Interdisciplinary Program of Graduate Studies in Basic and Applied Cognitive Science

Dissertation Project

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Modulating Time perception through video gaming and brain training software

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Abstract: Time perception is an aspect of our everyday lives that we usually take for granted but do not yet fully understand. Several computational and cognitive models have attempted to account for the way we perceive time and make temporal duration judgments. According to one such cognitive model, the Attentional Gate Model (AGM), each person’s temporal percept is dependent on processes such as attention, working memory, and processing speed. In order to examine the effect that the aforementioned processes have on time perception, participants were trained in a series of tasks and asked to perform a production as well as a reproduction dual task before and after training. That is, they had to perform a temporal (time estimation) and a non-temporal (identification and naming of Greek letters) task simultaneously. According to the AGM, the need to divide attention differentially affects production and reproduction dual tasks. In the production task, divided allocation of attention should lead to a produced duration that is longer than the actual time intervals participants were asked to produce, while division of attention in reproduction dual tasks should lead to an underestimation of the actual durations presented. The participants in our study were assigned to one of three training groups. Specifically, participants were trained for thirty days on either an action video game (group 1), which according to previous research increase processing speed, a brain training software (group 2), which aimed at improving working memory, or a processing speed software (group 3). Participants were asked to perform the dual tasks before and after the 30-day training period. A statistically significant result was detected for the reproduction task. Participants were significantly more accurate in reproducing target durations in posttest as compared to their performance in pretest. Specifically participants underestimated intervals less in posttest. This effect was evident across all experimental groups. No similar effect was detected for the production task. Thus, the
results of this study show that training on specific cognitive processes can enhance one’s temporal accuracy in an interval reproduction task.
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Plagiarism Statement

I declare that, apart from properly referenced quotations, this report is my own work and contains no plagiarism; it has not been submitted previously for any other assessed unit on this or other degree courses.
Introduction

Video games have become quite popular over the last decades, occupying a considerable percentage of our leisure time. In the U.S.A., studies have shown that adolescents spend on average 9 hours per week playing video games (Tobin & Grondin, 2009). Furthermore, video games have now become more portable than ever. Even those of us who are not considered habitual game players, have at some point used a handheld device or a mobile phone to play a favorite game. What is rather surprising is the fact that gamers are not primarily children. In fact, 29% of the gaming population consists of individuals over the age of fifty, while the average age of a gamer is actually 37 years old (Entertainment Software Association, n.d.)!

As with any emerging technology, there has been a considerable amount of debate, regarding the consequences of every new trend and as a result video games have been put under scientific scrutiny. Most of the criticism focuses on violent games, which have been associated with increased aggression (Ferguson, 2010). Addiction and decreased school performance are also considered harmful effects of video gaming (Gentile, Lynch, Ruh Linder, & Walsh, 2004). Recent studies however, claim that the negative effects of video games, even violent video games, may have been exaggerated (Ferguson, 2010). Statistics in Europe and the U.S., do not suggest that children engaging in video gaming are necessarily more violent, worse students or more inclined to have more severe behavioral problems (Ferguson, 2010). On the other side, several researchers have focused on the examination of the positive effects
of video gaming, and in exploiting these possible outcomes for educational (Annetta, 2010), health (Kato, 2010), and rehabilitation purposes (Durkin, 2010). Taking into consideration that most people regard video games as entertainment, scientific evidence that video games actually help or somehow advance the abilities of those involved, would cause educational and health practices to be seen under a completely new perspective.

In this thesis, we are mainly interested in exploring whether video games, as well as brain training games (a newly emerged industry of gaming products), can be utilized as tools for cognitive enhancement. In particular, we seek to examine whether action video games and brain training games (targeting processing speed and working memory) do actually produce cognitive enhancement, and more importantly whether these hypothetical benefits in a given cognitive process, generalize in tasks beyond the specific task being trained. In our effort to examine the latter, we based our research on time perception though the use of the Attentional Gate Model (AGM), which relies heavily on processing speed, working memory, and attention. Thus, supposing any cognitive benefits as a result of gaming or training on brain games actually occur, they should also be detectable in tasks which are explained by the AGM model given the involvement of the same cognitive processes.

**Attentional Gate Model**

Several cognitive models have attempted to account for the way people perceive time and make temporal duration judgments, in this thesis we will focus on one such model, namely the AGM. The AGM, in accordance with previously established timing models, suggests that time perception is a three stage process. Scalar-timing model first proposed that time perception is dependent upon an internal
clock, memory stores, and a decision mechanism (Church, 1984; Gibbon, 1991). The internal-clock consists of an oscillatory pacemaker, which emits pulses at a mean constant rate (Pouthas & Perbal, 2004). Furthermore, the internal clock also includes a switch and an accumulator (see Figure 1). Whenever an external signal designates the onset of a time interval, the switch closes allowing the pulse stream to be transmitted and pile up in the accumulator (Zakay, Block, & Tsal, 1999). Thereafter, on any given trial, the content of the counter is transferred into a working memory store in order to be compared later with the contents of a reference store, which contains long-term memory representations of the approximate number of pulses that accumulated on similar past occasions (Zakay & Block, 1994). Both stored pulse counts are transferred into the comparator in order to be compared, and as these counts grow closer the response rate increases.

Figure 1. A schematic representation of the Scalar-timing Model (Block & Zakay, 1996).

In an effort to consider the role of cognitive factors and explain human timing behavior, the AGM complements the scalar-timing model. Specifically, the AGM is a model developed to handle prospective duration timings. The critical characteristic of prospective timing is that the organism is aware beforehand that it will be required to make a duration judgment, and as a result its behavior is focused on temporal
information (Block & Zakay, 1996). Furthermore, the AGM assumes that the rate at which the pacemaker produces pulses is influenced by both internal tempo, processing speed, and stimulus induced arousal (Block, Zakay, & Hancock, 1998; Zakay et al., 1999). Finally, another important point at which AGM differentiates itself in respect to scalar-timing model is the addition of an extra critical component, namely a cognitive module in the form of an attentional gate (Zakay & Block, 1994). This gate is a cognitive mechanism controlled by the amount of attention that is allocated to time. Whenever an organism attends to time, as opposed to other non-temporal stimuli, the gate opens allowing a greater number of pulses to pass to subsequent parts, and be transferred to the counter (Zakay & Block, 1994). Attending to time simply increases the level of activity of the gate. The need for a switch in the model, however, still remains in order for it to control the cognitive counter. At the onset of a duration, indicated by a start signal, the switch which operates in an “all-or-none” fashion closes, the counter is set to zero, and the flow of signals is allowed to be transmitted to the cognitive counter and be summed over time (Block & Zakay, 1996). When another signal, indicates the termination of the time interval, the switch opens preventing this way the accumulation of more pulses, and at the same time the content of the counter is transferred into working memory (Zakay & Block, 1994; see Figure 2). The rest of the model is similar to the scalar timing model previously described.
AGM in Production and Reproduction Tasks

The AGM incorporates the notion that participants are capable of dividing attentional resources, among external events (non-temporal) and temporal information processing, and succeeds in explaining complex human timing behavior. In particular, according to the AGM, when a participant is instructed to perform a prospective duration judgment, and simultaneously to engage in a non-temporal task, less attentional resources are available for temporal processing and as a result some time units are lost somewhere in the process (Zakay et al., 1999). However, due to the fact that clock, attention, and memory processes are differentially involved in various kinds of paradigms, participants might overestimate time intervals in some cases, while underestimate the same durations in others. This differentiation depends on the kind of temporal task and methodology used in each case (Hemmes, Brown, & Kladopoulos, 2004).
For example, in a production task, participants are instructed to produce a specific time interval (e.g., 10 s) by using an appropriate and designated method (e.g., pressing a button when they believe the specified time interval to be over). Participants produce longer durations than the actual time interval, when processing is conducted simultaneously with a secondary non-temporal task (Pouthas & Perbal, 2004). Diversion of attention from temporal processing, interrupts the accumulation of pulses during the production phase and a number of pulses fails to be accumulated. Due to this loss of pulses, a greater number of time units needs to be accumulated in order for the participant to judge the prescribed duration as being over and as a result he/she is led in an overestimation of the time interval (Pouthas & Perbal, 2004). On the other hand, in a reproduction task, participants have to estimate target duration and then reproduce it by performing a specified operation (Zakay, 1990). The estimation period of the reproduction task is referred to as the encoding phase. (Pouthas & Perbal, 2004). When the participant is required during the encoding phase, apart from the temporal task, to also engage in a concurrent non-temporal task, there is a need for him/her to divide attention between two different types of information processing. Since less attention is allocated to time, according to the AGM, the gate does not open as wide and a number of pulses fail to be accumulated. As already mentioned, perceived duration is proportional to the number of time units accumulated, thus, this aforementioned loss of pulses will lead in shorter time estimations, which in turn will lead in shorter time reproductions than the actual time interval.

In the experimental work of this thesis, we will use a production and a reproduction dual task in order to explore the consequences of our training regimen. The specifics of the dual tasks utilized, as well as the training interventions, are described in detail in the methodology section of this thesis.
**Video Games**

As already mentioned above, according to the Entertainment Software Association around 72% of the U.S.A. population, that is about 225 million people, play some sort of video game. By the term video game, we refer to any electronic game that involves interaction with a user interface, in order to generate visual feedback on a video device. Originally, video games were designed to entertain. However, very soon after they were first introduced, scientists begun to recognize various effects of video games as far as education and cognition were concerned. In this study, we are particularly interested in a specific type of video games, namely action video games.

Although there are no hard and fast rules for the classification of video games, there are certain characteristics a video game must bear in order to be considered an action video game. To name a few, the game must be characterized by extraordinary speed, both in terms of moving objects as well as of succession of events. Furthermore, in order for the player to successfully engage in an action game, he/she must be able at all times to deal with a high degree of perceptual, motor, and cognitive load and to use this informational load to develop and accurately implement a precise motor plan in a very limited period of time. Moreover, the game must be highly unpredictable, spatially as well as temporally. Finally, in order for a game to qualify as an action game, apart from the above, it must also require peripheral processing with items appearing on various possible positions on screen (Green, Bavelier & Li, 2009). There are many other categories of video games. However, we limit the work done in this thesis to action video games because a substantial amount of research claims that action video games specifically enhance a wide variety of perceptual and
cognitive capabilities, such as enhancement of processing speed, hand-eye coordination, spatial allocation, and distribution of visual attention and peripheral vision (Green, Bavelier & Li, 2009).

Anyone who has ever played a video game immediately realizes that time is of essence. The player usually needs to respond as quickly as possible to multiple features on screen, by manipulating a mouse, keyboard or joystick and pressing the appropriate combination of buttons. Delays in processing and responding usually have severe consequences for the progress of the game, and as a result players have a strong motivation to be as fast and accurate as possible. Furthermore, players have to respond to a much greater amount of sensory information than one usually has to deal with in real life circumstances, resulting in exposure to stimuli being actually “more than normal” (Green et al., 2009). Thus, taking into consideration the fact that absence of stimuli exposure may cause certain cognitive processes to weaken under specific circumstances, the central question that arises is whether the reverse is also possible. That is, does the overexposure to sensory information caused by video games result in positive outcomes? If so, can video games be utilized as tools to enhance specific cognitive processes? Another important question that must be addressed is the following: do any hypothetical benefits due to video game training generalize to other tasks beyond the specific task being trained?

Bavelier and colleagues have conducted extensive research in order to study how individuals learn and adapt to changes in experience induced by video game training (Green et al., 2009). According to their findings, playing first person point of view action video games affects several aspects of cognition, attention, and perception. It is important that their findings do not remain limited to habitual video game players, but also extend to non-players when trained on video games for specific
periods of time. According to their research findings, video game players possess better hand-eye coordination, reduced reaction times, enhanced abilities in gathering and manipulating spatial information, better peripheral processing capabilities, and enhanced visual attention (Green & Bavelier, 2004).

Specifically, video game players (VGPs) appear to possess increased processing speed, and as a result they react faster than non players (Dye, Green, & Bavelier, 2009). This comes as no surprise as one considers the important role speeded reactions and decisions play in an action video game. Furthermore, Bavelier and colleagues claim that this increase of speed is not accompanied by decreased accuracy. In fact, in tasks that require accurate responses to quickly presented stimuli, VGPs exhibit higher levels of accuracy than non video game players (NVGPs; Green, 2008). When comparing directly VGPs to NVGPs, it would be natural to expect that people with inherently faster reaction times tend to engage more in video gaming since it is easier for them. However, when extensively trained on action video games, NVGPs also demonstrate reduced reaction times after a period of training (Green, 2008). In this thesis we are particularly interested in this positive outcome of video gaming. For the purposes of our experiment we trained participants on an action video game, which as already mentioned enhances processing speed. According to the AGM model described, temporal judgments depend (among other processes) strongly on processing speed. Therefore, we expect that if benefits of video gaming generalize to other tasks beyond the specific task trained, differences should also be detectable in temporal perception tasks, which according to AGM are also dependent on processing speed. Furthermore, as mentioned above, VGPs demonstrate enhanced visual attention as compared to NVGPs. By the term visual attention, we refer to the cognitive process by which certain features are selected for further processing, while
others remain unattended (Green & Bavelier, 2006). This is the case, for example, when one is driving a car. In order to successfully and safely drive, one must attend to other cars, pedestrians, and signs, while leave irrelevant information such as scenery, pedestrian clothing, and shops windows go unnoticed. Researchers in this case demonstrated that playing video game enhances the overall capacity of the attentional system. This has been exhibited by the fact that VGPs are capable to visually apprehend at once a greater number of items than NVGPs, a process known as subitizing (Green & Bavelier, 2003). Furthermore, this is also supported by the fact that VGPs exhaust their attentional resources more slowly than NVGPs; that is VGPs are capable of processing gaming distractors even in cases when the target has become quite demanding. NVGPs on the other hand, in this case, will focus and concentrate all available resources in the processing of the target leaving none for distractor processing. At this point the target has become so demanding that no resources are allowed to spill over to extraneous distractors. The degree of distractor processing has been proposed to provide an index of available attentional resources. The fact that VGPs process distractors even when target has become quite difficult is indicative that they possess enhanced attentional resources. (Green & Bavelier, 2003, 2006). In another of their experiments the aforementioned researchers showed that VGPs show evidence of allocating attention over space more effectively. Specifically, a useful field of view (UFOV) paradigm was adopted which is regarded as a suitable task to measure the distribution of visual attention across a visual scene. In this task, participants were asked to localize a very briefly presented target at eccentricities up to 30°. Again, in this paradigm VGPs outperformed NVGPs across the various experimental conditions (added distractors, different eccentricities etc.), establishing
that gaming enhances distribution of attention over a wide field of view (Green & Bavelier, 2003, 2006).

In order to examine whether this enhanced attentional capacity is profound also in areas which are not within the game training zone, the experimenters tested the distribution of visual attention of VGPs and NVPGs at three eccentricities, one indisputably within training area, one outside training area and one at the boundary. VGPs outperformed NVGPs in all cases. According to the researchers, this constitutes generalization of training benefits, since enhanced allocation of spatial attention was evident even at untrained locations in VGPs (Green & Bavelier, 2003). In our opinion however, in order to be able to claim generalization, a completely different task than the one used for training should be utilized. In case a strong improvement effect was detectable in a completely different in nature task, - yet governed by the same processes-, would constitute robust evidence that benefits of video game playing do in fact generalize. Thus, in this thesis we seek to examine whether benefits due to video gaming training will be detectable in temporal tasks which even though strongly dependent on processing speed are completely different in nature than the training regimen adopted.

**Brain Training Software**

In this thesis we are also interested in another category of software, namely brain training software. Brain training is a rather newly emerged software industry, and it is based on the lifelong capacity of the human brain for neural plasticity (Ball et al., 2002). Psychology and neuroscience studies of the adult brain have exhibited that brain plasticity is a bidirectional process governed by competitive mechanisms, and that depending on the circumstances the brain can be either strengthened or degraded.
Therefore, by using appropriately designed training paradigms it is possible to substantially improve in function and even recover from losses in sensation, cognition, memory and motor control (Mahncke, Bronstone, & Merzenich, 2006). Consequently, the software industry taking advantage of this need for appropriate programs has introduced brain-training software aiming to help one maintain or even improve cognitive functions through the regular use of computerized tasks (Owen et al., 2010). These standardized tasks aim at refining specific cognitive processes such as attention, memory, processing speed etc. In order for improvement to occur though, participants have to routinely occupy themselves with appropriately designed mental activities. These mental tasks is important to guide the participant, provide feedback, and adapt their difficulty continuously based on participants performance, so as to remain challenging at all times (Ball et al., 2002, 2007; Mahncke et al., 2006; Willis et al., 2006). We are all looking forward to the ultimate training regimen that for a few minutes a day we will be able to maintain and enhance our cognitive abilities. However, the central question that arises in the brain-training field is not whether performance on cognitive tests actually improves, but rather, whether these benefits transfer to untrained tasks, or lead to generalized cognitive improvements.

As with video games, even though a considerable amount of research has been performed, scientific findings on this matter remain rather controversial. Indicatively we refer to the IMPACT study (Smith et al., 2009), in which participated 524 elderly individuals. Participants in the experimental group used a computer-based series of scientifically designed exercises targeting fundamental cognitive processes. The participants in the control group watched and were quizzed upon a computer-based educational program. People in both groups used their program for one hour per day, 5 days a week and for a period which lasted 8-10 weeks. Participants in the
experimental group, as compared to those in the active control group, made substantial progress in memory and speed of processing. Moreover, participants underwent memory assessments and based on their performance researchers inferred that benefits generalized and brain training led to a broader brain function improvement. Furthermore, the IMPACT study participants in the experimental group were asked to report whether they observed any improvements or changes in their everyday lives. Participants indeed noticed a wide variety of improvements in their daily lives. These changes ranged from remembering a shopping list without having to write it down, to hearing conversations in noisy restaurants more clearly, to living more independently, feeling more self-confident, having improved self-esteem, finding words more easily etc. (Smith et al., 2009).

On the other hand, in a large-scale study with 11430 participants conducted by the BBC, no evidence supporting transfer effects to untrained tasks were detected (Owen et al., 2010). Participants in this study also, were trained on cognitive tasks designed to improve memory, reasoning, planning, visuospatial skills, and attention. Even though participants improved in all training tasks, they failed to improve in untrained tasks, even ones closely related, and despite the fact that they had been trained on a broad range of cognitive functions (Owen et al., 2010).

Brain training software is a rather new industry. Supposing brain-plasticity-based programs actually work, they would be beneficial for all of us, since they have numerous applications for cognitive improvement and rehabilitation. Therefore it is necessary that further research on the subject of brain training be conducted. In this thesis we as well, seek to examine whether there are any benefits from brain training software and moreover whether these hypothetical benefits will transfer to untrained temporal tasks, thus providing robust evidence for benefit generalization.
Methodology

The aim of this study is to examine whether it is possible to modulate time perception by refining particular cognitive processes. Specifically, we are interested in examining whether benefits due to training of particular cognitive processes (i.e., working memory and processing speed), will generalize to temporal tasks, which even though might be governed by the same cognitive mechanisms are completely different in nature. We hypothesize that, if enhancements of processes due to training actually occur, and moreover if these positive effects generalize to tasks beyond the specific training task, time perception should also be affected. That is, according to the AGM, participants should be led to more accurate time judgments after a period of training. As a result, such enhancements would have important implications for both cognitive rehabilitation regimens as well as modeling in the time perception domain.

Participants

For the purposes of this experiment a total number of thirty-three healthy individuals (22 females and 11 males) were recruited. All participants provided informed consent in order to participate in the study. During the training period there were three withdrawals due to difficulty to conform to daily practice requirements. Thus, the data concerning the aforementioned participants have been excluded from the analysis. The participants’ ages ranged from 18 to 35 years old (mean age = 28 years). Older participants were considered inappropriate for this study, due to time perception literature showing that older adults are characterized by reduced controlled attentional resources, as well as different rates of the internal clock due to decline in
processing speed (Lustig, 2003). Therefore, we hypothesize that if a transfer effect is
detected in a healthy population after training, this effect will be evident, and
probably even greater, in an older adult population. Healthy individuals are less prone
to show improvements immediately after training due to ceiling effects (Ball et al.,
2007), thus a group of older people, which has already experienced cognitive decline,
is more likely to exhibit a transfer effect. Furthermore, participants were required to
be Greek native speakers, to be able and willing to commit to the demands of the
experiment, and to have normal hearing and visual acuity. In order to rule out the
possibility that individuals with inherently better working memory or faster
processing speed were accidentally selected, all participants underwent an initial
working memory and vigilance assessment.

**Assessment Tasks**

*Digit Span:* The working memory assessment was a computerized version of
the ‘digit span’ task and was used to assess how many digits presented in a sequence
the participant can successfully recall. In the version we adopted a staircase pattern
where each successful trial was being followed by a new sequence, which was a digit
longer than the prior. Each unsuccessful trial was followed by a sequence, which was
a digit shorter than the last presented (Owen et al., 2010). Participants would recall
the digit list and use their keyboard to record their answer. The program would give
feedback to the participants by first showing them the word correct or incorrect
accordingly. Immediately afterwards the original digit sequence and below it the
recalled list would appear on screen. Participants could easily and quickly see at
which point they had made a mistake. The assessment was terminated when the
subject completed a total number of sixteen trials, either correct or incorrect. The
main outcome measure of the assessment was the average digit span. The digit span reported here is a mean of the 50% point of recall, which is actually the mean of the attempted lengths (Mueller, 2009; Mueller, Seymour, Kieras, & Meyer, 2003). The software was developed with Psychology Experiment Building Language (PEBL; a database of experiments that is freely available at http://pebl.sourceforge.net/).

Vigilance: In the vigilance assessment task, participants were asked to sustain their attention on letter stimuli, which appeared in the center of a computer screen. This assessment lasted around 14 minutes. Participants were required to respond to letter stimuli as soon as they detected them on screen, unless the letter that appeared was the letter “X”, in which case they were not supposed to do anything. The assessment included 18 blocks of trials. Each block had an inter-letter interval equal to 1000, 2000, or 4000 milliseconds, chosen randomly among blocks. Assessment was terminated after all 18 blocks were presented. The main measures for this assessment were mean response time, number of hits, and number of false alarms at each inter-letter interval. This assessment was also part of the PEBL battery mentioned above.

Experimental Tasks
As soon as initial assessments were completed, participants were assigned to one of three experimental groups. Participants, who had some experience with video games in the last twelve months, were assigned in the video game group, regardless of the type of video game they played. The rest were randomly assigned to the brain training groups. Each group underwent a different kind of training (see below). Prior to the initiation of training, participants of all three groups were asked to perform two temporal tasks; a reproduction and a production dual task. In the duration reproduction dual task, participants had to evaluate the display duration of a blue
square presented in the center of a computer screen. There were overall six possible target durations, 500 milliseconds and 1, 2, 5, 14, and 38 seconds. While participants were being engaged trying to evaluate the duration of the display, they had to perform a simultaneous secondary non-temporal task. Specifically, participants were asked to read aloud Greek alphabet letters, which were presented randomly in the center of the blue square at a random inter-stimulus interval ranging from 350 to 950 milliseconds (see Figure 3). At the beginning of each trial, the sentence “Evaluate the target duration” appeared at the bottom of the screen in Greek and the duration was presented (encoding phase; Pouthas & Perbal, 2004).

![Figure 3. A screenshot of the Reproduction Task.](image)

When the encoding phase was completed, the sentence “Reproduce duration just evaluated” was displayed in Greek, and the blue square reappeared, this time though without letters. Participants had to press the “Enter” button as soon as they judged that the previously displayed duration had elapsed in which case the blue square disappeared from the screen (reproduction phase; Pouthas & Perbal, 2004).
In the production dual task, participants were explicitly asked to produce a target duration given to them in conventional units (seconds or milliseconds). Specifically, at the beginning of each trial, a sentence like “Produce 2 seconds” appeared at the bottom of the screen. The blue square appeared, and participants had to press the “Enter” button as soon as they judged the specified time period to be over in which case the blue square disappeared. Apart from trying to keep track of time in the production phase, participants had again to read aloud letters of the Greek alphabet that appeared in the center of the square in random inter-stimulus intervals ranging from 350ms to 950 ms in this case also. Participants were told that they were being recorded whilst reading the letters. However, this was not the case; what actually happened was that the experimenter in the adjacent room ensured that participants conformed to the instructions provided.

At the initial experimental phase, the target durations were 5, 14, and 38 seconds (18 participants, 6 within each training group). Subsequently, three more durations were added, those of 500 milliseconds and 1 and 2 seconds (12 participants, 5 in the video game group, 3 in the braintwister group and 4 in the visual search group). We considered the additional durations necessary, because training tasks, which aim at processing speed as well as the video games, utilized trained very short time durations. Thus, it seemed probable that one would be able to detect a robust transfer effect in very short durations, even if one might fail doing so for longer time intervals.

Programming for both tasks (production and reproduction dual task), was implemented using the Neurobehavioral Presentation experimental control Software, a stimulus delivery and experimental control program for neuroscience.
Training Tasks: During the one-month training period, participants were assigned to one of three experimental groups. Participants with some experience in video games in the last twelve months were assigned in the video game group. The rest were randomly assigned in the brain training groups. The first group was trained on an action video game called Chicken Invaders (see Figure 4) developed by Interaction studios (Prouskas, 2002). A customized version of the game was given to the experimenters free of charge and a demo of the game is freely available at http://www.interactionstudios.com/.

Figure 4. Screenshot from the Chicken Invaders video game (Prouskas, 2002) utilized for training the processing speed group.

According to video game literature, action video games increase speed of processing without sacrificing response accuracy (Dye, Green, & Bavelier, 2009). The particular game chosen is a fast-paced video game in which participants have to shoot
chickens appearing at various unpredictable positions on the screen. In addition, participants have to avoid the eggs the chickens lay which will cause them to lose one of their lives in case they touch the spaceship they maneuver. Finally, apart from avoiding the eggs, they have to pick up as much as possible of the food and weapon upgrades that appear whenever a chicken is accurately shot. All of the above occur in rapid succession and participants have to remain focused in order to successfully progress in the game and react both quickly and accurately. The version which participants played was a customized version of Chicken Invaders 3. Specifically, whenever a participant quit the game, the developer of the program had arranged so that the experimenter would receive by email statistics regarding the session game duration, the accumulated duration the participant had spent on the game since he/she started training, the number of missions he/she had played, and finally the participant’s score. This way the experimenter was in a position to ensure that the participant actually followed the instruction provided and was progressing in the game.

The second experimental group engaged daily in a visual search task (Mueller, 2009), in which participants had to detect and identify specified targets within distractors (see Figure 5). The task was completed after 180 trials. The total duration depended on the participants’ speed and usually ranged from ten to fifteen minutes. Participants were encouraged to be as fast as possible, being careful though not to sacrifice accuracy. The difficulty of the task was varied in terms of color of target (same or different from the color of distractors), existent or non-existent target, display speed of the target, variable number of distractors, and variable number of targets. The main output measure concerned target detection time in the various conditions. However, whether the participant found the intended target was also
recorded. Participants had to mail the training log file every day to the experimenter in order to make sure that they conformed to the rules of the experiment and that their response times were actually becoming faster across the various conditions.

![Visual Search Training Task](image)

**Figure 5. Visual Search Training Task.** In this case participants have to press a mouse key as soon as they detect the target. Immediately afterwards, small circles substitute letters and participants have to click on the circle they previously detected the target.

Since speed of processing training involves computerized non-verbal exercises that are presented for a very brief period of time and require detection of a target, identification, discrimination, and localization (Ball, Edwards, & Ross, 2007), we consider this training software and video game suitable for processing speed training. However, one must take into consideration that any task designed to improve processing speed, definitely requires and affects other cognitive and sensory skills as well. This task is called “vsearch” and it is part of the PEBL battery, available at the PEBL experiment database previously mentioned.
The third experimental group was trained on a working memory task. In this task participants saw a series of stimuli (blue squares), which could appear at one of eight possible positions on screen at the rate of 3 seconds per stimulus. The participant had to decide on each trial whether the current stimulus matched the one presented \( n \) items back in the series. The value of \( n \) changed from block to block, according to the participants’ performance, incrementing by one when participants’ performance improved and decrementing by one item as participants’ performance worsened (see Figure 6).

![Figure 6: Screenshot from Braintwister n-back task. Introductory shot indicating at which shots the participant should have pressed A.](image)

Participants in this training group completed 15 minutes of daily practice on the n-back task. N-back is one of the training tasks of the “Braintwister” application developed by the Division of Experimental Psychology and Neuropsychology, University of Bern. The Braintwister application was given freely to us for the
purposes of the experiment and in this experiment we utilized the visual mode of n-back task. N-back is a rather demanding task for working memory since it requires both static storage processes (especially in the 0-back and 1-back conditions) as well as dynamic processes at higher levels in order to store, match, and update square positions according to the value of n (Jaeggi, 2005). In order to ensure that participants in this group actually conformed to the requirements of the experiment and actually improved on the task on which they were being trained, we monitored their daily progress, by having them email their log files to the experimenter and examining whether the mean level of n increased during the thirty day training period.

To summarize, all three groups underwent a thirty-day training period in which participants had to engage in the training tasks for fifteen minutes daily at a site of their choice (e.g., in the comfort of their own home). Their progress was monitored on a daily basis in order to ensure that participants followed the instructions and moreover that they were actually improving on the task on which they were being trained. Three participants were excluded from the study because they failed to conform to instructions. After the training period was completed, each participant was retested on the dual temporal tasks described previously in order to detect any changes regarding time perception.

Supposing our hypothesis holds (i.e., training benefits transfer to tasks different than those being trained), we should be able to detect effects on the temporal tasks as well, and participants should produce more accurate time judgments. Time perception according to AGM, shares many of the features and processes of the training tasks, yet, it is different enough to avoid mere practice effects.
Results

Training Task Results

In order to ensure that participants conformed to the instructions provided to them, and also in order to examine whether they actually improved on the task on which they were being trained their daily progress was monitored.

For the participants in the first experimental group (video game group), a log file regarding their progress in the game was emailed to the experimenters automatically at each participant game logout. The log file contained data regarding the participant’s session score, as well as the overall score he/she had achieved in the game during all his/her sessions. Furthermore, from the log file we could see the number of missions the participant had played. A new mission starts whenever a participant loses all his lives. From the scores it was evident that all participants steadily progressed in the game. According to self reports a number of participants ($N = 5$) completed the game and progressed to more advanced versions of the game. The log file also contained information regarding the time duration the participant played during each session as well as the overall time the participant had engaged in the game. This way the experimenters ensured that participants conformed to the time limitations set to them, according to which they had to engage in the game at least fifteen minutes daily. All participants in this group conformed to the instructions provided, and therefore no data have been excluded from the analysis for this experimental group.

Participants of the Braintwister group (i.e., trained on braining training software known to enhance working memory), emailed to the experimenters daily the
output file regarding their progress. Analysis of the training function revealed that
participants in this group improved steadily in their performance on the working
memory task (Figure 7).

![Braintwister](image)

**Figure 7.** In this figure performance enhancement in the Braintwister task is illustrated. For
each session, the mean level of n achieved by the participants is presented. The level of n-
back depends on participants’ performance.

Performing analysis of variance among the three ten-day periods of training,
showed that training performance varies as a function of overall training time.
Specifically, a statistically significant difference, $F(2,27) = 36.891, p < .001$, in mean
level performance was found among the first ten-day period in comparison to the
second, as well as among the third ten-day period in comparison with both the first
and the second periods as demonstrated by Bonferroni post hoc tests. These results are
compatible with previous research results (Jaeggi et al., 2008), according to which the
benefits of this brain training software are responsive to the dosage of training. In this
group, a total number of twelve participants were originally assigned, however two
participants failed to conform to the time constraints of the experiment and one
participant misunderstood daily practice guidelines. Therefore, the data of these three
participants were excluded from the analysis.
The third experimental group was trained on a visual search task (i.e., targeting enhancement of processing speed). Participants in this group also informed experimenters of their daily progress, by emailing the output file of their daily practice. In this case the response time in which the participant detected the target was the main measure of interest. Trials on each condition, on which the participant failed to identify the target among distractors, and instead designated a flanker, were excluded from the analysis. Therefore, the main measure for this group is the mean response time for correct trials across the various conditions. In Figure 8, the mean response time for correct trials achieved by the participants is presented. In this case no target was present and the number of distractors varied between three possible conditions (i.e., 10, 20, and 30 distractors).

![Processing Speed Training](image)

**Figure 8.** This figure shows processing speed enhancement in the visual search task. For each session, the mean response time for correct trials achieved by the participants is presented. The response time depends on participants’ processing speed. Response times are presented for conditions in which no target was present and number of distractors varied among 10 (blue), 20 (red), and 30 (green) distractors.

Analysis of the gain scores (last session response time – first session response time) demonstrated that participants became faster in their responses, with a gain of
449msec for the 10-distractor condition, 872msec for the 20-distractor condition, and 1378 for the 30-distractor condition. Furthermore performing an analysis of variance for response time across the three ten-day training periods revealed a significant difference for the condition at which 20 distractors were present, $F(2,27) = 23.420$, $p < .001$, as well as for the condition at which we had 30 distractors, $F(2,27) = 15.530$, $p < .001$. On the contrary, for the 10-distractors condition no statistically significant difference was found, $F(2,27) = 3.089$, n.s.

Similar results were obtained for the conditions in which one target was presented between flankers and the number of distractors again varied among 10, 20, and 30. The analysis of variance in this case resulted in statistically significant results across all conditions $[F(2,27) = 7.150$, $p < .003$, $F(2,27) = 4.887$, $p < .015$, $F(2,27) = 24.822$, $p < .001]$. In Figure 9 the mean response time for correct trials achieved by the participants is presented. In this case a single target was present, and the number of distractors again varied between 10, 20, and 30. Bonferroni post hoc tests revealed that for conditions with 10 and 30 distractors the difference was significant across all conditions. For the 20 distractors condition though, the difference was significant only between the first and third and final ten-day training period. These results indicate that the increase in processing speed in this case is also responsive to the amount of training.

Finally, for the last three conditions (Figure 10) in which five targets were presented between distractors, results were statistically significant across all conditions as revealed by the analysis of variance. For the 10-distractor and 20-distractor conditions the results were significant across all ten-day training periods $[F(2,27) = 5.751$, $p < .008$, $F(2,27) = 8.067$, $p < .002]$. For the 30-distractor condition, a statistically significant result was obtained only between the first and the last ten-day training period, $F(2,27) = 5.043$, $p < .014$. 
Figure 9. Processing speed enhancement in the visual search task is illustrated. For each session, the mean response time for correct trials achieved by the participants is presented. The response time depends on participants’ processing speed. Response times are presented for conditions in which a single target was presented among 10, 20 or 30 distractors, designated with the blue, red and green line respectively.

Figure 10. Processing speed enhancement in the visual search task is illustrated. For each session, the mean response time for correct trials achieved by the participants is presented. The response time depends on participants’ processing speed. Response times are presented for conditions in which five targets was presented among 10, 20 or 30 distractors designated with the blue, red, and green line respectively.
As it is well established in scientific literature, in this thesis as well it became apparent that participants across all experimental groups, succeeded in making progress on the task on which they were being trained.

**Temporal Tasks Results**

In order to examine whether any generalized benefits occurred due to training, participants were tested prior to the initiation and after the ending of training on two temporal tasks.

All statistic analyses regarding the temporal tasks were performed in terms of two performance indices, which were adopted to assess accuracy and consistency. The accuracy index was computed by taking the ratio of the produced or reproduced duration to the target duration (500msec, 1, 2, 5, 14 or 38secs). This index reflects the accuracy of temporal judgments and allows different target duration estimations to be compared. The other performance index is the coefficient of variability (CV) and it is computed by taking the ratio of the standard deviation to production or reproduction mean. This index represents the variability of temporal judgments of each participant and allows experimenters to evaluate how consistent participants were in producing or reproducing the same target duration. This index also allows for comparisons between different target durations.

**Production Task Long Durations**

Regarding the production task, according to our hypothesis, based on the AGM model we expected that participants would overestimate time durations. The reason for this overestimation is that when participants are occupied with a secondary task during time production, some pulses are lost and fail to pile up in the accumulator. As a result a greater number of pulses need to be accumulated in order
for the participant to judge the prescribed time period as being over and he/she is led this way to time overestimations. By refining cognitive processes, through video gaming and brain training, we hypothesized that if benefits generalize, participants should produce more accurate time judgments in post-test as compared to pre-test. In Figure 11 mean duration estimations (for long durations 5, 14, and 38 secs) in pre-test and post-test are presented.

![Figure 11. Mean duration estimations for the three experimental groups for the production task are presented in this graph for pre-test, as well as post-test. Mean duration judgments illustrate that participants in this case did not overestimate target durations in pre-test, as was hypothesized based on the AGM predictions.](image)

In this thesis, we failed to verify the hypothesis that participants would significantly overestimate target durations in pre-test ($M = 5.34, 14.26$ and 33.48 s for the 5-, 14- and 38-sec conditions, respectively). This finding however, is consistent
with other studies which also fail to verify the AGM model. Therefore, we believe that more research that will further elaborate and clarify the model is necessary. Furthermore, ANOVAs with two within-subject factors (duration: 5, 14, and 38 secs) (pre-test/post-test and one between-subject factor and (experimental group: videogame, braintwister, and visual search) carried out on time estimation accuracy index, revealed a main effect regarding durations $F(2,50) = 12.695, p < .001$. That is, participants were significantly more accurate in short durations of 5 seconds (mean = 1.063) as compared to 38 (mean = 0.872) seconds. Moreover, they were more accurate at the 14 seconds (mean = 0.987) duration as compared to 38 seconds.

Regarding participants accuracy in post-test as compared to pre-test, no statistically significant difference indicating generalized benefits, was found. In the following graph (Figure 12), pre- and post-test accuracy is illustrated.

**Figure 12.** Temporal accuracy (estimated duration / target duration) on production task, for the three target durations (5, 14, and 38 secs) across the three experimental groups (video game, working memory training, processing speed training).
Regarding the consistency of participants’ time estimations (Figure 13), an ANOVA with two within-subject factors (duration: 5, 14, and 38 secs and pretest/posttest) and one between-subject factor (experimental group: videogame, braintwister, and visual search) was carried out on time coefficient of variability index. Though the analysis revealed only a marginal effect regarding the test performance, $F(1,25) = 3.895, p = .060$, the results could be indicative that participants became more consistent in their time judgments in post-test as compared to pre-test. We believe that a larger sample of participants will further clarify this.

![Figure 13](image)

**Figure 13.** Coefficient of variability (standard deviation/mean production) for the production task, for the three long durations (5, 14, and 38 secs.) in pre-test and post-test and across the three experimental groups (videogame, braintwister, and visual search)

**Reproduction Task Long Durations**

According to the AGM literature, we hypothesized for the reproduction task that participants would underestimate reproduced time durations. The main reason for this is that when participants are occupied with a secondary task during encoding
phase, some pulses fail to add up in the accumulator, and as a result time intervals are stored as shorter (than they actually are) in working memory. As an outcome, the participant underestimates time durations during reproduction phase. Again, we hypothesized that if benefits due to training generalize, participants should be led to more accurate time judgments, at post-test as compared to pre-test.

Regarding our first assumption, participants in this case indeed underestimated time intervals (pretest 5 sec. mean = 4689.556, pretest 14 sec. mean = 9630.794, pretest 38 sec mean = 20555.806). In the following graph (Figure 14) participant time estimations in pretest and posttest are demonstrated.

**Figure 14.** Mean duration estimations for the three experimental groups for the reproduction task are presented in this graph for pre-test, as well as post-test. Mean duration judgments illustrate that participants in this case underestimated target durations in pre-test, as was hypothesized based on the AGM predictions.

Furthermore, ANOVAs with two within-subject factors (duration: 5, 14, and 38 secs and pretest/posttest) and one between–subject factor (experimental group: videogame, braintwister, and visual search) carried out on time estimation accuracy index (Figure 15), revealed a main effect regarding both the test and the duration factor. Duration reproductions were significantly more accurate in posttest than in
pretest, \( F(1,25) = 13.217, \ p < .001 \). Participants were significantly more accurate at the 5 seconds duration \( (M = 0.892) \) than at the 14 seconds \( (M = 0.739) \) and the 38 seconds duration \( (M = 0.576) \). Moreover, they were significantly more accurate at the 14 seconds duration than at the 38 seconds.

**Figure 15:** Temporal accuracy (estimated duration / target duration) on reproduction task, for the three target durations (5, 14, and 38 secs) across the three experimental groups (video game, working memory training, processing speed training). Participants were significantly more accurate at shorter durations and significantly more accurate at posttest than pretest.

Regarding reproductions variability, an ANOVA with two within-subject factors (duration: 5, 14, and 38 secs and test: pretest/posttest) and one between-subject factor (experimental group: videogame, braintwister, and visual search) was carried out on time coefficient of variability index. No statistically significant results were obtained in this case. Figure 16 shows the coefficient of variability across the three experimental groups and the various time interval conditions.
Contrary to what was expected, results failed to agree with the AGM model in the production task, and duration judgments were not overestimated as we expected. Participants did not become more accurate in their time estimations after the one month training period. However, certain trends show that perhaps participants become less variable. This might be indicating that even if our time perception does not get refined, it becomes more stable.

On the contrary, results regarding reproduction task durations judgments and accuracy, were completely compatible with the model. Participants underestimated time intervals when a secondary task was imposed during the encoding phase. Furthermore, participants became more accurate after the one month training period. This fact, supports the hypothesis of transfer of training benefits to untrained tasks. In
both cases however, further research, with a larger number of participants recruited in this case is necessary.

**Production Task Short Durations**

The short time durations (500msecs and 1 and 2 secs) experiment is still in progress and only a very limited number of participants (N = 10) has completed the experiment so far. Therefore we only have preliminary data available at this stage. Regarding the production task (Figure 17), an ANOVA with two within-subject factors (duration: 500msec, 1 and 2 secs and pretest/posttest) and one between-subject factor (experimental group: videogame, braintwister, and visual search) carried out on time estimation accuracy index, revealed again a main effect regarding durations. $F(2,14) = 5.229, p < .020$. That is, participants were significantly more accurate in longer durations of 2 seconds ($M = 1.171$) as compared to 1 ($M = 1.382$) seconds, and 500mseconds ($M = 1.553$). This finding is consistent with previous findings according to which people are better at temporal judgments at which target intervals are moderately short, and are worse at judging medium, long and very short durations. Specifically, individuals have a tendency to overestimate short durations (e.g. 500msec and 1 sec) and to underestimate durations which are considered to be longer (e.g. 38 sec; Hemmes et. al, 2004; Fortin & Rousseau, 1998)
Figure 17. Temporal accuracy (estimated duration / target duration) on production task, for the three target durations (0.5, 1 and 2 secs.) across the three experimental groups (video game, working memory training, processing speed training).

An ANOVA with two within-subject factors (duration: 500msec, 1 and 2 secs and pretest/posttest) and one between-subject factor (experimental group: videogame, braintwister, and visual search) was carried out on time coefficient of variability index (Figure 18). The analysis revealed again a main effect regarding durations $F(2,14) = 4.743, p < .027$, as well as a main effect regarding test $F(1,7) = 5.687, p < .049$. According to the data, participants time perception becomes more reliable after training, since variability is reduced at posttest ($M = 0.274$) as compared to pretest ($M = 0.364$). Regarding durations, participants are less variable at their time estimations concerning the 2 seconds time interval ($M = 0.203$) than they are for the 500msec interval. However, it should be stressed that the number of participants that have completed the short durations experiment is very limited and we only have preliminary data. As can also be seen from the graphs, the standard error is quite considerable.
Figure 18. Coefficient of variability (standard deviation/mean production) for the production task, for the three short durations (.5, 1 and 2 secs), in pretest and posttest and across the three experimental groups (videogame, braintwister, and visual search).

Reproduction Task Short Durations

For the reproduction task, ANOVAs with two within-subject factors (duration: 500msec, 1 and 2 secs and pretest/posttest) and one between-subject factor (experimental group: videogame, braintwister, and visual search) carried out on accuracy and variability indexes revealed a main effect for durations in both cases, $F(2,14) = 6.790, p < .001$ and $F(2,14) = 3.916, p = .045$ respectively. According to the data obtained participants are more accurate (Figure 18) at the 2 seconds durations ($M = 1.003$) than they are at the 1 second ($M = 1.379$) and at the 500msec duration ($M = 2.222$). Furthermore, participants are less variable (Figure 19) at the 2 seconds durations as compared to the 1 second ($M = 0.360$) and the 500 msec duration ($M = 0.230$).
**Figure 19.** Temporal accuracy (estimated duration / target duration) on reproduction task, for the three target durations (.5, 1 and 2secs.) across the three experimental groups (video game, working memory training, processing speed training).

**Figure 20.** Coefficient of variability (standard deviation/mean production) for the reproduction task, for the three short durations (.5, 1 and 2secs.), in pretest and posttest and across the three experimental groups (videogame, braintwister, and visual search).
Discussion

In this thesis, we utilized an action video game and brain training software in order to examine whether these kinds of software can be used as tools to refine specific cognitive processes. For the purposes of our experiment, participants were trained on selected software aiming at enhancement of processing speed and working memory for a thirty day time period. Apart from testing whether participants actually improved on the task on which they were being trained, we were also interested in examining whether these hypothetical benefits would generalize to tasks, beyond the ones being trained. Supposing generalization to untrained tasks actually occurs, new light could be shed to rehabilitation regimens, educational strategies, and training practices.

In order to examine whether generalization occurs, before the initiation and after the ending of training, participants were asked to perform duration production and reproduction dual tasks. According to time perception literature, the way we perceive time and make duration judgments is governed by cognitive processes such as processing speed and working memory. These processes are involved in different ways in production and reproduction tasks. We hypothesized that if generalization due to training actually occurs, alterations should also be detectable in the temporal tasks utilized in our experiment. Our work differentiates itself from other studies in aiming at examining whether enhancements will be detectable in a completely different task than the standard ones used for training. A considerable amount of studies (mostly on
video games), assert that generalization actually takes place. However, the tasks that are used in most of these studies, are fairly similar to the ones used for the training itself. We believe that this does not constitute robust evidence that general cognitive enhancement occurs. Participants in this case might get better on the tested paradigms, only due to excessive practice. After all human species have an enormous capacity for learning when properly trained. If our hypothesis holds, improvement will also be detected in temporal tasks, which are completely different than the ones used for training. Thus, it would comprise sufficient evidence to assert generalized cognitive enhancement.

Our experimental hypothesis was based on the AGM. The specific model was chosen because it incorporates cognitive factors such as working memory, processing speed, and attention in its framework. Furthermore, it is our opinion that the way in which these cognitive factors contribute to time perception needs further clarification and hence more research on the model is necessary.

According to our data, the participants in our experiment significantly improved on the tasks on which they were being trained. This is a common finding across research examining benefits of video gaming and brain training. This is rather unsurprising due to the immense ability of humans to learn virtually any skill, given the appropriate training (e.g., Bavelier, Green & Dye, 2009). In the paradigms adopted in this thesis, participants significantly improved on the working memory task on which they were being trained. Furthermore, their processing speed increased as was exhibited from the visual search task. However, does this learning constitute generalized cognitive enhancement? Furthermore, will these enhanced abilities carry on existing when continuous practice ends or will they deteriorate and eventually completely wear out?
In order to address the first question, we utilized the two temporal tasks described in detail in the methodology section of this thesis. In the production dual task, no statistically significant difference regarding the accuracy of the temporal judgments was obtained, neither for the long (5, 14, and 38 sec) nor for the short durations (.5, and 1 and 2 sec). Therefore, no generalization can be asserted based on these results. As far as variability is concerned, a statistically significant difference was obtained for short durations, indicating that participant judgments were less variable in posttest than in pretest. For the long durations, this difference was marginally significant. We believe this finding is rather important, because even though we failed to exhibit a generalized cognitive enhancement in the production task, we demonstrated that at least temporal judgments become more reliable. Participants themselves stated that they felt they became better at estimating time intervals as they progressed in the task, while most of them mentioned that they found this task extremely difficult in the beginning. One could argue that producing more reliable judgments in a way constitutes generalization of benefits. In any case, we will further examine this issue in future experiments.

In terms of the AGM, we failed to verify one of the basic predictions on which the production task was based. According to the model, sharing of attentional resources in the production phase should have led to overestimations of the targeted time intervals, as was explained in detail in former sections of this thesis. Furthermore, we hypothesized that if training benefits generalize, participants would produce more accurate temporal judgments in posttest as compared to pretest. Since we had hypothesized that time intervals would be overestimated in pretest, more accurate judgments actually implies shorter judgments in posttest than in pretest. However, participants did not overestimate time intervals in pretest and they didn’t
get significantly more accurate in posttest. This finding is not unique in this study. Other researchers have found unexpected results in terms of the produced durations (Pouthas & Perbal, 2004). It should be noted here, that research on duration judgments has produced diverse findings and conclusions. Many researchers agree that temporal estimates are usually shorter when a secondary non-temporal task is imposed under estimation, production and reproduction procedures (e.g. Block, 1992; Macar, Grondin, & Casini, 1994). According to other researchers however, temporal judgments are not conformed to shortening under concurrent non-temporal tasks, but lead to overestimation of shorter intervals and underestimation of longer durations (e.g. Kladopoulos, Hemmes & Brown, 1997). One should take into consideration that temporal judgments are subject to many methodological issues, in which the kind of the adopted paradigm (prospective vs. retrospective judgments) and the estimation method (verbal estimation, time production, time reproduction, and comparison) play a significant role. Each method actually activates different time-related processes, thus yielding different responses (Grondin, 2008; Zakay, 1990).

Regarding the reproduction dual task, statistically significant results were obtained concerning both accuracy and duration. As we had predicted, based on the AGM, participants underestimated time intervals when a secondary task was imposed during the encoding phase. Furthermore, participants became significantly more accurate after the one month training period for the long time intervals (5, 14, and 38 sec). This fact establishes that training benefits transfer to temporal perception in terms of reproduction. No statistically significant results however, were detected in regards to accuracy for the short durations (.5, 1 and 2 sec). As it has already been mentioned though, only a limited number of participants has completed the experiment for the short durations so far. Therefore, no safe conclusions can be drawn at this point. As
far as variability is concerned, no statistically significant results were obtained for the long durations. On the other hand, a statistically significant result showed that participant judgments regarding the 2-sec time interval were more reliable than their judgments concerning the .5- and the 1-sec interval.

There are various reasons for explaining the failure to detect a generalized cognitive enhancement in the production task as a result of brain training and video gaming. First of all, perhaps the selected software was not the most appropriate. The software we selected targeted processing speed and working memory. Particularly, they targeted working memory and processing speed for visual stimuli. The AGM, however, does not make clear the exact way in which these two processes contribute in time perception. We assumed that the selected software would yield the desired outcome, since the temporal tasks adopted for pretest and posttest also addressed the visual modality. However, taking into consideration that all video games or brain training software are not created equal, it was really difficult for us to point out the critical components that a software must bear in order to lead in modifications in certain domains. We should note here however, that statistically significant results regarding accuracy were detected in the reproduction task. Therefore, it seems highly improbable that the selected software were not the appropriate one. Perhaps then, the temporal tasks that were used for benchmarking were not the most appropriate ones. According to the model however, they are sufficient since they incorporate the exact same processes we aimed at improving. The question however that arises is how sensitive they are in reflecting even minor changes in the fundamental processes that govern its function. Taking into consideration that one of the most basic assumptions (overestimation of time intervals in production task) failed to be verified, a finding of other studies as well (Pouthas & Perbal, 2004), we infer that further clarification and
elaboration of the model is necessary. This is also supported by the fact that in reproduction task participants got significantly better and all predictions regarding underestimation of durations got confirmed. There is a possibility that production and reproduction tasks are not governed by the exact same processes after all.

It is also important to consider the chance that perhaps the thirty day training period was not enough to produce a measurable effect in the production task. Given however, that a considerable effect was detected in the reproduction task it seems reasonable that this period should also be sufficient for the production task as well. Furthermore, taking into consideration the fact that participants started to exhibit evidence of progress on all three paradigms as soon as the first ten-day period had elapsed, renders the possibility that the training period was not adequate to seem highly unlikely. However, it should not be ignored that participants demonstrated statistically significant difference in their performance from ten-day period to ten-day period. Therefore; the possibility that a more extensive training regimen might have eventually produced a transfer effect in terms of production also cannot be excluded.

Another major shortcoming of this experiment is the limited number of participants that have completed it so far. Presumably, a larger number of participants might have succeeded in producing a significant transfer effect in the production task as well.

Another factor that should be considered is that the way in which training is administered plays a significant role on how sufficient it is. It is important that the task utilized remains demanding at all times but is not overwhelming. In our case, the Braintwister task constantly adapted its difficulty level depending on the participants’ performance. In the visual search task, however, even though there were different levels of difficulty these levels did not vary in accordance to participant’s response time but were presented in random order. In the video game the difficulty would
increase steadily as long as the gamer did not lose, but would return him/her to anchor points in the game, whenever the gamer lost all of his/her lives and the game was terminated. To achieve maximum enhancement as an output, the game difficulty must be manipulated as to be “just barely too difficult” for the participant since this mode of training produces the largest training gains. A training regimen harder or easier than that may cause learning to be less efficient (e.g., Ball et al., 2007; Green & Bavelier, 2004). Thus, had we used a video game and processing speed task, that would fully adapt to participant’s performance might have yielded stronger effects in both temporal tasks.

Furthermore, this training study differs from others because its participants were healthy young individuals with ages ranging from 18-35 years old. Older people who have experienced cognitive slowing and memory deficits are probably more likely to receive the greatest possible benefits from processing speed and working memory training. Therefore, we believe that if we had recruited a group of participants comprising of older people the exhibited effects would be much stronger. However, this is only an assumption that future research will either confirm or reject. Another question that arises is how long do train effects retain after the termination of training? The answer of this question is out the scope of this thesis. Answering it requires longitudinal studies, and prolonged observation and monitoring of the same participants’ cognitive processes. It would be really interesting to examine whether people that are habitual VGPs or engage regularly in brain training software maintain enhanced cognitive abilities for a longer period of time or are in a reduced risk to be diagnosed with dementia. There have been a number of longitudinal studies regarding brain training for a time period up to five years (e.g., Ball et al., 2002; Willis et al., 2006) but no longitudinal studies that we know of concerning video games. The field
requires more studies which will include a large number of participants (not necessarily elderly), long-term follow up, and examination on how video gaming and brain training influence the everyday lives of those involved.

As was shown in this thesis there is evidence of transfer of training benefits to untrained tasks, such as the reproduction dual task utilized in this case. It is important that this finding was detected in a completely different task than the training paradigms adopted. Therefore, generalization of training benefits can be asserted in this case. This is a rather important finding since various groups of people can benefit from video gaming and brain training software. Currently, many researchers are interested in developing video games and brain training software, that will be specifically designed to enhance cognitive, perceptual (e.g., Nintendo Brain Age), and motor skills by incorporating specific characteristics. The most important application that training might have is for rehabilitation of individuals with reduced perceptual or cognitive functioning such as the elderly. Old people are the ones who suffer most from memory deficits, hand-eye coordination, reduced processing speed, reaction times etc. As a result their quality of life is often negatively influenced. Using appropriate training regimens, specifically designed for their needs, will allow them to maintain their cognitive capabilities and executive functioning for a longer period of time. Thus, they will be capable of postponing the natural consequences of aging and live independently for many years more. Furthermore, scientists are studying whether it is possible not only to keep declines at a steady point after they have first initiated but also whether they can through training reverse them (e.g., Green & Bavelier, 2004). Video gaming and brain training could also be used to help children who exhibit attention deficits or people who suffer from specific visual problems (e.g., amblyopic). Brain training and video gaming can be used for training specific
professionals whose jobs require enhanced perceptual capabilities such as pilots or surgeons (Green & Bavelier, 2004).

The ways that video gaming and brain training can aid specific populations are endless. Taking that into consideration as well as the fact that information technology is an important part of our lives nowadays video gaming and brain training software may be providing the medium that facilitates learning, reshapes, and enhances visual-motor, spatial, and cognitive skills. Before, however, using any type of software to train particular processes, the characteristics that a brain-training program or a video game must bear in order to enhance the targeted processes, as well as the training schedule that will be followed should be carefully designed. Video game and brain training research is a new field of research seeking to exploit the endless possibilities of the human mind and its amazing capability to be reshaped by experience.
REFERENCES


Brain and Vision Lab at the University of Rochester. (n.d.). Brain and Vision Lab at the University of Rochester. Retrieved 2011 03-08 from http://www.bcs.rochester.edu/people/daphne/games.htm


