

Note. * $p<.05$, ** $p<.01$, *** $p<.001$

8.4. Impulsivity

The s-UPPS-P comprises five subscales exploring impulsivity within a non-clinical population (i.e., positive and negative urgency, lack of perseverance, lack of premeditation, and sensation seeking). Compared to the DASS-21, there is no official cut-off score to determine high levels of impulsivity compared to lower levels, which only allows correlational analyses to be used. Table 8.7 includes the descriptive statistics for all the subscales of the UPPS-P.

Table 8.7. Descriptive statistics of the UPPS-P

	Minimum	Maximum	Mean	SD
Negative urgency	4	16	9.58	3.27
Positive urgency	4	16	10.29	2.40
Global urgency	4	16	9.94	2.46
Lack of premeditation	4	14	7.41	2.27
Lack of perseverance	4	15	7.98	2.39
Sensation seeking	4	16	10.55	2.80

First, correlations within the UPPS-P variables were explored and showed that both the urgency scores, lack of premeditation, and lack of perseverance highly correlated with each other, even after the Benjamin-Hochberg correction. However, sensation seeking, a more motivational measure, did not correlate at all with negative urgency and lack of premeditation, and only correlated with positive urgency and lack of perseverance after the correction. See Table 8.8 for the details. The other correlations observed were run with the POGQ measures. The correlations show associations between positive urgency and the measures of problematic gaming; the other measures of impulsivity either not correlating post-correction or only showing a few correlations. Table 8.9 includes the detailed correlations.

Table 8.8. Correlations between the UPPS-P variables

	Positive urgency	Global urgency	Lack of premeditation	Lack of perseverance	Sensation seeking
Negative urgency	.490*	.905*	.435*	.169*	-.071
Positive urgency		.815*	.407*	.179*	.284*
Global urgency			.488*	.200*	.092
Lack of premeditation				.449*	.023
Lack of perseverance					-.247*

Note. [a]Significant pre-correction, *significant post-correction.

Table 8.9. Correlations between the UPPS-P and the POGQ variables

	Negative urgency	Positive urgency	Global urgency	Lack of premeditation	Lack of perseverance	Sensation seeking
POGQ total score	.238*	.352*	.336*	.100	.243*	-.079
Preoccupation	.161[a]	.225*	.221*	.152[a]	.224*	-.171[a]
Overuse	.217*	.313*	.303*	.086	.135	.028
Immersion	.115	.335*	.246*	.031	.178[a]	.085
Social isolation	.178[a]	.215*	.227*	.112	.343*	-.206*
Interpersonal conflicts	.200*	.151[a]	.210*	.020	.037	-.046
Withdrawal	.209*	.251*	.266*	.078	.185[a]	-.155[a]

Note. [a]Significant pre-correction, *significant post-correction.

8.5. Gaming

Introduction

This section is separated into three main parts: (i) Regression on hours spent gaming weekly, (ii) *t*-test based on the Internet Gaming Disorder (IGD) criteria (i.e., healthy vs. disordered), and (iii) *t*-test based on gaming habits (i.e., gamers vs. non-gamers). As mentioned in the Participants section, 170 of the participants considered themselves gamers and played on average 13.89 hours per week. Of these 170 gamers, 26 met the IGD criteria (i.e., presenting five or more of the symptoms). To avoid comparing the 26 IGD participants to the 144 remaining healthy gamers, it was decided to handpick 26 healthy gamers matching IGD participants in terms of age, gender, and level of education. In some cases, a perfect match could not be found (e.g., a 20-year-old male IGD and a 20-year-old female healthy gamer) due to these data not existing. Even though some adaptations had to be made, the two groups did not differ in level of education ($t[50]=1.12$, $p=.270$), gender ($t[50]=.00$, $p=1.000$), or age ($t[50]=-.03$, $p=.976$).

Regression

One important variable of interest in this thesis is the amount of time spent gaming per week. In this section, the variables affecting this association were explored first through a correlational analysis, and the significant ones (i.e., post-correction) were included in a regression analysis. Among the personality questionnaires (DASS-21, s-UPPS-P), only the depression levels and lack of perseverance significantly correlated with weekly gaming post-correction; lack of premeditation, sensation seeking, and anxiety levels being significant pre-correction. Regarding the problematic or disordered gaming variables, all the measures of the POGQ except immersion and overuse, as well as the IGD criteria, significantly correlated with weekly gaming post-correction. Overuse was significant pre-correction. Therefore, all these variables were included in the regression analyses. The model was significant overall and explained 20.40% of the variance, r = .452, $p<.001$. Within this regression model, only the preoccupation subscale of the POGQ was significantly associated with weekly hours ($p=.005$). The coefficients and *p*-values of all the variables can be found in Table 8.10.

Table 8.10. Regression coefficients on weekly hours spent gaming

	Beta	*t*	*p*-value
Depression	.148	1.327	.138
Lack of perseverance	.010	.105	.916
Preoccupation	.270	2.837	.005
Social isolation	.032	.318	.751
Interpersonal conflicts	-.037	-.370	.712
Withdrawal	.026	.247	.805
IGD criteria	.148	1.327	.187

IGD criteria t-test

As aforementioned, 26 IGD participants were compared to 26 healthy gamers matched in terms of age, gender, and level of education. The 52 participants were included in *t*-test analyses on the DASS-21, POGQ, and UPPS-P variables. The results were systematically significant except for stress levels and the immersion subscale of the POGQ. For more details, see the Table 8.11 which includes the means of both groups and the statistical data.

Table 8.11. *t*-test based on the IGD criteria cut-off score

	Healthy gamers mean	IGD mean	*t*(46)	*p*-value
Preoccupation	4.69	6.27	3.517	.001
Overuse	5.77	9.00	4.659	<.001
Social isolation	4.42	6.69	4.634	<.001
Interpersonal conflicts	3.12	5.23	3.920	<.001
Withdrawal	6.38	10.35	5.338	<.001
Negative urgency	8.85	11.31	2.942	.005
Positive urgency	9.04	11.54	3.988	<.001
Lack of premeditation	6.50	8.38	2.799	.007
Lack of perseverance	8.08	10.12	3.103	.003
Anxiety	10.77	13.12	2.520	.015
Depression	12.62	17.35	4.103	<.001

Gamers and non-gamers

The 170 gamers from the sample were compared to the 173 non-gamers on the survey questionnaires non-related to gaming, since the non-gamers could not complete the gaming questionnaires. The results showed that the gamers had a higher level of depression but lower levels of negative urgency, positive urgency, and global urgency than the non-gamers. The full results are shown in Table 8.12.

Table 8.12. *t*-test on the gaming habits

	Gamers	Non-gamers	*t*(243)	*p*-value
Depression	12.94	11.82	2.256	.025
Negative urgency	9.12	10.05	-2.652	.008
Positive urgency	9.94	10.64	-.2737	.007
Global urgency	9.53	10.34	-3.112	.002

In addition to comparing the survey results between the gamers and non-gamers, the two common tasks between all of the experiments (i.e., DST and ANT-R) were also analysed. Only the 229 participants (38 males, 20.71 years old, SD = 4.32) who took part in the laboratory experiments were included. Seventy-five of these participants reported playing videogames for an average of 10.53 hours per week (SD = 8.44), 28 of these being males. When comparing the gamers and non-gamers on the different DST variables using a *t*-test, there was no significant difference for the number of digits repeated forward ($t[223]=-.73$, $p=.468$) and backward ($t[223]=-1.11$, $p=.268$) or the difference between these two score ($t[223]=.30$, $p=.769$) or the multiplicative score ($t[223]=.31$, $p=.759$).

However, the analyses run on the ANT-R yielded significant results on the reaction times (RTs) which are displayed in Table 8.13. Globally, the gamers were faster than the non-gamers in all the conditions. To verify whether it was due to an improved attentional focus rather than a faster processing speed, four extra variables were calculated. The first one was to measure the effect of the multiple arrows, were the participants' RT when confronted with a single arrow was subtracted from the multiple arrows' RT. The second one was to measure the effect of congruence, where the RT when seeing congruent arrows (i.e., all directed the same way) was subtracted to the RT when seeing incongruent arrows (i.e., flanking arrows oriented differently than the target one). The final two explored the effect of informative cueing, where the RT from an informative cue (i.e., indicating where the arrows were going to appear) were subtracted from the non-informative cues (i.e., either appearing both above and below, or appearing in the middle of the screen). When comparing these variables between the gamers and non-gamers, the effect of flanking (i.e., multiple arrows), congruence, and middle-cueing (i.e., cue appearing at the same position than the cross) were far from being significant (i.e., respectively t=1.40, p=.162; t=.60, p=.551; and t=1.29, p=.200 – df=227) while the effect of having two cues was almost significant (t[227]=1.88, p=.062). In the case of dual-cueing, it appears that the gamers lost less time (30.33ms) compared to the non-gamers (36.51ms), but a difference of about 30ms would be negligible even if it was significant.

Table 8.13. *t*-test on the ANT-R between the gamers and non-gamers

	Non-gamer	Gamer	$t(227)$	p-value
Mean RT	452.00	430.31	2.628	.009
Single arrow RT	427.17	407.81	2.550	.011
Multiple arrows RT	478.37	454.18	2.626	.009
Multiple congruent arrows RT	452.44	429.15	2.665	.008
Multiple incongruent arrows RT	507.19	481.68	2.575	.011
Informative cue[1] RT	435.04	416.10	2.273	.024
Dual cue[2] RT	467.19	443.23	2.821	.005
Central cue[3] RT	471.55	446.43	2.884	.004

Note. [1]Single cue appearing either below or above the fixation cross; [2]Two cues appearing both below and above the fixation cross; [3]Cue appearing at the same location than the fixation cross.

8.6. Demographic data

The demographic data (i.e., the age, gender, and level of education) were explored through three different types of analysis. First, age being a continuous variable, its association with the different psychometric scales were explored using correlational analysis. Second, as gender is a dichotomous variable, a *t*-test was used. Finally, educational level was explored using an ANOVA due to its ordinal aspect.

The correlations between age and the different variables explored within the survey showed six significant correlations prior to any correction applied for measures of the s-UPPS-P and anxiety levels. After the Benjamin-Hochberg correction, only the correlations with the s-UPPS-P remained significant at $p<.05$. Age correlated significantly with negative urgency (r = -.196), positive urgency (r = -.223), global urgency (r = -.239), and lack of premeditation (r = -.168). Concerning the *t*-test based on gender, several comparisons were significant and shown in Table 8.14.

Table 8.14. *t*-tests on the survey variables between the males and females

	Males	Females	*t*(243)	*p*-value
Anxiety	10.41	11.60	3.127	.002
Stress	12.81	13.80	2.149	.032
Negative urgency	8.64	10.04	3.947	<.001
Positive urgency	9.56	10.64	3.991	< .001
Global urgency	9.10	10.34	4.762	< .001
Lack of premeditation	6.97	7.62	2.496	.013

Note. [1]Single cue appearing either below or above the fixation cross; [2]Two cues appearing both below and above the fixation cross; [3]Cue appearing at the same location than the fixation cross.

Finally, the last set of analyses explored the effect of education level on the other survey variables. First, all the participants who replied “other” when asked about their education level were not included in these analyses, as nothing was known on their actual education level. In this sample, 53 of the participants had a secondary school degree, 178 a college level, 56 had a Bachelor’s degree, 21 a Master’s degree, and eight a PhD or equivalent. Since only eight participants indicated having a PhD, they were not included in the ANOVA analysis[4]. Several comparisons were significant (e.g., stress levels, negative urgency, and immersion), but prior to observing these results a modification was brought upon the sample. Indeed, participants with completed secondary school and college levels shared similar scores as testified by the systematically very high *p*-value (i.e., p=1.000

[4] The reason these data have been excluded rather than merged with the Master’s as a “postgraduate” group is due to the older age of the Ph.D. participants.

systematically). The same kind of observation was true for the difference between Bachelor's and Master's degree, the *p*-value being very high as well. For this reason, instead of an ANOVA on these scores, the secondary and college levels were united in pre-university and Bachelor's and Master's degree in university. Based on these two groups, *t*-tests were run on all the variables again, the significant results being included in Table 8.15.

Table 8.15. *t*-test on the self-reported measures between the pre-university and post-university education levels.

	Pre-university	University	*df*	*t*	*p*-value
Anxiety	11.60	10.49	306	2.345	.020
Negative urgency	10.02	8.70	306	3.087	.002
Positive urgency	10.63	9.61	306	3.289	.001
Global urgency	10.32	9.16	306	3.659	<.001
Lack of premeditation	7.65	6.97	306	2.242	.026
Total score POGQ	37.34	33.13	147	2.442	.016
Overuse	6.04	4.98	147	2.457	.015
Immersion	11.54	9.93	117	2.794	.006

8.7. Discussion

DASS-21 scores were closely related to the s-UPPS-P scores as hypothesized, although lack of premeditation did not show any association with the DASS-21 subscales and positive urgency only exhibited one significant correlation with stress levels. POGQ measures mainly correlated with the depression and anxiety measures, with stress also showing significant correlations, including one with the total POGQ score. The only measure of the POGQ not significantly correlated with any of the DASS-21 measures was immersion, which indicates that a high immersion score would not necessarily be negative or lead to negative affect.

Interestingly, the DASS-21 cut-off score determining different levels of psychopathological symptoms (i.e., normal, mild, moderate, severe, and extremely severe) allowed deeper analyses of the association between these symptoms and impulsivity and gaming disorder. First, in the case of depression, most of the differences observed occurred when comparing normal levels of depression to moderate levels (i.e., the two extreme groups within this sample). These differences indicated that a higher level of depression was associated with a higher level of urgency (i.e., negative urgency and lack of perseverance), and overall problematic gaming symptoms as well as subcomponents (i.e., preoccupation, overuse, social isolation, and interpersonal conflicts). Concerning the sensation seeking component of impulsivity, the opposite trend was observed with a lower score associated with higher levels of depression.

Concerning anxiety and stress, the interpretation is slightly more complex due to the higher number of groups present within the sample. Despite this fact, the results can be compared to the previous ones because the differences mainly occurred when comparing two notably different groups (i.e., normal level vs. moderate level, moderate level vs. severe level, and normal level vs. severe level). These results showed that for higher levels of anxiety, the participants exhibited more impulsive behaviours (i.e., negative and positive urgency, and lack of perseverance) as well as higher total problematic gaming and its subcomponents (i.e., overuse and withdrawal) scores. Higher stress levels were associated with higher level of negative urgency and problematic gaming (i.e., total score and interpersonal conflicts and withdrawal subscales). Similar to the depression scores, higher levels of anxiety and stress were associated with lower levels of sensation seeking. This opposite association reflects the motivational aspect of this component compared to the other factors of the UPPS-P model which refers to self-control (Billieux et al., 2014; d'Acremont & Van der Linden, 2007).

Interestingly, the only facet of the problematic online gaming not associated with the depression, anxiety, and stress scores was the immersion variable. Although it was globally expected that higher levels of problematic gaming would be observed with these three variables, the lack of difference for immersion fits the previous literature indicating that this variable is an indicator of passion rather than an addiction (e.g., Charlton & Danforth, 2007; Deleuze, Long, Liu, Maurage, & Billieux, 2018). Indeed, immersion (i.e., being an integrative part of the game) can be seen as both a coping mechanism (i.e., playing to avoid everyday life hassles) or a healthy motivation to play videogames (i.e., wanting to be part of the game to experience the game universe).

Concerning the s-UPPS-P, it was first shown that while urgency (i.e., both positive, negative, and global), lack of premeditation, and lack of perseverance highly correlated with each other, sensation seeking did not correlate with these measures as much. This is probably due to sensation seeking being a motivational measure compared to the other measures of the UPPS-P being related to self-control. When exploring the associations between the s-UPPS-P and the POGQ, it appeared that the two main measures correlating with the POGQ were the urgency measures and lack of perseverance, lack of premeditation not correlating at all with any of the POGQ measures and sensation seeking only correlating negatively with social isolation.

The exploration of gaming was done in three ways. First, a multiple linear regression was performed to find the best predictors of the weekly hours spent gaming, including multiple variables which significantly correlated (i.e., post-correction) with time spent gaming. The regression significantly explained 20.40% of the variance, preoccupation being the only significant predictor. Second, the different variables from the survey were compared based on IGD criteria, where 26 IGD participants were compared to 26 healthy gamers matched in terms of age, gender, and education levels. When comparing these two groups, the IGD participants scored significantly higher on most of the POGQ variables with the exception of immersion, which again appears to indicate that immersion tendencies are not related to a disorder or problematic use. Furthermore, the IGD participants also exhibited a significant difference with the s-UPPS-P measures and both anxiety and depression. The final analysis simply compared gamers and the non-gamers on the survey measures, only showing a difference in terms of depression, positive urgency, negative urgency and global urgency. Interestingly, while the IGD participants exhibited higher levels of urgency, the gamers showed lower levels of urgency when compared to non-gamers.

When observing the effect of gaming on the task performed during the laboratory experiments, it appeared that there was no effect on any of the calculated DST variables. However, it appeared that the gamers were systematically and significantly faster than the non-gamers on the ANT-R which would result from an improved processing speed rather than an enhanced attentional focus (whether top-down, spatial, or bottom-up). Indeed, when analysing the differences between the conditions to observe how increased difficulty would affect the participants' RT, no significant difference was observed between the gamers and non-gamers. This indicates that none of the conditions affected the non-gamers more than the gamers, and that the faster RT of the gamers has nothing to do with attention.

Chapter 9: Discussion of key findings

9.1. Chapter overview

The principal aim of this thesis was to explore the potential underlying mechanisms of the time loss effect (i.e., underestimation of time spent on an activity) observed among gamers. For this purpose, eight chapters were written, first exploring the theoretical explanations behind time loss, and then describing the experiments performed to explore these theories. The first theoretical chapter explored time perception and the variables affecting it, the second chapter the cognitive skills affected by gaming (i.e., whether positively or negatively), and the third one explored how time perception and gaming may be related.

Regarding the results chapters, the first experiment explored a new model of time perception, the Dual Process Contingency Model (DPCM), which would have been the basis of this thesis. Afterwards, the second and third experiments studied both the baseline time perception of gamers and how this time perception may be affected by attentional skills and emotional affect. Finally, the eighth chapter explored the common data between the three experiments (i.e., Attention Network Task – Revised [ANT-R] and Digit Span Test [DST]) as well as the survey data completed by the experiments' participants as well as additional participants recruited on gaming forums.

This chapter, the final discussion, first summarizes the key points highlighted in the theoretical chapters and then the key findings from the three experiments. Afterward, the limitations from the methodology and the materials will be discussed before the implications and the contribution to knowledge of this thesis. Finally, this chapter will be concluded with the final remarks.

9.2. Summary of the theoretical chapters

The first chapter of this thesis defined time perception, which is basically the ability to estimate a time duration. According to the theory, time perception is currently divided into two separate paradigms, namely retrospective time perception (RTP) and prospective time perception (PTP) (Levin & Zakay, 1989). The first one is unconscious and post-hoc, a participant estimating a duration *a posteriori* without any prior warning of time estimation. The second one is ad-hoc, the participants being warned that they will have to estimate a duration prior to the interval to evaluate. Due to their different natures, it has been postulated that they would rely on different cognitive skills (Block & Zakay, 1997).

Due to its unconscious nature, RTP appears to be more fitting for models based on the memory and the way memories are stocked. According to the Contextual-Change Model (CCM; Block & Reed, 1978), a retrospective estimation would be based on the events (i.e., contextual changes) happening in the interval evaluated. This theory postulated that the more changes can be observed in a time interval, the longer it will be estimated retrospectively. Regarding the PTP, it is better explained by models based on a timer and attentional resources such as the Attentional-Gate Model (Zakay & Block, 1995). This model postulates a central mechanism (i.e., the pacemaker) emitting a regular pulse which is gathered in the accumulator before being compared to previously memorized durations. Two other parts of the model regulate the pulse flow, first a switch operating in an on/off design (i.e., open when measuring time, closed otherwise) and second a gate which opens more or less based on attention (i.e., the more attention brought upon time, the more it is open).

To identify the potential variables affecting an individual's time perception, an extensive literature search has been performed on four different databases (e.g., *Google Scholar*, *PubMed*) using terms specific to the field of time perception as well as potential variables which could affect it (e.g., "executive function", emotion). After deleting the papers not fitting the different inclusion/exclusion criteria, two main sections were extracted, namely "emotional interference" and "time perception and cognition". For more details on the paper search method, see 'Section 1.4. General Method'.

Emotional interference was studied through the scope of different stimuli (i.e., emotional expressions, visual stimuli, and auditory stimuli). The visual stimuli lasting between 200 and 1600ms appeared to lead to an arousal effect which increased the pulse rate, leading to an overestimation of time (e.g., Fayolle et al., 2014; Gil & Droit-Volet, 2012). On the other hand, shorter or longer visual stimuli led to a shortening effect due to respectively an attention effect (Smith et al., 2011) and a fight or flight effect (Angrilli et al., 1997). The attentional effect would be due to the stimuli being recognized as "threatening" and being processed faster to allow a proper reaction. The fight-or-flight effect indicated that attention would be diverted from threatening stimuli for longer durations which would result in more attention brought on time and an elongation of estimation. On the other hand, if the stimulus is pleasant, it will drag the attentional resources, limiting the attention remaining on time, hence the underestimation. The case of emotional expression is simpler to interpret, as it systematically led to an overestimation of duration (e.g., Droit-Volet et al., 2004; Lee et al., 2011), with the dynamism of the stimuli (i.e., static vs. animated pictures) enhancing this effect (e.g., Fayolle & Droit-Volet, 2014) and an averted gaze nullifying it (e.g., Doi & Shinohara, 2009). The last type of stimuli explored were auditory (e.g., a music or a sound) and led to both underestimation and overestimation of duration. However, due to the lack of studies on that specific field, no conclusion could be reached.

Concerning the effect of cognition on time perception, the results are mostly clear and were discussed in four different sections (i.e., coding simplicity, cognitive load, attention, and executive functions). Affecting only the RTP due to its effect on memory, it appears that a more complex coding of a stimulus will lead to an overestimation of duration (Macar, 1996; Ornstein, 1969). On the contrary, cognitive load (i.e., the amount of cognitive resources required to achieve a task) appears to solely affect conscious time perception, due to the importance of attention in PTP. The results showed that when the task was more complicated, the participants tended to underestimate duration (Baldauf et al., 2009; Marshall & Wilsoncroft, 1989). This previous effect appears to be attentional, the participants focusing more on the complicated task, which would reduce attention brought on time. This hypothesis was corroborated by studies showing that participants underestimate time in a dual-task paradigm (Burle & Casini, 2001; Macar et al., 1994). These dual-task studies also pointed out that time perception may be an executive function, as the participants exhibited a bidirectional interference when performing a task evaluating an executive function at the same time as a temporal task (Brown et al., 2013; Brown & Perreault, 2017).

The second chapter of this thesis explored how gaming, whether disordered or healthy, could affect cognition both positively and negatively. First, gaming disorder was briefly discussed, mentioning the inclusion of Internet Gaming Disorder in the fifth edition of the *Diagnostic and Statistical Manual of Mental Disorders* (DSM-5; American Psychiatric Association, 2013) and the inclusion of

Gaming Disorder (terminology used within this thesis) in the 11th revision of the International Classification of Diseases (ICD-11; World Health Organization, 2018). Despite the variety of videogames and their associated structural characteristics, the research mainly focused on Massively Multiplayer Online Role-Playing Games (MMORPG) when studying gaming disorder and First-Person Shooter (FPS) games when exploring the cognitive improvement among gamers. Globally plaid videogame genres such as the Multiplayer Online Battle Arena (MOBA) or Real-Time Strategy (RTS) games were not considered previously. To observe which cognitive skills have been explored among gamers, the same method as the previous chapter was used for the literature search, with the exception of the keywords used (e.g., videogame, decision-making). The results of this search, after the exclusion of non-fitting papers, led to two main sections exploring the positive and negative impact of gaming on cognition. For more details on this method, see ‘Section 2.3. General method’.

All the studies in the section on the positive impact of gaming included healthy gamers. The first positive impact of gaming discussed was the task-switching skill which is the ability to switch between two different tasks over a same stimulus without losing in terms of speed and accuracy (Miyake, 2000). What has been found is that the gamers had superior switching abilities compared to non-gamers, especially when the participants were cued before the switching (Colzato, 2010; Green et al., 2012). The improved switching abilities exhibited by gamers could result from the numerous different “inputs” required in videogames (e.g., reloading a weapon, capturing a base, shooting enemies). Interestingly, it appeared that RTS games were associated with higher levels of cognitive flexibility (i.e., ability to switch between different tasks) compared to FPS games (Dobrowolski et al., 2015). This would make sense, as RTS games often require the gamer to switch between several crucial tasks in order to win a game (e.g., commanding a group of units, constructing a building, and building new units). As indicated by the cueing effect (i.e., improved flexibility amongst gamers following a cue; Karle et al., 2010), it is possible that gamers would exhibit a better attentional focus compared to non-gamers which tends to be supported by attentional studies (e.g., Cain & Mitroff, 2011; Chisholm et al., 2010; Mishra et al., 2011).

The studies on attention based their thoughts on three different models of attention, namely the Attentional Network Task (ANT; Fan et al., 2002), the Theory of Visual Attention (TVA; Bundesen, 1990), and the bottom-up/top-down split of attention (Desimone & Duncan, 1995). Although these models differ in their interpretation of attention, they all split attention into a controlled process (i.e., top-down, control of the attention by the individual) or uncontrolled process (i.e., bottom-up, attention being captured by the salient stimuli). The results in this section mainly indicated improved processing speed (i.e., faster reaction-time [RT]; Cain & Mitroff, 2011; Castel et al., 2005), improved top-down attention (i.e., controlled allocation of attention; Cain et al., 2014; Chisholm et al., 2010), and a couple of studies showed improved bottom-up attention (Cain & Mitroff, 2011; Mishra et al., 2011). Enhanced top-down attention could be linked to the constant focus required while playing action games, the slightest lapse of attention potentially leading to a death in-game. Potentially improved bottom-up attention could be related to the stimuli randomly appearing in videogames which requires the gamers to react promptly (e.g., enemy appearing, and important items). Finally, it appeared that gamers had better sub-second time perception, which is mainly related to reflexes, even though more research would be required (Donohue et al., 2010).

The second part of this chapter examined the negative impact of gaming on cognition, which was only observed with disordered gamers. First, basing their thoughts on loss of control (i.e., the inability to not play videogames) research has been conducted on the association between gaming disorder and inhibition. The results of the different studies on this topic contrasted, some showing an impairment (Ko et al., 2015; Littel et al., 2012) while others showed no such results (Chen et al., 2015; Colzato et al., 2013). The lead explanation for such contrasting results lies within emotion. Indeed, Ko et al. (2015) as well as Liu et al. (2014) showed that the gamers' inhibition would worsen when confronted with gaming pictures. These results indicate that an emotional state induced by gaming pictures among disordered gamers interferes with their cognitive skills. Finally, the last cognitive skill explored was decision-making which can be split into three categories (i.e., risky decision-making, decision-making with learning process, and delay discounting). The studies on this topic systematically showed that gamers exhibited impaired risky decision-making (Pawlikowski & Brand, 2011; Wang et al., 2016), that is a difficulty to make a cautious decision in a risky situation (e.g., preferring 50% chance of winning £10 instead of 100% chance of winning £7). Furthermore, the gamers also discounted their rewards more steeply (Nuyens et al., 2016; Yao, Chen, et al., 2015), that is they preferred smaller immediate rewards over larger delayed rewards (e.g., preferring £5 now rather than £10 in a week). Importantly, only one study showed significant results with a task requiring the participants to learn the rules of the task (Nuyens et al., 2016). Interestingly, this study showed impaired decision-making only after the gamers understood the rules of the task (i.e., the risk of the decision) which indicates that their impairment lied within risky decision-making, confirming the prior results.

The third chapter of this thesis was a bridge between the two first chapters, exploring how time perception and gaming are related. The objective of the chapter was to guide the research conducted within this thesis. The variables potentially explaining the time loss effect observed among gamers were explored within this thesis as much as possible within a thesis timeframe. A first common point between time perception and gaming is attention which is mainly important within PTP (i.e., through the AGM; Zakay & Block, 1995). First, it appears that gamers exhibited both a better top-down and bottom-up attention. Interestingly, having a better attentional focus should lead to better conscious time perception, as the individual should be able to better focus on time. Similarly, working memory, an important aspect of time perception (i.e., when comparing the current duration estimation with previously stored interval durations; Zakay & Block, 1995) appears to be improved among the gamers, mainly regarding the visual sketchpad (Lau-Zhu et al., 2017; Seya & Shinoda, 2016). These two points appear to indicate that not only should gamers not exhibit impaired PTP, but they should actually show the opposite trend (i.e., an improved conscious time perception) which does not fit the observed time loss effect in two ways. First, time loss supposes an impaired time perception rather than an improved one. Second, it is unlikely that the gamers consciously try to perceive time while gaming, they would indeed try to estimate their session duration a posteriori. These two points indicated that the time perception implicated in the time loss effect would be the RTP.

When exploring which aspect could affect the gamers' time perception, emotion stood out. First, gamers exhibit a stronger brain reactivity when confronted with gaming stimuli compared to non-gamers (Ahn et al., 2015; Zhang et al., 2016), which makes sense as non-gamers should not react strongly to gaming stimuli. Nonetheless, it appeared that disordered gamers reacted even more strongly than healthy gamers (Ko et al., 2013; Thalemann et al., 2007). Concerning time perception, although the section on emotion showed that some emotional stimuli (i.e., sound, music, emotional expression) would lead to overestimation of duration (i.e., opposite effect than time loss), an underestimation effect was achieved in some cases (i.e., for longer duration with emotional pictures; Smith et al., 2011). In addition, studies exploring the effect of enjoyment showed that it could lead to an underestimation of time (Campbell & Bryant, 2007; Gable & Poole, 2012), which would fit the time loss effect (i.e., gamers having fun would underestimate the session duration). Interestingly, as disordered gamers exhibit stronger reaction than healthy gamers it could be hypothesized that the effect of videogames on their time perception would be stronger than for healthy gamers, explaining the extreme time loss effect observed. However, it is important to note that the interference of emotion on time perception can be managed through emotion regulation. For example, in the case of time perception, when experimenters virtually increased the perceived level of control over negative stimuli, the overestimation caused by these stimuli disappeared (Buetti & Lleras, 2012; Mereu & Lleras, 2013). This is of interest when considering that while videogames can be used to regulate emotion (Villani et al., 2018) and have been used as a therapeutic tool (Kuosmanen, Fleming, Newell, & Barry, 2017), it appears that in the case of gaming disorder, this regulation would be disrupted (Seo et al., 2012; Wichstrøm et al., 2018). Therefore, while healthy gamers would exhibit a normal reactivity to gaming stimuli and would be able to regulate it, disordered gamers would exhibit a stronger reactivity which they could not properly regulate. This interaction between emotion, time perception, and emotion regulation could explain the time loss effect observed among gamers, whether healthy or disordered.

A final consideration within the interaction between gaming and time perception is flow state (i.e., the loss of self-awareness when fully focused on a task where the level of difficulty matches the individual's skills; Csíkszentmihályi, 1975). Indeed, according to Zakay (2014), flow is on a continuum with boredom, the first one leading to underestimation while the second one would lead to overestimation. While the overestimation effect created by boredom has been certified by several studies (Danckert & Allman, 2005; Watt, 1991), the direct effect of flow on time perception lacks studies. Nonetheless, when considering that a flow state would lead to underestimation of time due to the full attentional pool being requested by the task at hand, numerous studies support an underestimation linked to a flow state (Burle & Casini, 2001; Macar et al., 1994). According to these studies, attention diverted from time due to the task at hand would lead to the attentional gate closing (Zakay & Block, 1995), resulting in less pulses accumulated and compared, hence the underestimation.

Concerning the methodology chapter, it started by stating that this thesis is in line with the positive pragmatism philosophical assumption due to its quantitative approach of research. The quantitative approach has been preferred due to the continuous aspects of the main variable of this thesis (i.e., temporal estimation). Regarding the temporal estimation, or time perception, several tasks exist measuring this phenomenon (e.g., reproduction task, and comparison task). Several were excluded as they did not fit retrospective time perception (i.e., production, generalization, and bisection tasks), or simply allowed single testing in RTP (i.e., reproduction task and comparison task). Consequently, the only viable option to allow multiple testing in a retrospective setting was the estimation task (i.e., presenting a duration to participants and asking him to evaluate it). The second most important variable in this thesis was gaming disorder. The primary objective of this thesis was to compare gamers and non-gamers, which does not need any questionnaire. However, this thesis was also the opportunity to test how gaming disorder may impact time perception. For this purpose, two approaches have been selected based on the work from King et al. (2013) which identified 19 scales measuring gaming disorder associated with 16 different facets of this variable (e.g., preoccupation, and deception). Based on these thoughts, this thesis used two different gaming disorder scales to cover 13 of the 16 aforementioned criteria of gaming disorder: the IGD criteria (American Psychiatric Association, 2013) and the Problematic Online Gaming Disorder Questionnaire (POGQ; Demetrovics et al., 2012).

The other variables explored within this thesis were selected based on their interaction with both gaming and time perception. Basically, any personality trait or cognitive skill which was known to be affected by gaming and could impact the participants' time perception were controlled within this thesis either through a task or a questionnaire. First, as aforementioned, both working memory and attention are crucial within time perception and are known to be related to gaming. Therefore, two tasks assessing these concepts have been included in the experiments, namely the Attention Network Task–Revised (i.e., ANT-R; Fan et al., 2002) and the Digit Span Test (DST, measuring working memory; Weschler, 2008). The other variables measured within this thesis have not been mentioned in this section yet and will thus be discussed briefly. First, it is known that gaming disorder is associated with elevated levels of impulsivity (Billieux et al., 2011; Ko et al., 2017), despite the measures varying between the studies (e.g., Barratt Impulsiveness Scale–BIS, UPPS). It is noteworthy that higher impulsivity was associated with a faster cognitive tempo (i.e., faster pacemaker rate within the AGM, leading to overestimation; Zakay & Block, 1995) and that pathologies associated with higher impulsivity (e.g., Attention Deficit/Hyperactivity Disorder, borderline disorder) are associated with overestimation of time (Stanford & Barratt, 1996).

Like impulsivity, depression is a common comorbidity with gaming disorder even if it is unsure whether gaming disorder is the cause or consequence of depression disorder (Bargeron & Hormes, 2017; Männikkö et al., 2020). According to the longitudinal studies, it is likely that their relationship is a vicious circle because it appeared that a higher depression level leads to more severe gaming disorder, and that gaming disorder would in turn increase depression levels (Gentile et al., 2011).

Concerning time perception's relationship with depression, it appears that patients suffering from depression report that time is slowed down during depressive episodes, which tended to indicate impaired time perception associated with depression (e.g., Gallagher, 2012; Msetfi et al., 2012). However, it has been argued that these observations are related to time experience rather than time perception *per se* (Oberfeld et al., 2014; Thönes & Oberfeld, 2015). While time perception is the accurate estimation of a duration, time experience is the subjective feeling of time passing by. This concern arose from the inconsistent results on the interaction between time perception and depression, some studies showing that depressed participants tended to overestimate time (e.g., Biermann et al., 2011), other showing the opposing result (e.g., Gil & Droit-Volet, 2009), or failing to find any effect (e.g., Thönes & Oberfeld, 2015). It is possible that for longer durations than the ones tested (i.e., below one minute), time perception would be affected too due to impaired sustained and selective attention (Gualtieri et al., 2006) which is crucial within long duration estimation (Zakay & Block, 1995).

Finally, gaming disorder is associated with higher levels of stress and anxiety (Bargeron & Hormes, 2017; Wartberg et al., 2017), although no conclusion can be drawn concerning the direction of this associations (i.e., whether gaming disorder causes stress and anxiety or the opposite). However, several variables appear to alter the association between these two variables such as favourite game genre (Bonnaire & Baptista, 2019), the gamers' motivations to play games (Király et al., 2015), and mindfulness levels (Yu et al., 2018). This if of interest because anxiety and stress are known to negatively affect time perception, leading to systematic overestimation of time (Bagana & Raciu, 2012; Campbell & Bryant, 2007).

However, it is important to note that in the case of anxiety, lengthened time perception was observed among anxious individual when confronted with the object of their anxiety. For example, in the case of social anxiety, the participants overestimated the duration of angry or fearful faces compared to neutral faces (e.g., Yoo & Lee, 2015); or arachnophobe participants overestimated time when observing a spider (e.g., Buetti & Lleras, 2012). Importantly, this last study showed that perceived control over the situation played a crucial role in the interaction between anxiety and time perception because an increased sense of control inhibited the effect of anxiety on time perception (Buetti & Lleras, 2012).

Due to these reasons, these variables (i.e., working memory, attention, impulsivity, depression, anxiety, and stress) were controlled in all the experiments of this thesis, results which will be explained in detail in the section "9.4. Key experimental findings".

9.3. Implications and contribution to knowledge

Not gaming-related, the first experiment of this thesis aimed to validate a model of time perception which would have unified both the retrospective and prospective time perception in a single cognitive model. This model, created by Thomas and Weaver (1975), postulates that both time perception paradigms rely differently on two variables. The first one, attention, is based on the timer's model of time perception such as the AGM, where the more one thinks about time, the longer the interval will be estimated and vice-versa. According to the second variable, segmentation, the more contextual changes happen within an interval (e.g., 4 x 4 words from different semantic groups vs. 16 words from a same semantic group), the longer the interval would be estimated (i.e., based on the memory-based model of time perception such as the contextual-change model). According to these authors, while PTP would mainly relies on attention and timing mechanisms, being barely affected by segmentation levels, RTP relies on segmentation levels. Thomas and Weaver (1975) validated this model for extremely short duration (i.e., maximum 100ms), and later on this model was validated for longer durations (i.e., up to 15 seconds, Zakay 1993). However, since 1993 this model has never been tested, and remained solely validated for relatively short durations while this thesis aimed to explore longer durations. Indeed, the main point of this thesis was to explore the underlying mechanisms of the time loss effect (i.e., underestimation of time while playing) observed among gamers. Therefore, since a gaming session will systematically exceed minutes, even an hour, a model validated upon duration shorter than 15 seconds was not valid. This thesis thus aimed to revalidate this model with longer durations, which allowed the unification of both paradigms which were until then studied separately.

To understand this thesis' contribution to knowledge, previous studies exploring time perception among gamers need to be summarised. First, Rivero et al. (2012) explored time perception of gamers for durations up to 60s in a prospective setting, using both an estimation task and a production task. This study failed to find any result between frequent and occasional gamers in prospective time perception, but, as aforementioned, the gamers should only exhibit impaired retrospective time perception and not a prospective one. When it comes to retrospective time perception, three studies were conducted in this domain, most of these not showing any convincing results. First, Rau et al. (2006) compared experts and novice gamers on a famous videogame (i.e., *Diablo II*), making them play for 30, 60 or 90 minutes and asking them to estimate the duration of their gameplay. The authors did not find any significant results, which could be due to the method used, as the novice players were simply gamers who did not play *Diablo II* before. As a matter of fact, when comparing the percentage of internet-addicted participants within the two groups, the numbers were similar (i.e., 30% in the expert group and 35 in the novice one). And when one knows that gaming disorder is particularly prominent within internet addiction, it is highly possible that the "novice" gamers were actually normal gamers who just happened to play other games.

The next studies exploring RTP aimed to obtain several estimations from their participants (Woods and Griffiths, 2007). Importantly, instead of waiting until the end of the whole experimental session to ask the participants to estimate the three tested intervals (i.e., 13, 37, and 45 minutes), the authors required the participants to provide an estimation at the end of each interval. As a result, while the first tested duration was systematically estimated retrospectively, the two following durations were estimated prospectively. This fact could have greatly affected the non-significant results the authors got. Finally, the only study finding a significant difference in terms of temporal estimation was conducted on both RTP and PTP, although the authors did not separate their analyses for the two paradigms (Tobin & Grondin, 2009). The main findings from these authors are that gamers tend to underestimate time spending playing videogames compared to reading (for an eight-minute duration) and that regular gamers (i.e., more than seven hours per week) tended to underestimate a 24-minute session on a videogame compared to more occasional gamers (i.e., between one and six hours per week).

From observing the previous studies, a clear exploration of gamers' time perception was missing compared to non-gamers. Indeed, these studies compared different types of gamers (i.e., mostly regular and non-regular) which could limit their results. Another way these studies explored the effect of gaming on time perception is by comparing the estimation of gamers while doing a random activity compared to estimations of a gaming session. However, observing that gamers tend to underestimate the time spent gaming compared to reading does not mean that there is a time perception impairment among the gamers. It is possible that if the authors put non-gamers in front of a videogame for the first time, they would have underestimated time compared to reading a book as well. In conclusion, the first contribution to knowledge brought by this thesis is a clear comparison of gamers and non-gamers on exactly the same activities, to avoid any confounding variables.

Furthermore, this thesis was built on a strong rationale, beyond the fact that gamers tend to exhibit time loss (i.e., underestimating time spent gaming). This rationale led to the deletion of prospective time perception to solely focus on retrospective estimations, which appeared to be more adequate. As observed in the previous studies (i.e., Rau et al., 2006; Rivero et al., 2012; Tobin & Grondin, 2009; Wood et al., 2007), only one experiment properly explored retrospective time perception, yet the groups compared were inadequate, an issue which was corrected as aforementioned (i.e., comparison of gamers and non-gamers in this thesis). Also, this rationale led to the integration of two potential variables which would explain why gamers tend to exhibit time loss, instead of simply showing it. These two variables (i.e., attention and emotion) were never explored in previous studies observing gamers' time perception and constitute a major update in the field.

9.4. Key experimental findings

Before testing gamers' retrospective time perception, the first study aimed to validate a new model of time perception which would unify both retrospective and prospective time perception (i.e., the DPCM; Thomas & Weaver, 1975). This model is based on two main variables (i.e., segmentation and a timer) which affects both time paradigms (i.e., RTP and PTP) differently. Conscious time perception relies more on the timer while unconscious one is more affected by the segmentation variable. This model has first been validated with durations shorter than 100ms (Thomas & Weaver, 1975), then with durations between 12 and 15s (Zakay, 1993). Based on this, the rationale behind this study was to assert whether RTP and PTP were related within longer durations (i.e., longer than one minute), as testing only RTP among gamers would become irrelevant if that was the case. If that model was to be validated for longer durations, a triple interaction should be observed between the segmentation, timing, and time perception paradigm, which was the hypothesis behind this experiment.

To test time perception of participants, a non-temporal task was created, as the group of participants performing the estimation retrospectively had to remain "busy" for the same duration as the prospective group without knowing about the time perception aspect of the experiment. For this purpose, a Word Recalling Task (WRT) was created in which participants were presented random words in three blocks varying in terms of duration (i.e., 55s, 155s, & 355s). The reason why none of the durations represented an exact number of minutes (e.g., 360s being exactly 6 minutes) was to avoid participants guessing the exact duration by rounding up to the minute. To affect the timing mechanism, it was decided to vary the difficulty of the task, the higher the difficulty, the less attention brought upon time. To fluctuate the segmentation levels, the words were either split by one celebrity name (i.e., in the middle of the block) or by three celebrity names (i.e., at each fourth of the task). The only difference between the prospective and retrospective groups was that the first one was told that they would have to estimate the duration of each block at the end of the task, while the second was not. Consequently, the second group (i.e., the retrospective one) was convinced that the experiment aimed to test short-term memory, hence the WRT. On top of the WRT, which was the main task of this experiment, the participants performed tasks measuring the attentional resources and working memory, as well as completed questionnaires measuring the confounding variables aforementioned.

The first analysis run on the estimation provided by the participants was to delete the outliers which were considered as any estimation twice as long as the real duration (i.e., over 110s for the short duration, 310s for the medium duration, and 710s for the longest one). This barely affected the medium and long duration, but numerous short duration estimations had to be deleted from the sample (i.e., 25 out of 98 participants). Post-deletion of the outliers, the error rate of the estimations (i.e., how much the estimations differed from the real duration) were compared between the three blocks, which showed that the longest block had the highest variability. This result fit the Scalar Expectancy Theory (SET; Gibbon et al., 1984) which states that the longest the duration, the higher the lack of precision in the estimation provided.

The most important part of this experiment was to test whether this model was valid for durations over one minute, as the shorter durations used to first validate it were not viable to test gamers. A model including the three dichotomous variables (i.e., timing, segmentation, and the time paradigm) was tested through a General Linear Model Multivariate with the three durations (and the total duration) as the dependent variables. The results were unilateral, as none of the durations were correctly predicted by the model, and none of the variables significantly affected the participants' estimation. Accordingly, the DPCM appears to not fit longer durations (i.e., over one minute) despite its previous validation with short durations (i.e., under one minute). This was of importance for this thesis, as its global aim was to assess the gamers' time perception in order to understand why they tend to underestimate the time spent on videogames and even if a gaming session can last less than an hour, it will never last less than a minute. Therefore, using a model of time perception which would only work for durations under one minute (i.e., longest duration validated being 15s) would not be viable. Furthermore, it is important to note that the level of difficulty, which should at least affect the PTP due to the lack of attentional resources available for time estimation, did not exhibit any significant result. It was thus hypothesized that even the simple task was too complicated to allow any attentional resources to focus on time. This hypothesis led to the creation of a new simpler task for the rest of the thesis.

The only significant result observed on time perception within this experiment is the overestimation of the long block by the gamers compared to the non-gamers. Interestingly, when splitting the prospective and retrospective estimations, and comparing the longest estimation between the gamers and non-gamers, the results remained significant only for the prospective setting. More importantly, observing the actual estimation changed the interpretation of the results drastically. Indeed, the estimation provided by the gamers (i.e., around 360s) was much closer to the real duration of the longest block (i.e., 355s) compared to the non-gamers' estimation (i.e., 240s). Both the lack of results in the RTP and the more accurate time perception among the gamers in the PTP tend to support the hypothesis formulated at the end of the third chapter. Indeed, it was hypothesized that improved attention and working memory observed among the gamers may impact their prospective time estimation positively. It was also hypothesized that the gamers' affected RTP would result from a hyper-reactivity to gaming cues, and that when not confronted with these stimuli, their RTP would remain accurate.

Based on the theory and these results, the following studies explored only the RTP to study the time loss effect observed among gamers. First, it was decided to compare the gamers' and non-gamers' baseline time perception (i.e., temporal estimation provided without any external variable). As the participants had to provide estimations retrospectively, a non-temporal task had to be used similarly to the previous experiment. However, as the previous task was deemed too complicated even in its simplest setting, a new task was created so that difficulty would not alter the results. To keep using word stimuli, to avoid including any new confounding variables, it was decided to create a Lexical Decision Task (LDT) in which participants were asked to decide if a string of letters was a real word (e.g., SHIRT) or a string of consonants (e.g., KSTRF). This task included three blocks of varying durations (i.e., 72s, 192s, & 336s), again, none of these durations was close to an exact minute duration (e.g., 72s was preferred over 60s which is an exact minute). To measure eventual confounding variables, the same tasks and questionnaires as in the first experiment were used, even though none of these variables affected the estimation provided by the first experiment's sample.

As for the first experiment, any estimation at least twice as long as the real duration (i.e., 144s, 384s, and 772s) was excluded from the analyses, which led to an important decrease of the sample for the shortest duration (i.e., only 14 remaining out of 44). Consequently, for this experiment, the total duration was based only on the medium and long block. Compared to the first experiment, the error rate of the estimation provided did not differ between the three different durations, which is expected as the Scalar Expectancy Theory was observed for PTP, this experiment measuring RTP. The main analysis of this experiment was a *t*-test comparing the three estimations provided by the gamers and non-gamers, which did not show a single significant difference. Interestingly, the hypothesis behind this study was the absence of results, as it was expected that the gamers would exhibit an impaired time perception only when observing gaming stimuli. The only extra analysis led based on gaming habits was comparing the players of Role-Playing Games (RPG) to the other gamers, which again did not show any significant result. Based on these non-significant results, the third and last experiment of this thesis could be conducted.

The purpose of this last experiment was to not only compare the gamers' and non-gamers' time perception, but also to observe the separate and conjoint effect of attention and emotion on their RTP. Despite the hypothesized lack of effect of attention on RTP (i.e., due to the unconscious aspect of this cognitive skill), it was still included for two reasons. The first and most important reason was that an increase of attention on the task meant an increase of attention on the stimuli included within the task. These stimuli being gaming pictures, it was hoped that an increased attention toward these would increase their effect on the gamers' time perception. The second reason lies within the dual-process models of addiction (D'Hondt & Maurage, 2017; Noël, Brevers, & Bechara, 2013) which postulates that addiction would emerge from an imbalance between an affective system (i.e., based on associative learning, related to motivation and emotion) and a reflective system (i.e., based on memory and executive functions). Therefore, it would be possible that while attention itself would not affect the gamers' RTP, its interaction with emotion would have an impact. To affect the attention brought upon the task, a more complicated version of the LDT was created where instead of comparing words to strings of consonants, the participants were comparing words to non-words. These non-words were selected through a careful process (i.e., see section "7.3.3.2. Behavioural measures" for more details on the process) to look like potential real words and confuse the participants. Concerning the gaming pictures, a selection was made based on the most popular games and game genres at the moment of the experiment, the final 24 pictures being selected based on real gamers preferences (i.e., see 'Section 7.3.3.2. Behavioural measures' for more details).

The blocks' durations were identical to the first experiment, and the same process was applied to delete the outlying estimation provided by the participants. As for the second experiments, a lot of the short duration estimation had to be deleted, leading to only 59 estimations remaining out of 134 participants. The only significant difference observed in term of error rates between all the duration was between the medium and short block, the latest being less accurate than the medium block, which could be due to the number of estimations lost. Concerning the gamers' time perception, it could not simply be explored through a *t*-test as both the type of pictures and the task difficulty had to be included in the analysis. For this reason, a General Linear Model Multivariate was used, the three durations as well as the total duration being included as dependent variables. This analysis was run separately between the gamers and non-gamers, and while it was not significant for any of the durations for the non-gamers, it was significant for both the medium and long durations among the gamers. When exploring the significant effect, it appeared that the difference for these durations was a main effect of the picture type, where the gamers underestimated the duration when observing gaming pictures compared to neutral pictures. Furthermore, there was a significant interaction between attention and picture type. This interaction showed that while the gaming pictures would lead to a longer estimation in the easy task, the opposite effect was observed in the complicated setting of the task. This could indicate an effect of flow, where the easy task would be too simple for the gamers based on their skills, leading them to find it boring and not fully focus on the task. On the other hand, when the task difficulty matched the gamers' skills, the gamers would remain focused on the task, as in a state of flow, which would allow a proper effect of the gaming pictures. Of course, this is only speculation, and more research should be conducted on this interaction.

Although this is only a hypothesis, the results on the LDT corroborate it. Indeed, when exploring the performance of the gamers compared to the non-gamers on this task, including both the pictures included and the difficulty as independent variables, a significant effect emerged. While the global RT of the gamers were shorter, indicating a better processing speed, it appeared that this difference was due to a difference of performance for the non-words. Indeed, while there was no significant difference for the real words, the gamers reacted faster than the non-gamers for the non-words. The higher performance of the gamers compared to the non-gamers could explain that they indeed got "bored" in the easier task compared to the non-gamers, which could potentially support the previous hypothesis about the interaction between picture type and difficulty.

The final analyses of this thesis concerned the data common to all the experiments (i.e., the ANT-R, DST, and the survey data). The reason for gathering all these data together was to increase the sample and the amount of data instead of analysing smaller groups separately. Some results were expected, such as a better performance of the gamers on the ANT-R or correlations between the gaming variables and self-reported measures (e.g., depression, impulsivity). In summary, it appeared that when participants exhibited higher levels of depression, they were also more impulsive and were more prone to exhibit higher levels of gaming disorder. Concerning stress and anxiety levels, similar results were observed where higher levels were associated with more impulsivity and gaming disorder. It is noteworthy that only the groups differing in term of symptoms showed multiple significant differences on these variables (e.g., normal level of depression compared to severe level of depression). The most interesting result regarding these differences, was that the only POGQ variables not related to depression, stress, and anxiety was immersion, which was only correlated with the urgency score in the UPPS-P. It would then appear that a high immersion score is not problematic as it is not related to any negative outcome. Inversely, the only POGQ variable to be related to the three negative outcomes measured in this thesis was withdrawal, which was systematically higher in the stressed, anxious, and depressed groups. On the other hand, interpersonal conflicts was higher among the depressed and stressed groups and overuse was higher among the depressed and anxious groups. This different interaction among the POGQ variables is of interest when considering it in the context of the work of Charlton and Danforth (2007) who differentiated high engagement from addiction. According to these authors, several constructs used within the definition of behavioural addiction would indicate a high engagement rather than an addictive behaviour. These peripheral criteria include cognitive salience (i.e., thinking regularly about the game), tolerance (i.e., needing to spend more time gaming), and euphoria (i.e., positive mood change when gaming). On the other hand, the core criteria include conflicts (e.g., with work or the loved ones), withdrawal symptoms (i.e., negative mood when not playing), relapse (i.e., inability to stop playing), and behavioural salience (e.g., skipping meals or sleeping less to play more). Although the authors made no mention of the immersion construct explored within this thesis, Deleuze et al. (2018) indicated in their study that while escapism (i.e., avoiding reality to cope with negative emotions) may be related more strongly to addictive use rather than high-engagement, it was not the case for immersion. Therefore, this lack of association between depression, anxiety, and stress with immersion tends to support the idea that immersion belongs to the peripheral criteria and indicates high engagement rather than disordered use.

With regards to gaming itself, three types of analysis have been performed. First, the variables correlating with weekly time spent gaming were entered into a linear regression in order to observe which were the best predictors of this gaming habit. It was observed that the whole model explained 20.40% of weekly time spent gaming, the only remaining significant predictor being preoccupation. It is important to note that nothing can be said about the direction of this relation, as it is possible that an individual spending a lot of time on gaming would be passionate about videogames, which could result in a lot of thoughts about this hobby. Again, this relates to the results obtained by Charlton and Danforth (2007) observing that the time spent gaming, as well as preoccupation (i.e., thoughts directed towards gaming when not playing) are not core items of addiction. It is therefore possible that the participants in this study presenting disordered gaming use (i.e., according to the POGQ) spend more time playing games and thinking about their videogames more often than participants with healthier use. Furthermore, it is important to note that the participants in the studies in this thesis were recruited within a community sample, and that none of the participants presented a score high enough to be considered "disordered" (i.e., based on Demetrovics et al., 2012, cut-off score of 65). This means that although preoccupation and time spent gaming predicted the POGQ total score, this was among a healthy population, thus not necessarily indicating an association between disordered use and these variables.

The second analysis compared gamers and non-gamers, showing lower levels of urgency among non-gamers, which is surprising as most of the studies on the topic tended to find the opposite results (e.g., Billieux et al., 2015b; Ryu et al., 2018). However, these studies mainly recruited disordered gamers, which could explain the differences of results compared to this study. Therefore, it was decided to compare the disordered gamers within this sample (i.e., any participants with an IGD score above 5) to the healthy gamers. Due to the small number of IGD participants (i.e., 26), a selection of 26 healthy gamers matched on their education levels, gender, and age was made. When comparing these two groups, it appeared that the gamers indeed had higher urgency levels, as well as global impulsivity levels and depression and anxiety scores. Again, when comparing IGD to healthy gamers, almost all the POGQ scores differed significantly to the exception of the immersion score, which would further indicate that high immersion levels are not systematically associated with problematic experiences.

Finally, when comparing the scores of the gamers and non-gamers from all the three experiments on the ANT-R, a global faster reaction time was observed for the gamers which indicates a better processing speed. These results do not necessarily indicate that the gamers within this sample had better attention levels, as it could solely be due to their overall faster RT. To observe this effect, new variables were created, comparing the conditions between them (e.g., the difference of RT between a single arrow or multiple arrows to observe the flanking effect). When comparing these new variables between the gamers and non-gamers, none of the differences reached significance. These results indicate that the previously observed results were due to a better processing speed rather than a better attentional focus from the gamers. Finally, when comparing the gamers to the non-gamers on the DST, there were no significant results between any of the variables. This could be due to a ceiling effect, as most of the participants performed very similarly on this task.

9.5. Limitations

9.5.1. Methodological

The quantitative approach to research preferred for this thesis, due to the main variable (i.e., time perception) being continuous, comes with limitations. First, the human mind is extremely complex, and no viable experimental model of a behaviour could possibly account for all the variables influencing the aforesaid behaviour despite the numerous controlled variables included in this experiment. For example, in the field of time perception and its emotional interference, the participants' emotion regulation, positivity and negativity, or simply their current mood (i.e., not the depression level which was controlled) could greatly affect the observed interaction.

The strength of such a method is its objectivity, replicability, and adaptability. Indeed, modifying this thesis' method would allow another researcher to observe how this change affects the results and deepen the understanding of the interaction between time perception and gaming. For example, replacing the scales which did not correlate with time perception by scales measuring the aforementioned constructs (e.g., emotion regulation, and positivity) would allow researchers to explore new concepts with a previously validated method. In addition, the quantitative method can struggle to explain the reason behind a behaviour. For example, while the last study showed that gamers tended to underestimate durations when confronted with gaming pictures, the reasons behind this fact remain unclear. The previous literature can help providing several explanations (e.g., the arousing effect of pictures–Angrilli et al., 1997; the stronger brain reactivity–Wang et al., 2017), but these would then need to be further tested in extra experiments.

Furthermore, a laboratory approach of emotion is always complicated especially when it comes to the concept of enjoyment or, put simply, "having fun". Although it is easy to achieve a reaction from a participant with emotional stimuli, that does not mean that the participant is enjoying the activity at hand (i.e., in this case, the lexical decision task). Interestingly, studies on inhibition used a similar method (i.e., including gaming pictures in their inhibition task) to disrupt disordered gamers' inhibition (Ko et al., 2015; Liu et al., 2014). These studies showed that even if the participants did not exhibit any impaired inhibition in the neutral task, they showed impairment when confronted with gaming pictures, supporting this thesis' method. Importantly, while in real gaming activities the gamers will be confronted with multiple complex input (e.g., videos, animation, and sound), this study only included static emotional pictures. The interest of such a basic method is to reduce the amount of potentially confounding variables. With this study, the specific effect of simple visual stimuli was explored and mostly understood (i.e., leading to an underestimating effect). The following studies could then focus on other types of gaming cues, such as the game sounds or music, to try understanding within which type of stimulus the time loss effect is the most prominent. Finally, once the most important type of gaming sensory input (e.g., video, and music) has been explored, the actual input of the gamers should be broached. For example, comparing time estimation of gamers while watching someone play a videogame they enjoy to their time estimation while playing for the same duration could bring interesting knowledge on time loss.

Specific to this thesis method, some matters arose from the participants recruited. To begin with, the first and last study lacked participants even if it reached the minimum requirement to run the analyses (i.e., at least 10 participants per group for both study). For the last experiment, this issue arose from the difficulty to recruit gamers during recruitment period for this thesis, as most of the participants who subscribed to this experiment considered themselves as non-gamers. Despite the numerous contacts established with different gaming societies, gaming forums, or gaming Facebook groups, the experiment had to come to an end with a low number of gamers. Furthermore, to allow the inclusion of more gamers, the definition of gaming (i.e., gaming inclusion criteria) was widened. For example, the participants who stated mainly playing on their mobile phone were included in the gaming group. This was decided due to a study showing that playing videogames on a smartphone was leading to improved cognitive skills to the same extent as console or computer gaming (Huang et al., 2017). The last limitation from this study's samples concerns gaming disorder. This thesis aimed to explain time distortion observed among disordered gamers, yet the only measure of gaming disorder lied within two questionnaires, most of the participants not fitting the criteria. Therefore, instead of comparing disordered gamers, healthy gamers, and non-gamers, this thesis focused on the comparison of gamers and non-gamers in order to broach a first comparison and maybe open the door for more research exploring the specific effect of gaming disorder on time perception.

Finally, the second and third experiment samples mainly comprised female participants (i.e., n=6 and n=19 respectively). This poses a limitation in two main aspects: (i) most of the previous studies on the cognitive impact of gaming mainly recruited male participants (e.g., Colzato et al., 2013; Dobrowolski et al., 2015), (ii) it appears that videogames do not affect male and female gamers' cognitive skills to the same extent (Sariyska et al., 2017). Concerning the first point, there is currently a preconception that most of the gamers are male, which therefore led researchers to mainly include these in their studies. However, according to recent statistics (e.g., Statista, 2019; Interactive Software Federation of Europe, 2019), it appears that the percentage of male and female gamers are roughly similar (i.e., 54% of male in Europe and in the United States of America). Concerning the second point, it appears that while the measures of gaming disorder were negatively associated with male gamers' decision-making and positively with their impulsivity (i.e., according to the Barratt Impulsiveness Scale; Patton et al., 1995), these associations were absent among female gamers. Although decision-making, to the best of the author's knowledge, has not been associated with time perception, it has been shown that impulsivity directly affects time perception. However, it is important to note that this effect of time perception was only observed prospectively, while the second and third experiment of this thesis explored time retrospectively. Therefore, although the samples used represent a limitation concerning the generalisation of the results to male gamers, this does not go against the previous literature on the association between gaming and time perception.

9.5.2. Stimuli

The stimuli selected within the three experiments were all chosen through a careful process. In the first experiment, familiar and simple words were compared to unfamiliar and complex words to observe how the difficulty of the task would affect the participants' time estimation. To select these two words categories, the *MRC Psycholinguistic Database from the University of Western Australia* (Coltheart, 1981) was used, especially the following variables: familiarity, number of syllables, and number of letters. Controlling these variables made sure that the complicated words would actually be harder to recall for the participants compared to the familiar words. As a matter of fact, when comparing the number of words recalled between the two conditions, it appeared more words were recalled in the easy condition than the complicated one. The reason why the easy task remained too complicated to not affect time estimation of the participants prospectively was not related to the words being overly complicated. Indeed, the reason behind this overwhelming difficulty to remain focused on the task is most likely due to the amount of words the participants had to recall (i.e., 113 words spread out between three blocks). When changing the non-temporal task into a Lexical Decision Task, it was decided to keep the simple stimuli, as the difficulty varied with the non-words rather than the words. The non-words were either strings of consonants (i.e., easy task) which did not need further control, or non-words resembling real words (e.g., "CORI") which required further inclusion and exclusion criteria. To make the non-words eligible, they needed to include only grammatically existing onsets (i.e., the beginning of a word) and bodies (i.e., the other parts of the words). With these two conditions, all the non-words included in the LDT were grammatically correct, in other words, these non-words could potentially be real words. Furthermore, on top of controlling the bodies and onsets, the order of the letters (i.e., consonants and vowels) were controlled as well, every single word having its own matched non-word (e.g., "SHIRT" vs. "PSIGN"). Therefore, the words and non-words from this study were highly controlled and should not be considered a liability in these experiments.

However, some limitations exist within the pictures used in the third experiments which only affect the gaming pictures. First, although the pictures were tested among real gamers, there was still a first selection made by the experimenter. Indeed, pictures extracted from the most famous games and game genres at the moment the experiments were selected by the main experimenter, leading to a first list of 137 pictures. The issue with these pictures is that they were personally selected by the main experimenter which can be deemed subjective. Nonetheless, to select the 24 gaming pictures used in the third experiments, the 137 pictures were sent to gamers. These gamers had to evaluate these pictures on four different scales (i.e., valence, arousal, will to play, and gaming relatedness). Only the pictures two standard deviation above the average score on the four scales were first selected, leading to 40 potential pictures, from which 24 pictures were selected based on a careful observation of their score. Therefore, even though the 137 first pictures were arbitrary selected, the careful process used afterward counterbalanced that issue, making the process more objective. Unfortunately, due to the short amount of time available to select these pictures, only a small number of the gamers contacted managed to send back the evaluations on time. Consequently, these analyses were based on only nine gamers' evaluations, which could have biased the results. For example, some gaming genres were not represented at all after deleting the pictures not over two standard deviations from the mean score. This could be due to the small sample of gamers not playing these games and not being affected by these pictures.

9.5.3. Measurements

In the first experiment, the analyses showed that the Dual-Process Contingency Model of time perception did not work for the selected durations (i.e., longer than one minute). It was concluded that this model was simply not suited for longer duration than the one tested in the past (i.e., maximum 15s; Zakay, 1993) even if this could also be due to the way this model was tested in this thesis. Indeed, this model is based on two separate variables, first the attention brought upon time and second, the amount of contextual changes occurring within an interval (Thomas & Weaver, 1975). To fluctuate the amount of attention brought upon time, the recalling task used in the experiment had two levels of difficulty, the point being that for a higher level of difficulty, the participants could not properly focus on time compared to the easy condition. However, what the experiment showed is that even in the prospective, conscious, setting, the difficulty of the task did not affect the participants' time perception. Even more, there was no overall difference between the retrospective and the prospective time perception. It was thus hypothesized that the easy condition was already too demanding for the participants who could already not focus properly on their time estimation.

Referring to another model of time perception, the Attentional Gate Model (i.e., see 'Section 1.2. Models of time perception' for more details on this model), it can be postulated that the attentional gate would be entirely closed due to the lack of attentional resources left for the timing exercise (Zakay & Block, 1995). Therefore, if no pulses are going through the gate, a prospective estimation would be impossible, leading the participants to evaluate time in a retrospective setting, explaining this lack of difference between retrospective and prospective setting. The second variable of this model, segmentation (i.e., the separation of a group of stimuli in several smaller groups), did not affect the participants' estimation either. This is surprising as most of the models of retrospective time perception support an effect of segmentation on time perception, even outside the DPCM (Block & Reed, 1978; Block & Zakay, 1997). A potential reason for this lack of effect is the way segmentation was implemented within the experiments, that is through the inclusion of celebrity names at regular intervals. The point of these celebrity names was to include a "surprising" stimulus at regular intervals which separated the flow of words in small groups (i.e., either two groups or four groups depending on the condition). It is thus possible that the participants did not perceive this segmentation effect, and that a clearer separation of the stimuli should be used in further studies (e.g., different semantic groups, or different background colours).

The final point about this first experiment's main task concerns the duration included for the shortest and longest blocks (i.e., 55 and 355 seconds). The idea behind not using exact durations (i.e., in this case, one and six minutes) was to avoid the participants rounding up their estimations and ending up being extremely accurate. However, the durations used for these two blocks were close to an exact duration. Therefore, if some of the participants rounded up their estimations to the closest minute, it could have virtually improved their precision. Although this was a risk, when observing the data of the participants, their estimations were not deemed too close to the real duration to consider this methodological aspect an issue. Even though the previous experimental durations did not cause any trouble for the participants' estimations, the durations within the second and third experiments were changed to be further from round durations (i.e., 72s, 192s, and 338s). Furthermore, learning from the previous experiment's results concerning difficulty, the task changed from a recalling task to a lexical decision task, making it simpler. Finally, as the segmentation of variables was not explored within the two last experiments, all the methodological limitations from the first temporal task got corrected for in the last experiments.

In the third experiment, when including the gaming cues (i.e., the pictures), a methodological choice was made to include gaming pictures as primer (i.e., a priming stimulus before the main stimulus) instead of including the gaming cues as the main stimulus. In other words, the participant did not have to actively process the gaming cues, but they actually had to ignore them while processing the words or non-words. Although this could be a limitation from this experiment, three arguments support this methodological approach. First, this method has shown interesting results in diverse studies (Bai, Chen, Zhou, Liu, & Hu, 2019; Deleuze et al., 2019), even though most of these studies explored the effect of a priming picture on a following stimulus (e.g., including an emotional picture before a word and observe if it affects the participant's RT). In this thesis, the purpose of the priming stimuli was not to affect the following stimuli (i.e., the words or non-words) but to induce a mood change among the participants which would affect their temporal estimation. The second point supporting this method was that previous studies exploring the emotional reactivity of gamers in front of gaming cues used pictures rather than words or other stimuli (Ahn et al., 2015; Liu et al., 2014). Indeed, it is more likely that gaming pictures will elicit an emotional response from gamers instead of words, which is the processed stimulus in the lexical decision task. Besides, while there exist millions of gaming pictures online, there are less possible words usable in an experimental setting, especially because an important part of these words are game genres specific (e.g., Raid in Massively Multiplayer Online Role-Playing Games or Ganking[5] in Multiplayer Online Battle Arena games). This game specificity prevents some gamers from understanding part of the words used, limiting the impact of that word on their emotion. Finally, the results showed that the gaming pictures actually impaired the gamers' time perception, showing that this design had the expected results.

With regards to the controlled variables (i.e., the other non-temporal tasks and the survey), two limitations were noted. First, gaming disorder was measured through the nine dichotomous items created by Petry and et al. (2014) which has greatly been criticized within its own field (Griffiths et al., 2016) despite its wide-ranging use in diverse studies. It is noteworthy that most of these criticisms concern the concept of Internet Gaming Disorder developed in the DSM-5, rather than the measure of it. Therefore, most of these criticisms remain true no matter the measurement used. A limitation specific to the IGD criteria used is that newer measurements of the IGD with a better structure were developed since then (e.g., Ten-Item Internet Gaming Disorder Test – IGDT-10; Király et al., 2019). Also, since the completion of this thesis' studies, Pontes et al. (2019) published a self-report diagnostic tool based on the ICD-11 criteria which represents another interesting option to replace the IGD criteria used within this thesis. Even though the assessment of IGD within this thesis could be improved, it generated interesting results regarding the measures from the UPPS-P-s, POGQ, and DASS-21 scores. These significant results tend to indicate that even if the measure of gaming disorder can be improved for future research, the measure used in this thesis brought the expected results, even if it did not affect time perception. The second issue with regards to the survey is that it did not include a single measure of flow, which appears to be a crucial variable within the interaction between gaming and time perception. However, most of the studies which included a measure of flow did not measure the flow state of the participants per se but a measure of flow proneness (i.e., how likely an individual will experience flow states in their life). Although it could have been interesting to analyse the associations between time spent gaming

[5] Ganking is a term peculiar to the Multiplayer Online Battle Arena games. This term refers to the action of helping a team-mate on another side of the map to take the advantage.

weekly and flow proneness scores, how likely one can experience flow in one's life should not affect that person's time perception in the task at hand. Indeed, it is not because someone is more likely to experience flow that they will experience flow during the experiment.

9.6. Final remarks

The main objective of this thesis was to study a potential underlying mechanism of the time loss effect observed among gamers, namely impaired time perception. This variable was deemed of interest due to its main consequence, time spent gaming. Even though time spent online is not considered a criterion for gaming disorder, as one can spend time gaming without presenting a disorder, it is directly associated with the negative consequences in a gamer's life. Therefore, understanding this concept allows a direct intervention regarding time spent online, hence limiting potential negative consequences on one's life. After a theoretical exploration of the impact of gaming on cognition and the potential factors affecting time perception, a theory emerged. It appeared that gamers did not exhibit impaired prospective (i.e., conscious) time perception due to their improved attention and working memory. Instead, they exhibited impaired retrospective (i.e., unconscious) time perception only when confronted with emotional cues. Based on these results, gamers could be helped by redirecting their attention towards time, shifting their time perception from retrospective to prospective. Indeed, the studies in this thesis have shown that while gamers appear to demonstrate a biased retrospective time perception when confronted with gaming cues, their prospective time perception appears to be more accurate than that of non-gamers. A potential way to shift time perception would be a timer appearing in front of the game (e.g., in the corner of the screen), constantly reminding the participants of the time. This could potentially help the participants to adjust their time control.

However, even though the main aim of this thesis was thus retrospective time perception of gamers, the first study still tried to unify both time perception paradigms (i.e., retrospective and prospective) within a single cognitive model (i.e., DPCM) for long durations. Indeed, if the model was to be significant, studying only the RTP among gamers would become irrelevant, as the PTP would be of importance too. Two main results emerged from this study; first, the model was not significant for any of the durations explored. Beyond the several limitations discussed within this experiment which could explain such non-significant results, it was hypothesized that the lack of results was due to this model only being viable for shorter durations. The second important result observed was improved prospective time perception among gamers who were more accurate for the longest block compared to non-gamers who clearly underestimated the duration. This point is of interest when referring to the prior hypothesis that gamers could potentially exhibit an improved PTP due to their improved attention and working memory. Furthermore, the lack of results in the RTP paradigm was expected as it was hypothesized that it would be a result from an emotional effect.

The second and third study used a different temporal model (i.e., AGM) than the previous experiment as the previous model did not appear to be fit for measuring longer durations required within this thesis. The second study first aimed to explore the gamers' baseline RTP, that is, their unconscious time perception without any external variable, even though it was hypothesized that no difference would be observed with the non-gamers. The only key result emerging from this experiment is a confirmation of the hypothesis, as the gamers performed as well as the non-gamers for their time estimation. This further confirmed the theory upon which the first three chapters of this thesis are built, that the reason behind the gamers' impaired time perception lies in an external variable rather than their global time perception.

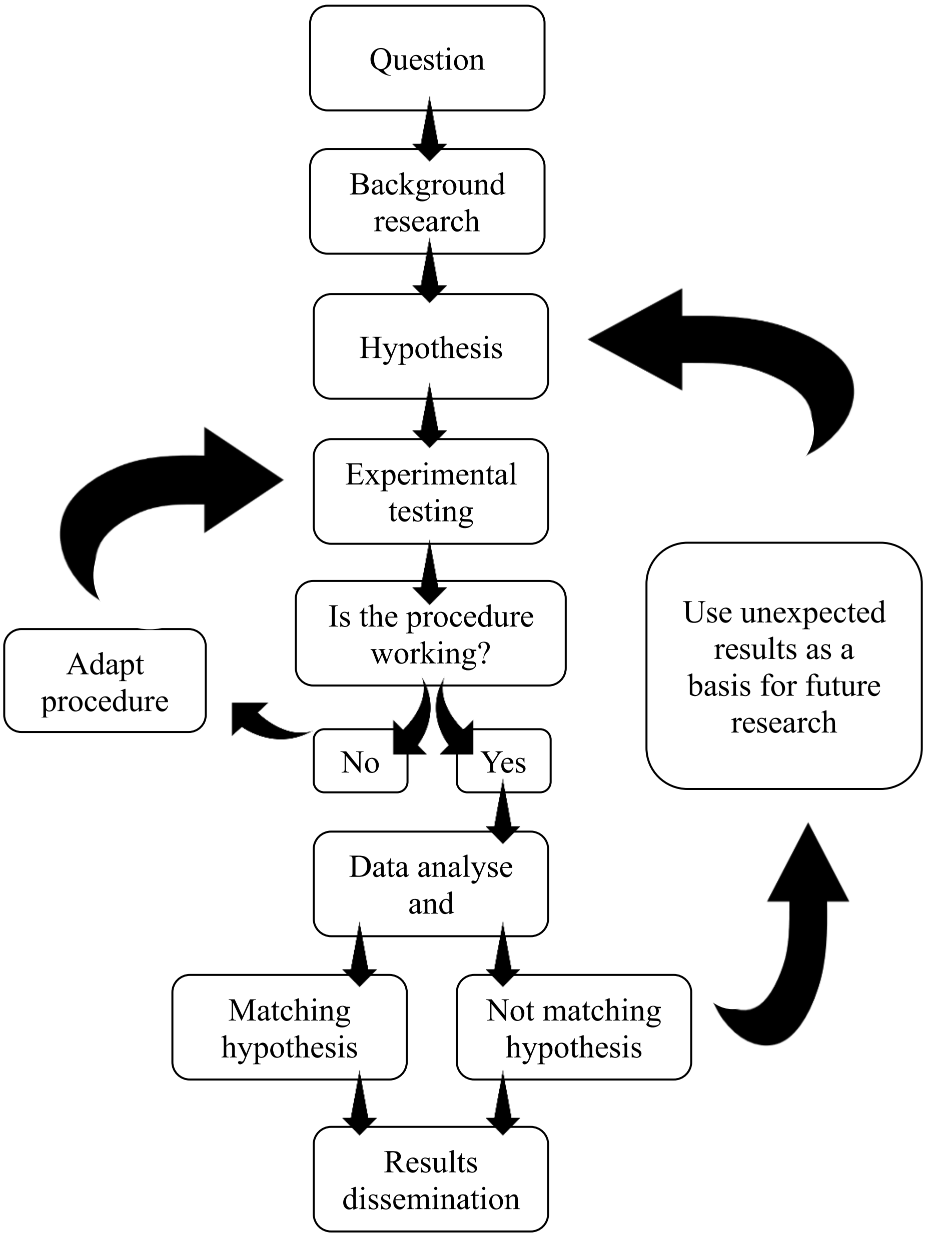
The third study then aimed to explore two potential external variables which could directly affect their time perception, namely attention and emotion. Although attention should not lead to an underestimation effect in RTP, it was decided to include it based on the prior dual-process model of addiction which explores cognitive processes through the scope of a reflective (i.e., cognitive) and an affective (i.e., emotional) system. To elicit an emotional answer from the gamers, gaming pictures first validated in a pilot study were included in the experiment and to fluctuate the level of attentional resources available, the gamers could either perform an easy or complicated task. First, the study confirmed this thesis' main hypothesis, that is, an impaired time perception in front of gaming stimuli, and this only for the gamers who underestimated the duration in the emotional condition. Second, there was a significant interaction between the task difficulty and the picture type, where the gamers would underestimate time when seeing gaming pictures in the complicated task contrasting with an overestimation when observing these in the easy task. This second result could indicate an effect of flow, the easy task being too easy for the gamers (i.e., not matching their skills) which would lead them to get bored and not properly focus on the pictures. However, when the task was more complicated, it matched their skill level, allowing a proper focus on the task and leading to the desired effect of the gaming pictures.

Several points of this thesis require more exploration in order to confirm the interpretation of the results. First, improved prospective time perception was based on a small gaming population and requires a proper study of gamer's prospective time perception to confirm this hypothesis. Second, the flow hypothesis is based on a single significant interaction, and although this is a viable interpretation, more studies are required. Furthermore, flow has been shown to directly affect time perception, whether prospective or retrospective, and is also prominent within the gaming population. Therefore, it appears crucial to explore the triple interaction between gaming, retrospective time perception, and flow in order to fully grasp the time loss effect observed among gamers. Third, it is important to mention that this study aimed to bring a first observation of gamers' time perception, and that for this purpose it was preferred to use three shorter durations rather than a single longer one. Therefore, the durations explored within these experiments are not fully representative of the durations experienced within a gaming session (i.e., maximum six minutes compared to sometimes few hours of gaming). It would thus be of interest to lead further studies exploring longer durations. Finally, while this study used gaming pictures to elicit an emotional response from the gamers, other types of gaming cues exist, such as music, videos, or simply playing a game. The pictures were preferred over other stimuli for the sake of controlling the confounding variables, but further studies should explore these different stimuli to observe how gamers' time perception is affected in these cases.

In conclusion, it appears that gamers have a better prospective time perception due to their improved attentional skills and an impaired retrospective time perception which only occurs when confronted with gaming cues. Theoretically, this is due to the arousing effect of the gaming pictures based on the research on gaming and on time perception. In the field of time perception, it appeared that, in PTP, the more arousing pictures (e.g., mutilation pictures) lead to more time perception impairment than the less arousing ones (e.g., disgusting detritus) (Gil & Droit-Volet, 2012). Concerning the gamers, their stronger brain reactivity to gaming pictures compared to non-gamers could indicate an arousing effect from gaming cues. This is of interest when one knows that the disordered gamers tend to react even stronger to gaming cues compared to healthy gamers, which can explain the stronger time loss effect observed alongside gaming disorder. These results could be of crucial interest for clinical work with disordered gamers. Indeed, knowing that observed time loss within this population is due to an emotional response to gaming cues could help reducing this impaired time control. As it was mentioned earlier in this thesis, a strong emotion regulation can disrupt the deleterious effect of emotion on time perception, leading to an accurate estimation. Since gaming disorder has been related to impaired emotion regulation, it would be of particular interest to help this population regulating their emotions, which could directly reduce the effect of gaming on their time estimation. In turn, this limited effect of emotion on their time perception would allow them to spend less time gaming, hence reducing the negative impact of videogames in their life.

Figure

Figure 1. Scientific method



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