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Does adding cue-directed action improve the learning of prime numbers in adults?
An exploratory study on action video games for learning based in neuroscience research

Does adding cue-directed action improve the learning of prime numbers in adults?

An exploratory study on action video games for learning based in neuroscience research

By

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SYNOPSIS

This study aimed to combine two theories that attempt to explain the influence of video games in learning, namely reward and action theories. Participant performance in an experimental game involving reward was compared with performance on a similar game which added an action feature. Learning under these two conditions was measured by recording the difference between pre-test and post-test response time (RT) and accuracy. These behavioural measures are complemented by self-reported perceptions of enjoyment, engagement and learning.

The research hypothesis ‘Adding cue-directed action improves the learning and of prime numbers in adults’ could not be statistically supported. However, other findings arising from measures in accuracy and speed as well as from the self–reported perception might be of interest in the design of further research in this area.

This current exploratory study cannot offer conclusive findings on the difference between a video game containing a cue-directed action and one without, but it might be of interest for future researchers wanting to explore novel educational ways to improve human learning based on neuroscience research.

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Carolina Gordillo

AUTHOR'S DECLARATION

I declare that the work in this dissertation was carried out in accordance with the regulations of the University of Bristol. The work is original except where indicated by special reference in the text, and no part of the dissertation has been submitted for any other degree.

Any views expressed in the dissertation are those of the author and in no way represent those of the University of Bristol.

The dissertation has not been presented to any other University for examination either in the United Kingdom or overseas.

Signed _______________________ Date: _____________

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Abbreviations

ACh: Acetylcholine

AVG: Action video game

AVGP: Action video game player; action video game playing

DA: Dopamine

fMRI: Functional magnetic resonance imaging

LTM: Long-term memory

MTL: Medial temporal lobe

NAcc: Nucleus accumbens

NAVG: Non-action video game

OFC: Orbitofrontal cortex

PE: Prediction error

PET: Positron emission tomography

PFC: Pre-frontal cortex

RT: Response time

STM: Short-term memory

VG: Video game

VGP: Video game player; video game playing

VTA: Ventral tegmental area

Chapter 1 Introduction

1.1 Overview

The proliferation of personal computers has facilitated the growth of video game (VG) and animation industry. The magnetic appeal of video games produces a level of engagement that every teacher would like to witness in their classrooms in the quest for an atmosphere especially conducive to learning. The increased access and popularity of VG has captivated the attention of researchers who see their potential to enhance learning by raising motivation. Though researchers have not yet fully how that engagement occurs, theoretical frameworks attribute it to the subjective experience and enjoyment of playing games as well as certain VG characteristics that make the experience enjoyable (Boyle et al., 2012).

Research on video games began with negative aspects, for example their implication in the development of violent and aggressive behaviours (Anderson and Bushman, 2001; Anderson, 2004; Gentile et al., 2004). The focus has progressively changed and today studies on video game playing (VGP) have shown positive effects on a series of skills related to enhanced learning, such as spatial cognition (Green and Bavelier, 2007), visual working memory (Boot et al., 2008), task-switching (Green et al., 2012), vision's temporal and spatial resolution (Green and Bavelier, 2006; Greenfield et al., 1994), sustained, selective and divided attention (Dye et al., 2009a), auditory perception (Barlett et al., 2009) and increased speed processing (Dye et al., 2009b).

Additionally, the advent of novel techniques for studying the human brain, such as functional magnetic resonance imaging (fMRI) has deepened knowledge and generated further questions for research studies in VGP. This has also contributed to the growing interest in neuroscience within the educational field with researchers aiming to complement theories of learning with new neurological data (Howard-Jones, 2008). However, this connection still has to mature in order to generate a framework of research in the area of human learning and education.

The positive effects of VG create the potential for using educational games aimed at supporting learning through non-traditional classroom methods. Kirriemuir and McFarlane, (2004, p. 4) describes two crucial themes in the development of educational games, namely:

1 – The desire to replicate the engagement and motivational elements of video games to "*make learning fun*".

2 – The belief that the "*learning by doing*" effect of games may be an effective learning tool.

Unfortunately, educational video games have not been as successful as entertainment video games from a motivational perspective because they have failed to include elements that produce engagement and motivation in players, such as uncertainty, competition or action. Instead, they are too simple and repetitive (Kirriemuir and McFarlane, 2004). Hence, they have failed to satisfy the expectations of regular gamers who, by playing educational video games, eventually realise of its disguised purpose of 'learning' which is distant and different from the entertainment one.

Therefore, there is a need for bridging studies that will combine neuroscientific findings of how the human brain responds to engagement and motivation with developing VGs for an educational purpose that feature the requirements to achieve such engagement and motivation.

1.2 Statement of the problem

It is a truism that in order to learn, a person must be willing; that is, they must be motivated and engaged. The question of how that occurs in human beings is an important one for educational settings of diverse nature. Therefore, it is necessary to bridge the understanding between motivation, cognition and emotion (Howard-Jones et al., 2011) in order to instil learning with the excitement produced by video games. Where these three intersect, neuroscience and education can combine to study and explain the phenomenon of video game engagement and learning and transferring this potential knowledge to the design of educational games.

The neuroscience of motivation and learning is one area that has shed light on learning environments and teaching practice from the perspective of reward and related dopaminergic activity (Wise, 2004).

There are two parallel explanations within neuroscience of how video games act in the brain to influence learning in adults, namely **reward theory** and **action theory**. Each stresses distinct video game features that activate different neural mechanisms via neuromodulator release.

Reward theory

Reward theory considers the influence of uncertain rewards during the gaming process. These have been shown to increase the levels of dopamine (DA) in the midbrain (Howard-Jones and Demetriou, 2009). This dopamine release has been associated with enhanced attention and memory encoding (Shohamy and Adcock, 2010; Shohamy and Wagner, 2008) as well as motivation (Berridge and Robinson, 1998). These, in turn, influence the learning rate in various learning stages from declarative to non-declarative memory systems.

Action theory

This theory considers the influence of acetylcholine (ACh) as a neuromodulator in the reported tendency of a specific type of video game (action games) to enhance a range of cognitive functions (Green and Bavelier, 2006). Acetylcholine is involved in the encoding of memories (Kukolja et al., 2009) and also orienting (Dye et al., 2009a). The latter is one of the visual attention process components (together with alerting and executive control) which uses spatial cues to focus attention to the position of an approaching stimulus. Orienting has been associated with ACh release in the fronto-parietal region (Corbetta and Shulman, 1998; Wilson et al., 2005). Acetylcholine's role in learning games seems to be triggered by a shift between cues and cue-directed action (Bavelier et al., 2012b; Howe et al., 2013).

Even though these two theories emphasise different features of video games (uncertain reward and fast-paced actions), it may be hypothesised that when combined in a video game, they might have an even greater influence in learning. Uncertain reward, on the one hand, would increase the level of dopamine release and therefore players will increase their levels of engagement and motivation. This will make players more attentive and receptive to new information within the game. On the other hand, cue-directed action would increase the level of acetylcholine release which has been associated with enhanced memory. Therefore, players will not only be more engaged and motivated but also their memory encoding and retrieval capacity would be enhanced. These two processes seem to be essential in learning consolidation which are understood as basic elements of education (Carew and Magsamen, 2010). Hence, these were the processes – engagement and memory – this study intended to precipitate via an experimental video game based on the features of reward and action.

1.3 Purpose of the study

The purpose of this exploratory study was to compare the learning of prime numbers in university students under two conditions: an experimental video game combining elements of reward and action theories versus another version of the game containing just the reward feature.

Studies have examined the influence of different game genres in learning (Amory et al., 1999; Green and Bavelier, 2006; Papastergiou, 2009). However, the study of educational VGs designed to enhance engagement and learning according to neuroscientific findings is rather rare. Furthermore, to the researcher's knowledge there is no study yet based on the combination of these two features within a VG aiming to explore the learning of an educational concept.

Using the *Zondle*[1] interface, two versions of a game on prime numbers were created for this experiment. The content of the game was based on two corpora of prime numbers. To measure participants' learning, pre- and post-tests were applied in which accuracy of responses as well as response time (RT) were recorded. Accuracy and speed of response were taken as indicators of learning. Additional data from participants regarding their attitudes and experience with video games in general and with this particular experimental video game were gathered via a post-test survey.

Due to the combination of action and reward features, a higher level of learning as measured by higher scores was expected in participants in the action game. Also, increased speed in response was expected as a result of learning automaticity.

[1] Zondle is a free educational application that allows to create, share, and play games in order to support learning and teaching in any subject, language, level and place (https://www.zondle.com).

Another aim of the study was to determine whether participants' preference for action video games (AVG) and self-reported engagement and learning influenced their performance.

1.4 Definition of terms

1.4.1 Learning

Many terms, including the concept of learning, are understood differently in the distinct areas of neuroscience and education. From a neuroscience view, learning corresponds to a change in behaviour involving any of the multiple memory systems. Corresponding biological changes also happen, i.e. in the brain, at both connectivity (neuronal networks) and structural (brain regions) levels. This can be observed in blood flow variations associated with the activated brain area. Activation shifts from one region to another depending on the learning stage, e.g. according to whether it is conscious (initial stages) or automatic (higher level of mastery) (Patel et al., 2013; Tracy et al., 2003). This interdependence of brain regions indicates that learning occurs through shifts in the intertwining of networks rather than in isolated brain regions.

From an educational perspective, potential explanations of learning have an eclectic basis including contributions from psychology and educational theories as well as cultural ideas and values (Howard-Jones, 2008). In addition to neurological activity, this conception of learning includes cultural, social and emotional aspects.

From this perspective, it seems that the biological and neurological contexts only provide a partial explanation of this multifaceted concept.

However, neuroscience explanations complement the social, cultural and emotional aspects of learning rather than replace them (Goswami, 2012). It is important to note that neuroscience findings are not of direct application to pedagogy. This knowledge needs to be mediated by educational tools, such as teaching knowledge, strategies and methodological resources. Hence, studies in the interface of neuroscience and education, such as the current one can seek to bridge these two perspectives by suggesting improvements that are grounded on relevant neuroscientific findings and eventually agreeing on a more integrated conceptualisation of learning.

For the purposes of this study, learning was understood from a combined perspective, acknowledging the fact that a change at neuronal level occurs as a consequence of external stimuli but also integrates elements of previously stored memories or knowledge in its processing. Therefore, findings from this study need to be understood in their particular and restricted neuroscientific meaning and further discussed under wider umbrella of the educational meaning, considering their implications and limitations to real learning contexts.

1.5 Research questions

This research work will revolve around the aforementioned aims through the following main research question:

1. What difference does it make to add cue-directed action to a video game in the adult engagement and learning of prime numbers?

And the following secondary research questions:

2. Is there a relationship between self-reported perception of engagement with the two video games and actual learning?
3. Is there a relationship between self-reported perception of learning with the two video games and actual learning?

This introduction presented the reader with a contextual overview of this research, including the background, need and main purpose of the current study, including the research questions. Chapter 2 contains a theoretical framework giving a detailed account of the neuroscientific findings of the two theories (reward and action) as well as a summary of the role video games have played in education. Chapter 3 describes the design used in this research. Chapter 4 deals with the presentation and analysis of results. Finally, chapter 5 contains the discussion and conclusions based upon the findings. In addition to addressing the research questions, this section also analyses those findings and suggests methodological improvements and ideas for further research in the area of learning through video games.

Chapter 2 Literature review

Research has examined the potential positive effects of VGs including their possible contributions to education. Neuroscience techniques have also broadened our understanding of the use of VGs for learning. Two theories provide support for the potential of VGs to aid learning, namely reward and action theories. In turn, they are supported by the activity of two neurochemicals which are related to motivation and engagement (dopamine) and memory encoding and retrieval (acetylcholine).

This literature review seeks to provide a framework for understanding the influence VGs might have on cognitive processes that affect learning by looking into brain processes involved in engagement and motivation. First, it presents an account of the relationship between VGs and learning and education with the potential benefits of entertainment VGs and the lack of engagement produced by educational VGs. Much has been researched on the characteristics VGs should have to be appealing to users. Recent research has developed into studying brain activity when being engaged on VGs. Neural elements and brain structures whose involvement in the effects of VGs in human behaviour has been suggested will be part of this literature review.

2.1 Video games in learning and education

Video games started as a popular form of entertainment around the 1980s. By the onset of the millennium, the flourishing industry of VGs had pervaded the lives of most young people in the developed world (Amory et al., 1999). The engagement that seems to captivate people's attention when they play VGs has been attributed to certain common characteristics – curiosity, fantasy and challenge – that contribute to establishing its central feature, being fun or appealing (Malone, 1981). Additionally, elements such as complexity and novelty are thought to contribute to the fun aspect of gaming (Malone, 1984; Rivers, 1990).

VGs are also perceived as being closely associated with learning (Amory et al., 1999). In an extensive review, Connolly et al. (2012) reported studies that claim that computer game play influenced areas such as perception, cognition and motivation as well as behaviour and the acquisition and comprehension of knowledge. According to Bavelier et al. (2012a), different cognitive abilities can be enhanced through the use of VGs; not because the games are designed to teach those abilities but because they indirectly facilitate the development of new skills that enable a better learning.

The effects of VGs have been researched in different dimensions including genre and outcomes classification (Connolly et al., 2012). Although there is no a standardised categorisation of game genres, VGs generally follow Herz's (1997) video game industry taxonomy which seems relevant for entertainment games but not so much for learning games. According to this classification, VGs may be distinguished as action games (generally characterised as the first-person shooting game, or where the task needs speed and accuracy to be achieved; some exhibit a great deal of violence as well), adventure games (a virtual world that needs problems to be solved to move forward), puzzle games, fighting games, simulations, role-playing games, strategy and sports games. This research will deal with a non-violent action game (AVG) in which the idea of movement and speed will be present.

2.2 How games improve cognition

As playing VGs is associated with learning, the need to distinguish and classify learning outcomes has also been discussed. A basic categorisation includes the learning of (motor) skills, cognitive outcomes (procedural, declarative and strategic knowledge) and affective outcomes (attitudes or beliefs) (Garris et al., 2002). More complex models add to the above mentioned motivational outcomes as well as learner's performance (Connolly et al., 2008).

Regarding cognition, video games players (VGPs) seem to do better than those who do not play VGs in several cognitive abilities such as spatial cognition (Green and Bavelier, 2007), visual working memory (Boot et al., 2008), task-switching (Green et al., 2012), and cognitive flexibility (Colzato et al., 2010). However, not all studies have been conclusive. Bailey et al. (2010) suggest that video game playing (VGP) negatively influences proactive cognitive control, essential for an individual to maintain goal-directed action in a non-engaging context. Although, the educational field may benefit from this potential enhancement in cognitive abilities through VGP, the findings by Bailey and colleagues may seem of particular interest for a real classroom setting in which it might be difficult to consistently provide a high level of stimulation for all students. On another note, Maass et al. (2011) challenges the benefits of VGs with data suggesting that high arousal games interfere with cognitive functions.

2.2.1 Acquisition of knowledge

Research has also addressed VGs used to support knowledge acquisition for both secondary and tertiary education in diverse curricular domains. Although findings are not conclusive yet, there have been improvements in memorisation of concepts and better knowledge of certain content areas such as computer concepts (Papastergiou, 2009) or cancer knowledge (Beale et al., 2007). However, a study comparing learning of paediatric knowledge through an online game versus using computer flash cards revealed that although students showed a preference for learning through games, this did not result in a difference in performance between the treatment and control groups (Sward et al., 2008).

Other studies in which elements of competition and feedback were introduced in games oriented to the acquisition of knowledge revealed that performance was not improved by the competitiveness but by feedback provided about the scores (Cameron and Dwyer, 2005) or feedback in the form of examples (Yaman et al., 2008).

2.2.2 Perceptual domain

Amongst the benefits accounted for the use of AVGs in the visual area, vision's temporal and spatial resolution, sensitivity and contrast seem to be enhanced (Green et al., 2010a; West et al., 2008). This finding is related to the ability to filter distractors in the visual field efficiently which leads to enhanced visual attention.

2.2.3 Attentional domain

The **attentional** domain also seems to be influenced by AVG play with a difference between the control directions of the attentional process (bottom-up or top-down). No differences were found in bottom-up attentional control between players and non-players, whereas top-down attention (sustained, selective and divided attention) were enhanced in individuals who played VGs in comparison to non-players (Dye et al., 2009a).

2.2.4 Problem-solving and decision-making domains

Regarding **working memory** and **problem-solving skills**, (Barlett et al., 2009) found that VGP improved performance on tasks involving working memory, auditory perception, addition and selective attention. At a higher level order of thinking, games demonstrated to provide complex situations to be solved that would support decision-making in real contexts (Mayer et al., 2004).

AVGs also seem to have a beneficial influence in **decision-making**, i.e., processes in which individuals use accumulated information over time to take action (Bavelier et al., 2012a) revealed that VGP enhanced the rate of information accumulation over time and that decisions made by players improved compared to a control group in terms of both speed and accuracy. This enhanced probabilistic inference suggests the possibility of VGs to teach how to learn.

All this research has deepened our understanding of the impact of VGs in diverse aspects of human behaviour and cognition. However, the questions of how transferable to real world these skills still remains unanswered. In fact, Bavelier et al. (2011) claim that such enhanced skills are rarely transferrable. However, Franceschini et al. (2013) showed in their study that dyslexic children who played AVGs daily for 80 minutes in nine sessions dramatically improved their reading abilities. Nonetheless, Green and Bavelier (2003) claim that this enhancement of certain abilities depends on the frequency and regularity of VG play.

Research in the area of VGs for learning is relatively new and involves much speculation and little hard evidence that supports a connection between their use and learning or cognitive enhancement (Connolly et al., 2012). Very little research regarding VGs and education is conducted in an authentic context such as the classroom, partly due to difficulties related to familiarisation of teachers with the software, curriculum constraints, and relevance and functionality of the content of the game (Kirriemuir and McFarlane, 2004). One of the implications for future research in this area as suggested by Perrotta et al. (2013) is to explore the inside of VGs from the specific mechanisms and principles of game-based learning to see how these elements influence learning in educational settings. To this, it may be added that looking inside the brains and see which processes and brain regions are involved when feeling engaged by VGs would complement the view proposed by Perrotta et al. (*Ibid.*) to design a correspondence between the inside of the video game and the inside of the human brain.

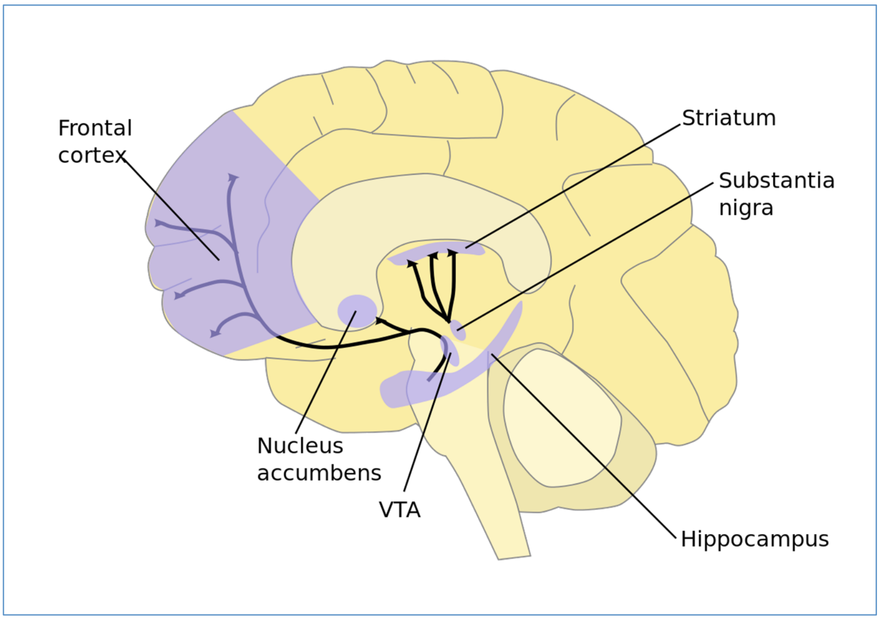
Consequently, it has been difficult to devise an underlying theory of VGs with regards to learning. The gains in cognitive improvement are not conclusive and literature seems divided regarding the impact of games on academic performance. The use of diverse research designs and the lack of a detailed explanation on the same affects the strength of the evidence found in this field (Perrotta et al., 2013). Despite this difficulty, findings converge into two possible theories based on the underlying neural processes of learning through games. The first, known as reward theory, relates to the sense of reward and gain and dopamine (DA) release in the midbrain, and will be reviewed in the next section. The second (reviewed in section 2.4) is the action theory, which is associated with the release of acetylcholine as a support of memory and learning.

2.3 Reward theory and video games

VGs seem to have elements that attract their users and enable them to develop skills according to the parameters outlined in section 2.1. The brain's reward system may be involved in this engagement.

A reward that comes to be associated with a pleasant stimulus acts as a reinforcement of behaviour. However as Berridge and Kringelbach (2008) noted, the reward is not the stimulus itself but the process of reacting to a stimulus produced within the brain and mind interface, implying the significance of previous experiences in this process.

From an anatomical perspective, the brain's reward system is a group of brain structures whose function is to control and regulate behaviour through the release of dopamine in the ventral tegmental area (VTA), nucleus accumbens (NAcc) and part of the prefrontal cortex (PFC). When the reward system experiences a pleasurable response to an external stimulus, the cerebral cortex sends a signal to the VTA which releases dopamine to areas in the midbrain, such as the NAcc and the hippocampus (Image 1). This dopamine release codes the level of desire and attention in relation to anticipated reward so that individuals act in the same way a next time in case needed (Clark et al., 2010). This mechanism explains how survival behaviours are learned in animals. In humans, however, in addition to primary rewards like nutritional or reproductive, there are also secondary rewards, which are not required for survival but desired for pleasure. Midbrain dopamine levels are associated with motivation for pleasures such as food, sex and gambling (Elliott et al., 2000).



Source: Wikimedia Commons (public domain) (Quasihuman, 2012).

Image 1: Dopamine projections in the brain.

From a psychological perspective, Berridge and Robinson (2003) have identified three elements involved in reward which makes this process more complex.

a) 'Learning' which entails the ability to represent and predict future rewards based on past experiences. This may lead to explicit and implicit knowledge.

b) 'Liking' or the pleasure of a reward, associated with opiates in the brain and can be conscious or unconscious.

c) 'Wanting' or the motivation, which processes can be conscious or implicit salience.

Dopamine's function in reward is related to the mediation of the 'wanting' but not the 'liking' or 'learning' element (Berridge, 2007). The 'wanting' aspect of a reward is coded by the level of midbrain dopaminergic activity (Berridge and Robinson, 2003). This is key to understanding that from the moment a VG is associated with learning, the attraction and engagement is lost. And with this, the chances to improve learning through an educational VG disappear.

Although there is not much direct evidence, there may be a close relationship between rewards and the engagement produced by VGs. It was Koepp et al. (1998) who first provided evidence of striatal dopamine release in humans during the performance of a motor task provided by a VG. With this study, the connection between behavioural manipulation and the release of dopamine was validated. However, a decade later the team participating in this research revisited it to illustrate possible biased results as a consequence of head movement in the scanner or changes in regional cerebral blood flow in the detection of striatal dopamine (Egerton et al., 2009). Also this research confirmed that it is mainly in the striatum where changes in levels of extracellular dopamine can be confidently detected.

Nonetheless, other studies have confirmed evidence preliminarily presented by Koepp et al. (1998). In their study about gender differences in brain activity while playing VGs, Hoeft et al. (2008) showed significant general activation in NAcc and OFC (orbitofrontal cortex) which together with the ventral striatum are involved in the prediction of future reward. On another note, Weinstein (2010), in his study of

VG addiction, revealed increased levels of dopamine release during VGP in healthy individuals whereas former ‘ecstasy’ consumers’ dopamine release was very little presumably as a result of sensitisation to the drug.

The challenges that VGs pose to their players can be explained by this dopamine-reward system. When players experience progress in their level of achievement, i.e., when they see that they perform the correct action and that is rewarded, they feel the pleasure associated with dopamine and continue playing under a motivational engagement (Willis, 2010). As dopaminergic activity in the midbrain would increase with the experience of pleasurable emotions, that is when the response to a stimulus is correct, decay in dopamine level will occur if the choice turns to be incorrect. In order to keep engagement and avoid frustration produced by constant mistakes, immediate feedback is important in order for the brain to avoid a future mistake (*Ibid*).

Additionally, the level of **predictability** of an outcome affects the level of dopaminergic activity (Schultz et al., 1997). The **prediction error** (PE) ratio, or the value that the outcome exceeds the expected one, makes people adjust predictions of a reward. Therefore, short-term historical context has an effect on the individual’s response to a reward. This can be understood as the experience of the ‘happy surprise’ (Howard-Jones et al., 2011) in which people would experience unexpected gains, adjusting their knowledge of the context and changing their preferences accordingly. Naturally, individuals will look for the scenario with the higher gains according to their experiences. If the outcome is below the initial expectation, then as the surprise is not a 'happy' one, there is a readjustment of PE. However, major spikes of DA are produced when surprise of an unexpected outcome (positive or negative) occurs. The connection between these two elements sheds light on the appeal of chance-based games even when most of the times people encounter a loss over a gain (Shizgal and Arvanitogiannis, 2003).

In addition, the anticipated reward size or value also influences dopaminergic activity in the striatum. However, this does not mean that the higher the reward, the higher DA levels. Activation of DA increases at the same rate for the best reward according to each situation (Knutson et al., 2001; Nieuwenhuis et al., 2005). Once again, the context can modify the response to a reward.

It must be noted that most of the knowledge from dopamine and reward comes from initial studies in animals and primates and as such they have limitations in the understanding of reward processes and learning in adults and children. Still, without those studies it would have been impossible to know details about projections of dopamine, since this kind of experimentation would be impossible to conduct in humans. Fiorillo et al. (2003), for example, in a study conducted in primates emphasized the concept of **uncertainty** and its relevance for estimating the accuracy of predictions because a reward that is not expected by the individual generates more dopamine activation than a reward that was completely expected (Berridge and Robinson, 1998). Uncertainty is another typical feature of VGs that may explain their engaging capacity for users.

Nonetheless, efforts to apply findings of this kind to human learning and in connection with VGs are being made. Howard-Jones and Demetriou (2009) provide evidence for the influence of uncertainty in engagement in computer-based learning games. When presented with uncertain gaming conditions, children as well as adults demonstrated greater preference and factual memorisation (children) and greater engagement with learning via affective response (adults).

These findings on the reward system and its relation to learning appear to be relevant to the use of learning VGs. The combination of elements that enable individuals to engage in learning tasks that relate to dopaminergic activity in the midbrain would contribute not only to produce interest and pleasure, but also to greater motivation, attention and memory (Willis, 2010). The relation between reward and memory systems seems plausible in the understanding of human learning. This relationship of DA and memory will be explained in the following section.

2.3.1 Effects of dopamine on memory

Dopamine is a neuromodulator that has been reported to have an essential role in cognitive disorders when their release shows malfunction (Montague et al., 2004). It is found across four main systems in the brain. Two of them are involved in reward and reinforcement (the mesolimbic system projecting to the NAcc) and in supporting cognitive activity (the mesocortical system, extending to the prefrontal cortex) (Clark et al., 2010).

Dopamine signals are related to reward and motivation but also to memories that meet these characteristics. The neuronal mechanisms of dopamine suggest its putative role in specific aspects of cognition like feedback processing and reward prediction (Shohamy et al., 2008).

To understand better the relationship between DA and memory, it is important to briefly review on memory systems. Memory has been widely studied and its representations and theoretical modelling have developed over time. Two main types of memory can be distinguished, namely short-term memory (STM) – also called working memory – and long-term memory (LTM), also known as episodic memory (Ward, 2010). STM stores limited information for a short time and can also be of use when performing tasks of major complexity (Baddeley, 2009). In LTM, a broader distinction of concepts can be found between declarative or explicit memory and non-declarative or implicit memory. While declarative memory involves the remembering of specific events (episodic memory) as well as the accumulation of general information or facts about the world (semantic memory), non-declarative memory refers to a form of knowledge that has been learnt and is reflected more on performance rather than through remembering (Baddeley, 2009).

Whatever the framework for memory is used, all acknowledge its importance for learning and performing cognitive tasks, such as solving problems. Dopamine has been related to modulation of memory as it modulates brain areas which in turn are connected to memory formation or storage such as the **hippocampus** (Shohamy and Adcock, 2010) or the **striatum** (Bäckman and Nyberg, 2013). The medial temporal lobe (MTL) is also implicated in the recalling of past events and the ability to imagining the future (Schacter and Addis, 2007).

Anatomical studies in animals have shown that dopamine has proven to be key in hippocampal LTM because it affects long-term potentiation (Otmakhova and Lisman, 1998), which is long-lasting increase of the synaptic strength between two neurons, and the persistence of episodic memories (Bethus et al., 2010; Rossato et al., 2009). Hippocampal outputs act as facilitators of dopamine signals in the midbrain, which enhances plasticity in the hippocampus through dopaminergic release (Lisman and Grace, 2005).

Dopamine neurons work in two modes, namely tonic and phasic (Grace et al., 2007). While in tonic mode, dopamine neurons maintain a permanent baseline level in the neural circuits. However, in the phasic mode their firing rates show dramatic increase or decrease, causing great changes in dopamine concentration (Schultz, 2007). Although there is no knowledge of how memory formation is modulated by dopamine (Shohamy and Adcock, 2010), tonic responses seem to have an important function in dopamine neurons via two mechanisms. The first refers to tonic activity influence in the increase of hippocampal dopamine in an indirect way through phasic bursts of dopamine. The second refers to the direct modulation of hippocampal encoding through tonic dopamine.

Evidence from fMRI, PET and genetic studies have shown that dopaminergic midbrain regions modulate episodic memory when interacting with the hippocampus under particular behavioural situations (Shohamy and Adcock, 2010). This circuit follows three general principles which are related to novelty engagement in modulation of the hippocampus; anticipation of reward as a driver in the interactions between hippocampus and midbrain dopamine regions; and application of memory in experiences supported by hippocampal-midbrain interactions.

Novelty

It has been demonstrated that novelty of the stimuli greatly activates the hippocampus and midbrain dopaminergic regions during memory encoding tasks (Kumaran and Maguire, 2006), which in turn increases the degree of synaptic plasticity in the striatum (Redgrave and Gurney, 2006).

Reward prediction

There are multiple ways in which hippocampal and midbrain activity seems to be modulated by reward (Shohamy and Adcock, 2010). Reinforcement learning assumes that PE is coded by dopamine release (Schultz et al., 1997), modulating plasticity in areas of both hippocampus and striatum, which work together in driving learning (Shohamy et al., 2008). However, it is important to note that although these two brain regions interact and share mechanisms, it is thought that they encode different types of memory, conforming two dissociable neural and cognitive systems: procedural memory and declarative memory (Doll et al., in press). Reward prediction is primarily associated with procedural memory (non-declarative) which has a more implicit and inflexible character and is reliant on the striatum (*Ibid.*). The hippocampus is thought to encode a more relational and declarative type of memory (conscious). There seems to be a connection between reward, midbrain activation and episodic memory, as reward-predicting stimuli seem to be associated with episodic memory for the reward cues used in the task (Wittmann et al., 2005). However, this activation of the midbrain takes place not only with reward cues but also when the encoding of memories is motivated through reward (Adcock et al., 2006). Therefore, episodic memory seems to be biased in order to keep information related to rewards.

Application

Representational flexibility, which leads to knowledge generalisation, seems to be another characteristic of episodic memory modulated by the interaction between hippocampus and midbrain. (Shohamy and Wagner, 2008) have shown that participants with greater activation of both hippocampus and midbrain simultaneously during learning could generalise what they have learned in a completely new situation with more accuracy and speed. The action of dopamine in facilitating this integration is not clear in this case. However, it is thought that a mismatch of signals sent to the hippocampus triggers midbrain dopamine in a similar fashion than when novelty or reward cues are at stake (Shohamy and Adcock, 2010).

Additionally, different studies (Bethus et al., 2010; Rossato et al., 2009; Singer and Frank, 2009; Wittmann et al., 2005) have demonstrated that the action of dopamine extends over a range of times: before, during and after an event. This evidence shows the presence of dopamine even before an experience and can last for a number of hours or days. In terms of learning, the relevance of this finding lies in the key feature of dopamine not only as a biological signal for teaching, but also would indicate the right moment of the signal to be used for producing learning (Shohamy and Adcock, 2010).

Research in humans has reported connections between future goal-directed behaviour and episodic memory. Shohamy and Adcock (2010) coined the term 'adaptive memory' to explain the process by which dopamine influences the episodic memories that will be formed and the way in which they will be represented and thus allowing the use of past experiences to be used in novel situations in a more accurate way. They also propose a framework that considers dopamine as a signal for learning based on salient events and expectations to account for motivation and its influence on memory.

The reward theory provides a plausible explanation for understanding the engagement experienced with VGs due to the correspondence between the elements of reward and most of the characteristics these VGs display. Additionally, the neurochemical relation of dopamine and memory sheds light on the processes occurring in the brain and by which this learning may be instigated and retrieved later for acquiring new knowledge, as in a permanent and enriching life process.

Sections 2.3 and 2.3.1 described how reward theory supports the understanding of learning at brain level when is triggered by a stimulus such as VGP. However, most of the cognitive enhancement produced by VGs appears to be confined mainly to the action genre (Bavelier et al., 2012a; Bavelier et al., 2012b). This has given rise to another theory supporting the learning through VGs, namely **action theory** and which will be reviewed in the following section.

2.4 Action theory and video games

This distinction in VG genres has been used for some time by various researchers conducting their studies specifically using AVG (Bavelier et al., 2012b; Green and Bavelier, 2003; Greenfield et al., 1994; Spence and Feng, 2010). These games are characterised by particular features like speed (with objects appearing and disappearing in the visual field; high-velocity moving objects), motor, cognitive and perceptual tasks (monitoring multiple and simultaneous characters and activity in several motor plans to make a choice), spatial and temporal uncertainty, and prominence to peripheral visual processing (as objects do not always appear in the centre) (Bavelier et al., 2011; Green et al., 2010a, 2010b).

Studies on AVG focus mainly on the possible effects that VGs featuring an action element have in comparison with the non-action ones. Also, they study the differences between action video game players (AVGP) and non-action video game players (NAVGP). The effects of AVG seem to be greater in regular players than in non-players and range from enhancement of cognitive abilities to therapy for impaired abilities (Bavelier et al., 2011) mainly in the domain of attentional and perceptual abilities (Green and Bavelier, 2012).

Action theory maintains that given the characteristics of AVG in terms of encouraging rapid continuous cue-directed motor responses, playing them regularly would help facilitate the identification of relevant information and the omission of distracting and irrelevant information, thus improving individuals' attentional control levels. This would enable people's capacity to adapt to new environments or learn new skills more rapidly (Bavelier et al., 2012b; Green and Bavelier, 2012). In fact, regular AVG players showed better performance of probabilistic inference than NAVG players (Green et al., 2010b). This is a reflection of the enhanced capacity of making decisions based on limited information that is not always developed through the AVG environment, which can be assimilated to most everyday situations in life (Bavelier et al., 2012a). Therefore this transferable skill would contribute to the enhancement of individuals' capabilities and performance in diverse tasks oriented to learning.

However, the idea of games in education to improve learning has existed long before the appearance of VGs. In the early 20th century, educational psychologist Alfred Binet used to ask his students to play games in which for a prolonged time they had to stay quiet, still and focused in order to learn how to concentrate attention in order to acquire the academic contents, because attentional control was considered an essential ability to learning (Binet, [1909] 2010). Based on the concept that other skills need to be developed in order to learn, (Green and Bavelier, 2012) suggest that AVGPs do not learn any one particular skill through VGs, but develop an enhanced capacity to learn regular patterns from the environment thus being able to perform more readily and accurately in novel situations. In other words, AVG play would be associated with learning to learn (Bavelier et al., 2012a) which is what most educational systems seek today.

In addition to the role of dopamine, it is also believed that a neuromodulator called acetylcholine (ACh) is involved in the allocation of cognitive resources as a result of playing AVG, although not through a direct link (Bavelier et al., 2012a; Bavelier et al., 2012b). Acetylcholine release regulates the attention paid to targets and distractors making it possible for a better allocation of perceptual resources. One function of acetylcholine is facilitating the plasticity of the cortex, which in turn has a role in the allocation and control of cognitive resources (Kilgard and Merzenich, 1998; Minces et al., 2013). Acetylcholine marks an expected uncertainty that interacts with other uncertainty signals in order to allow inference and learning in environments that are changeable and normally full of other stimuli (Yu and Dayan, 2005).

2.4.1 Effects of acetylcholine on memory

Acetylcholine has been long studied in neuroscience since its presence was discovered in mammals (Dale and Dudley, 1929). This neurotransmitter reaches two receptors, namely nicotinic (fast-acting) or muscarinic (slow-acting) (Clark et al., 2010). Mostly studied from a pharmacological perspective, the "cholinergic hypothesis" has its main and most recent subject of study based in impaired cognition and dementia and from there its relation to cognition and memory (Contestabile, 2011). The link is suggested because in Alzheimer's disease a deficit in working memory, attention and learning may be associated with a reduction of acetylcholine in the hippocampus and the cortex (Drever et al., 2011). Both acetylcholine receptors have been suggested as neuromodulators of synaptic plasticity in particular in the hippocampus – in the septohippocampal pathway –

where memory and learning are possibly rooted (Drever et al., 2011; Parent and Baxter, 2004).

Additionally, it has been hypothesized that the level of acetylcholine release influences the level of contributions of the neural systems to learning (Gold, 2003). However, Kukolja et al., (2009) studied the influence of cholinergic stimulation on episodic memory encoding and retrieval using fMRI. Memory encoding was enhanced but retrieval was interfered at the neural level. Acetylcholine is strongly associated to synaptic plasticity due to its influence in restoring memory. However acetylcholine's connection with memory and learning is still not completely understood.

Micheau and Marighetto (2011) consider that acetylcholine would then help coordinating the different memory systems and show a biphasic influence by establishing times and separating the encoding, consolidation and retrieval processes of memory and thus decreasing the interference in the learning process (Easton et al., 2012). The biphasic hypothesis plays with the levels of cholinergic activity which, according to the memory phase, can act favourably or detrimentally. In the presence of higher hippocampal cholinergic activation during training or tasks being performed there will be a facilitated processing of new information, which corresponds with the encoding phase of memory. However, when cholinergic activation diminishes, after finishing the task, the consolidation of information in the long-term memory occurs (Micheau and Marighetto, 2011) (Image 2).

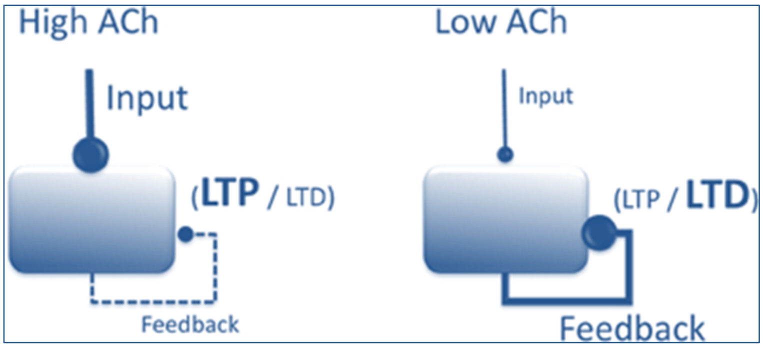


Image 2: Representation of ACh modulation effects (Newman et al., 2012)

Memory enhancement may arise by the action of different processes influenced by acetylcholine. For example, a greater strength in the afferent input to the cortex or a major modification of synapses through the enhancement of long term potentiation, particularly in the hippocampus which effects may be relevant for the encoding of new episodic memories (Hasselmo, 2006; Pepeu and Giovannini, 2004).

It has been traditionally believed that acetylcholine is a slow-acting neuromodulator that affects arousal states. However, cholinergic activity acts at various time fluctuations (tens of seconds, seconds and minutes) supporting and mediating cognitive and behavioural operations (Parikh and Sarter, 2008; Sarter and Bruno, 1997).

Regarding the cholinergic release, Howe et al. (2013) provide evidence of a neural mechanism that would support shifts from monitoring period to cue-directed behaviour in rats and humans. In the monitoring state, subjects keep their attention to the external environment waiting for a possible signal to appear. When a signal is detected this monitoring phase stops and then attention becomes an inward process, in order to retrieve rules associated with the signal and prospects to confirm a reward-leading response. These shifts between these two states in agreement with the detected tasks can be observed in several quotidian situations such as a musician who expects a cue to change the rhythm or a person working in quality control in a processing line waiting for a cue to pick a product for inspection, or a student in foreign language class waiting for a cue to know how to continue the conversation or in a maths class with an equation to be solved monitoring it first for a cue to indicate how to begin solving it.

Action theory and acetylcholine as its key neuromodulator provide a complementary approach to understand how some of the most used VGs have been suggested to produce such higher cognitive enhancements. Although dopamine and acetylcholine have been studied in relation to their influence in cognitive function in humans, their connection to AVGs is more recent and understudied. This involves challenges for methodologies and interpretations of results that need to be addressed in order to develop a less elusive theory of learning through VGs.

2.5 Summary

Two theories have been proposed for explaining the influence of video games in learning, namely reward and action theories. Neuroscience research has shed light on the brain mechanisms involved in these processes which are associated to the influence of neurochemicals – dopamine and acetylcholine – in the midbrain regions related to engagement and memory encoding and retrieval. Hence, they seem to have a close link to learning particularly of skills contributing to that learning to occur.

Whereas dopamine release is related to reward and its links to uncertainty and error predictability, acetylcholine is connected to fast-paced actions in which there is a shift from cues to cue-directed actions for its release.

Reward and action theories do not necessarily compete. In fact, together they seem to have a potential role in the success of a new type of learning VGs that include them both.

The elements of reward and rapid action are perceived by game-makers as essential features that increase pleasure and therefore engagement in the activity. Research in off-the-shelf AVG has demonstrated numerous enhancement in cognitive skills which seem to be key for learning development. However, these AVGs are not particularly intended to teach a specific content and most educational software seem to have failed in the inclusion of these features together, making them too obviously educational and perceived as not fun at all.

This research intends to explore chances of learning the specific content of prime numbers through a purpose-based VG containing the key elements from both reward and action theories. Speed and accuracy of responses will serve as indicators of learning in this study.

Chapter 3 Methodology

This chapter describes the methods used to examine whether adding action to a VG strengthens the capacity of the game to improve learning in adults, through increased engagement.

3.1 Design and research questions

Design

The study followed a pre-experimental pre-test – post-test design. The dependent variable – learning, defined by the difference in RT and score between the pre- and post-test – was recorded under 'Game' and 'No Game' conditions (this being the independent variable). A within-participants approach was adopted in order to control for individual differences and to give more power to the influence of independent variables (Field, 2012).

Participants completed four computer-based tasks based on prime numbers. Two of the activities were pre- and post-test and two others comprised the conditions for the experiment. Pre- and post-tests scores were recorded, along with RT. Any improvement between the pre- and post-test measurements was considered an indicator of learning. Scores and RTs from the two experimental conditions were also recorded in order to identify the most successful condition in terms of learning.

This research was mainly of quantitative nature with some qualitative aspects elicited through a post-experiment survey. The survey aimed to complement the experimental data in order to gather a more complete account of the experience of using video games for learning.

This research explores learning through use of VGs. Learning is defined in terms of a change of performance after the experimental conditions were applied.

Research questions and hypothesis

The main research question was set up in advance to serve as a guide for the study. Further, more specific research questions arising from the literature review were treated according to the 'Russian doll principle' (Clough and Nutbrown, 2007) to define them more precisely every time there was a new piece of information related to them. This rephrasing of research questions helped to deepen the understanding of the main research question as well as the research methods to be used.

The following research questions were addressed in this study:

Main research question

1. What difference does it make to add cue-directed action to a video game in the adult engagement and learning of prime numbers?

Secondary research questions

2. Is there a relationship between self-reported perception of engagement with the two video games and actual learning?
3. Is there a relationship between self-reported perception of learning with the two video games and actual learning?

The main research question stated as a hypothesis for this study is:

H1: A video game with a cue-directed action improves adult engagement and learning of prime numbers.

These additional hypotheses will be tested in the present study:

H2: Accuracy of recognising primes as measured by score in pre-test, post-test will be significantly higher in post-test compared with pre-test.

H3: Speed of recognising primes as measured by RT in pre-test, post-test will be significantly higher in post-test compared with pre-test.

H4: Pre-test – post-test differences in score will be significantly greater in the Game condition compared with the No Game condition.

H5: Pre-test – post-test differences in RT will be significantly greater in the Game condition compared with the No Game condition.

H6: Participants will prefer the game containing the action feature.

H7: Learning achieved in the action and non-action games will be correlated with self-reported engagement.

H8: Learning achieved in the action and non-action games will be correlated with self-reported learning.

3.2 Research setting

The experimental phase took place during the month of July in a dedicated room in the Graduate School of Education at the University of Bristol. Sessions were held individually with each participant and the researcher either in the morning or afternoon. The atmosphere was quiet and free of distractions enabling participants to concentrate on the task.

3.3 Participants

The study was conducted in female and male adults between 20-42 years old (*M* = 28.3 years). Thirty-two (32) participants were required in total in order to generate four groups of eight. Participation was voluntary and sampling was accessed via snowballing and open invitation to University students. As this is a university with an international hallmark, the sample included diverse nationalities and ethnicities. Participants did not receive payment or other incentive for taking part in this study.

3.4 Materials

3.4.1 Game software

The tasks were based on a computer game, *Action Rig*, created for the purpose of the study by adapting the *Zondle* interface (footnote 1). The game was based on the content of prime numbers[2], an area of knowledge that requires the application of a rule to determine them.

Players needed to select the prime number from a range of numbers shown. The game comprised two conditions for this game, namely '**Game**' and '**No Game**'.

The 'Game' condition involved the movement of an object in the screen, which had to be chased (on the screen, using the computer mouse) by the participant. This object was a square with a changing number inside. When the number turned into a prime, the participant had to click on it in order to select the answer (Figure 1).

Figure 1: Action Rig's Game condition screenshot. The box with the number moves around the screen.

In the 'No Game' condition the number square did not move. When the number turned into a prime number, the participant was asked to click on the button labelled SELECT on the screen or on the actual number square (Figure 2).

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[2] A prime number is an integer that has only two factors, 1 and itself. Thus, '3' is a prime number because it has only two factors, namely 1 and 3, whereas '9' is not a prime as it has more than two factors, namely 1, 3 and 9.

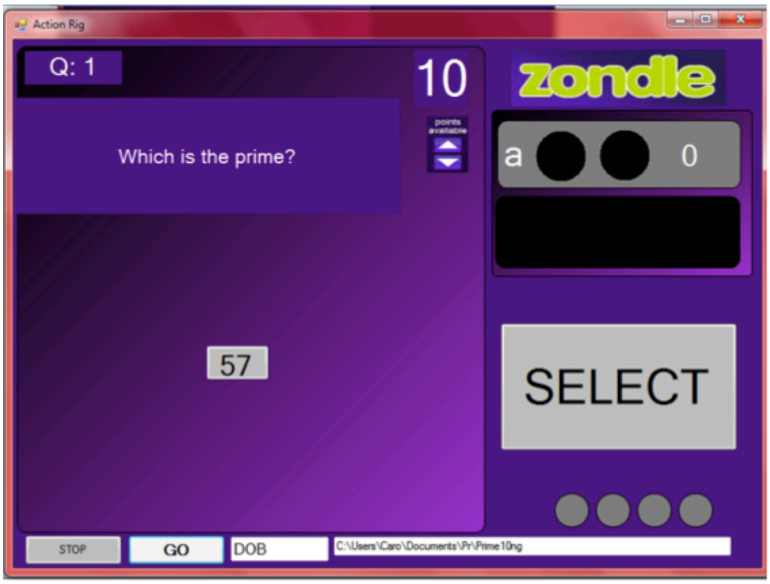

Figure 2: Action Rig's No Game condition screen. The box with a number remains static as the number changes.

In both experimental conditions, a green screen appeared for positive feedback following any correct response (Figure 3).

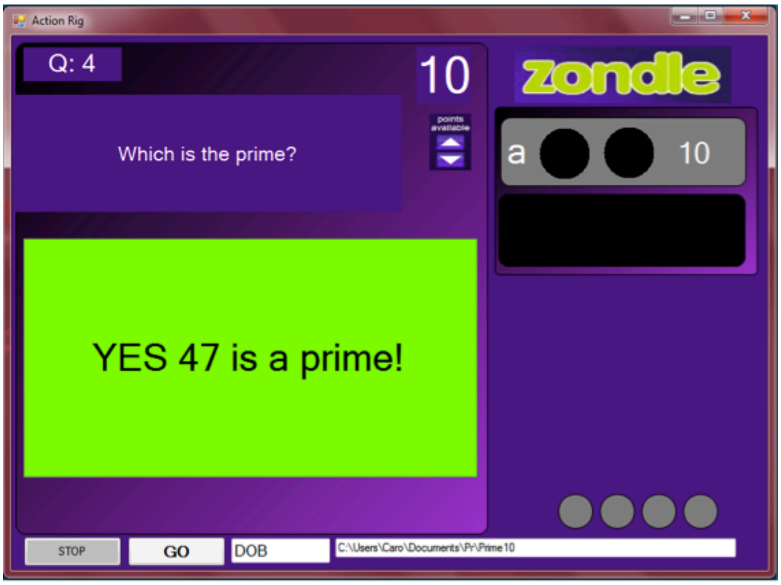

Figure 3: Positive feedback screen after a correct answer.

When the answer was incorrect, a red screen appeared explaining the mathematical reason for the incorrect answer, giving as well feedback that would increase their knowledge and avoid future mistakes (Willis, 2010) (Figure 4).

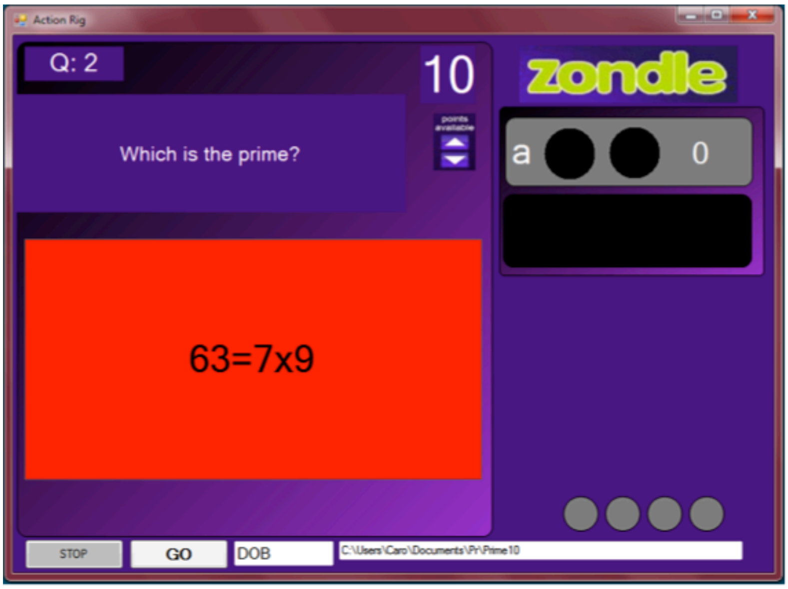

Figure 4: Feedback screen after a wrong answer.

The game comprised two corpora of prime numbers, which were randomly mixed by the software each time the game was played. **¡Error! No se encuentra el origen de la referencia.** shows the sets of prime numbers (shaded) selected for the game. These were obtained through an exploratory study further explained in section 3.6.1.

	Corpus 1 prime numbers			
Q1	4	2	6	8
Q2	17	12	15	27
Q3	28	29	33	39
Q4	44	47	49	51
Q5	57	61	63	69

	Corpus 2 prime numbers			
Q1	6	9	10	13
Q2	15	19	21	27
Q3	33	40	42	43
Q4	49	51	59	63
Q5	71	75	81	87

Figure 5: Corpora of prime numbers (shaded) used in Action Rig game.

Each version of the game consisted of 15 questions, so every prime number appeared three times. Each question comprised the sequence of numbers in random order.

The games recorded automatically measures of accuracy (scores) and speed (RT per answer).

3.4.2 Pre- and post-tests

All participants underwent a pre- and a post-test. The aim was to ascertain a baseline for each participant on knowledge of prime numbers and response time (pre-test) and to establish the difference in RT and accuracy between pre- and post-test after the experimentation of two conditions of VGs. These differences were considered an indicator of learning for the purpose of the experiment. There was also a second post-test, namely retention post-test (R-post-test) applied after some days in order to measure the level of retained learning. This post-test was identical to those applied before and after the experimental conditions.

Both pre- and post-tests were computer-based tasks too, but did not have elements of gaming such as the score or feedback on the choices made. However, they were time-based and there was a consuming time bar indicating the remaining time. Both pre and post-tests consisted of 10 multiple-choice questions in which participants had to choose the correct prime number out of a list of numbers presented (Figure 6). Data collected from these tests was expressed in seconds for RT and points up to 10 for accuracy of responses.

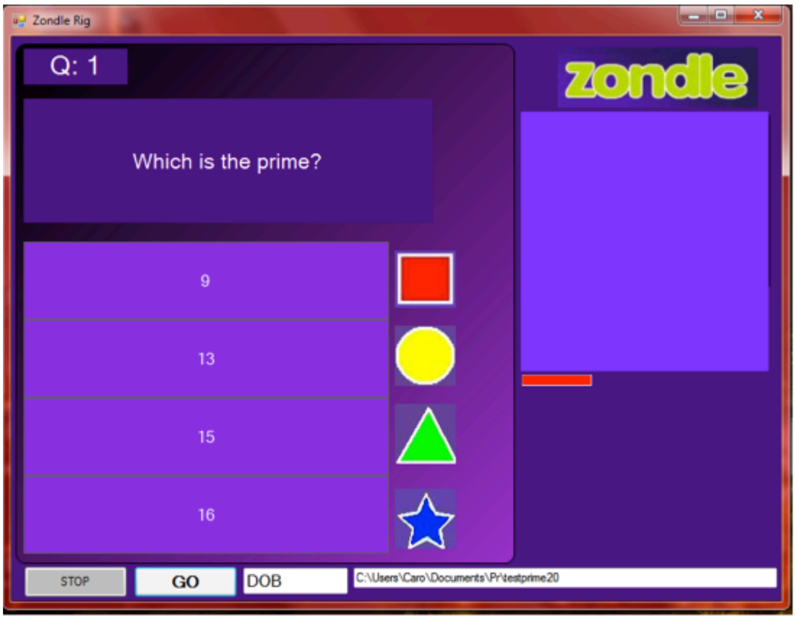

Figure 6: Pre- and post-test screenshot. Participants used the labelled keyboard to choose their answers.

3.4.3 Experiential survey

A Likert-scale survey and open-ended questions were used to obtain additional details of individual perceptions in order to explain any unexpected results derived from the experience with the games (Appendix A: Experiential survey on video games). The survey explored participant's perceptions in three domains: experience with video games in general; experience with the prime number games; and attitudes towards video games. A section of open-ended questions explored more detailed perceptions of the gaming experience.

3.4.3.1 Likert scale

a Experience with video games in general

This section asked about the participant's level of enjoyment, usage and engagement of both learning and action video games. It also gave participants the chance to express their self-perception regarding how good they would consider themselves at playing video games.

b Experience with prime number games

This section explored the participant's perception of their level of engagement, learning and difficulty of both conditions of the prime number video game. In particular, participants had the chance to express their preference for any of the conditions of the game.

c Attitudes towards video games

This section asked about the participants' attitudes to video games. It contained statements based on issues related to video game playing.

3.4.3.2 Open questions

Three short questions gave the participant the opportunity to express him or herself more extensively. This section also asked whether they would be inclined to repeat the experience of playing this game and to project how much they would remember of this experience of playing a video game.

Responses were coded following a content analysis perspective (Silverman, 2011) through iterative coding. Concepts such as reward, engagement and challenge were expected to be elicited under the reasons for preferring one condition over the other. Likewise, asking for the missing elements of the game intended to get information on what are the features that add to engagement or excitement with VG.

The analysis of results in section 4.5 details content categories established for the purpose of content analysis.

3.5 Validity and reliability

The computer applications (the games and the pre- and post-tests) were piloted in 6 people. These participants, who did not take part in the main study, were also asked about their experience with the game in terms of engagement, challenge and self-reported learning. Their answers in both game and feedback suggested that the corpora of prime numbers were easily identified, reducing the challenge level of the game. Hence, it was decided to conduct an exploratory study to seek for validity of the corpora used (see 3.6.1). This enabled the selection of the numbers for the two game corpora (¡Error! No se encuentra el origen de la referencia.**) based on authentic material. The level of difficulty was also raised in order to give the game greater challenge (Appendix C: Prime number corpora**

Original game corpora	**Modified game corpora used in this study**

Corpus 01 prime numbers			
4	5	6	8
7	8	9	10
30	31	32	33
36	37	38	39
42	43	44	45

Corpus 1 prime numbers			
4	2	6	8
17	12	15	27
28	29	33	39
44	47	49	51
57	61	63	69

Corpus 02 prime numbers			
8	9	10	11
12	13	14	15
20	21	22	23
27	28	29	30
47	48	49	50

Corpus 2 prime numbers			
6	9	10	13
15	19	21	27
33	40	42	43
49	51	59	63
71	75	81	87

Appendix D: List of results per case – RT and accuracy

PRE-TEST						POST-TEST						DIFFERENCE POST-TEST - PRE-TEST			
est 1	RT Pre-test Corpus 2	Mean C. 1&2 Pre-test	Score Pre-test	correct Corpus 1	correct Corpus 2	RT Post-test Corpus 1	RT Post-test Corpus 2	Mean C. 1&2 Post-test	Score Post-test	correct Corpus 1	correct Corpus 2	difference score	Diff. RT Corpus 1	Diff. RT Corpus 2	Learning from pre- and post-test (RT)
.06	5.99	6.02	9	4	5	4.40	4.61	4.51	9	5	4	0.00	1.65	1.38	1.52
.07	5.92	5.00	9	5	4	3.40	4.16	3.78	10	5	5	1.00	0.67	1.77	1.22
.86	4.96	3.91	7	4	3	4.85	3.65	4.25	8	4	4	1.00	-1.99	1.31	-0.34
.84	7.08	6.46	8	5	3	5.36	7.40	6.38	7	4	3	-1.00	0.48	-0.31	0.08
.03	5.63	5.83	4	3	2	6.75	6.62	6.69	6	3	3	2.00	-0.73	-0.99	-0.86
.94	13.97	11.95	8	4	4	8.02	7.80	7.91	10	5	5	2.00	1.92	6.16	4.04
.75	5.27	5.01	10	5	5	1.89	2.80	2.34	10	5	5	0.00	2.86	2.47	2.66
.35	12.42	13.88	6	4	2	4.73	6.50	5.62	8	3	5	2.00	10.62	5.91	8.27
0.4	7.0	8.7	6	3	3	6.16	5.16	5.66	7	4	3	1.00	4.23	1.84	3.03
4.0	3.5	3.7	10	5	5	2.38	2.41	2.40	10	5	5	0.00	1.58	1.09	1.34
6.2	6.4	6.3	7	4	3	4.51	5.59	5.05	8	4	4	1.00	1.65	0.84	1.25
6.2	7.7	6.9	3	1	2	4.03	5.12	4.58	8	3	5	5.00	2.16	2.58	2.37
4.7	3.7	4.2	8	5	3	3.99	3.98	3.98	9	5	4	1.00	0.74	-0.26	0.24
3.3	3.7	3.5	10	5	5	2.55	2.44	2.50	9	5	4	-1.00	0.73	1.29	1.01
7.9	7.3	7.6	6	2	4	6.10	5.76	5.93	8	4	4	2.00	1.82	1.55	1.69
8.0	15.9	17.0	6	3	3	8.02	13.68	10.85	7	3	4	1.00	9.99	2.25	6.12
.54	5.75	5.14	10	5	5	2.64	4.35	3.49	9	5	4	-1.00	1.90	1.40	1.65
.48	3.38	3.43	10	5	5	1.59	2.51	2.05	10	5	5	0.00	1.89	0.87	1.38
.03	8.64	8.33	6	2	4	4.63	7.60	6.12	9	4	5	3.00	3.40	1.04	2.22
.43	10.49	10.96	7	4	3	8.43	10.91	9.67	8	3	5	1.00	3.00	-0.42	1.29
.60	7.14	7.37	8	4	4	6.18	6.54	6.36	9	5	4	1.00	1.42	0.60	1.01
.10	9.46	8.78	5	5	5	4.11	4.44	4.27	7	4	3	2.00	3.99	5.03	4.51
.51	8.21	7.86	9	5	4	9.84	8.46	9.15	9	5	4	0.00	-2.33	-0.25	-1.29
.62	6.16	5.39	9	4	5	5.16	4.36	4.76	9	5	4	0.00	-0.54	1.80	0.63
.52	7.47	7.00	10	5	5	2.63	3.45	3.04	9	4	5	-1.00	3.89	4.02	3.96
.80	5.00	4.90	9	5	4	2.88	3.88	3.38	8	4	4	-1.00	1.92	1.12	1.52
.64	6.25	5.44	10	5	5	3.45	4.23	3.84	10	5	5	0.00	1.18	2.03	1.61
.85	14.11	12.98	4	2	2	12.64	18.15	15.40	7	4	3	3.00	-0.79	-4.04	-2.41
.75	3.64	4.69	3	4	3	3.91	5.38	4.65	5	3	2	2.00	1.84	-1.74	0.05
.75	7.83	7.29	7	3	4	4.60	3.69	4.15	8	3	5	1.00	2.15	4.13	3.14
.60	4.82	4.71	9	5	4	4.86	3.90	4.38	8	5	3	-1.00	-0.26	0.92	0.33
.58	11.56	9.57	8	5	3	5.15	7.65	6.40	7	3	5	-1.00	2.44	3.91	3.17
.98	**7.39**	**7.18**	**7.53**	**4.06**	**3.78**	**5.00**	**5.85**	**5.42**	**8.31**	**4.19**	**4.16**	**0.78**	**1.98**	**1.54**	**1.76**
.37	**3.21**	**3.19**	**2.11**	**1.12**	**1.02**	**2.36**	**3.28**	**2.74**	**1.24**	**0.81**	**0.83**	**1.41**	**2.65**	**2.08**	**2.07**

	PRE-TEST						R-POST-TEST				DIFFERENCE R-POST-TEST - PRE-TEST		
Gender	RT Pre-test Corpus 1	RT Pre-test Corpus 2	Mean C. 1&2 Pre-test	Score Pre-test	correct Corpus 1	correct Corpus 2	RT R-post-test Corpus 1	RT R-post-test Corpus 2	Mean C. 1&2 R-post-test	score	Diff. RT Corpus 1	Diff. RT Corpus 2	Retention of learning from pre- and post-test (RT)
F	6.06	5.99	6.02	9	4	5	6.92	5.38	6.15	8	-0.87	0.61	-0.13
F	4.07	5.92	5.00	9	5	4	3.37	3.64	3.51	10	0.70	2.28	1.49
F	2.86	4.96	3.91	7	4	3	3.93	4.42	4.17	9	-1.07	0.55	-0.26
F	5.84	7.08	6.46	8	5	3	5.19	5.22	5.21	9	0.65	1.86	1.26
F	6.03	5.63	5.83	4	3	2	7.37	10.02	8.70	9	-1.35	-4.39	-2.87
F	9.94	13.97	11.95	8	4	4	5.36	7.08	6.22	8	4.58	6.88	5.73
M	4.75	5.27	5.01	10	5	5	5.07	3.52	4.30	10	-0.32	1.74	0.71
M	15.35	12.42	13.88	6	4	2	6.84	9.81	8.32	8	8.51	2.61	5.56
M	10.4	7.0	8.7	6	3	3	9.10	9.51	9.30	9	1.29	-2.50	-0.61
F	4.0	3.5	3.7	10	5	5	3.22	1.86	2.54	9	0.75	1.64	1.19
F	6.2	6.4	6.3	7	4	3	6.06	5.56	5.81	7	0.10	0.87	0.48
F	6.2	7.7	6.9	3	1	2	6.67	6.06	6.37	7	-0.48	1.64	0.58
F	4.7	3.7	4.2	8	5	3	3.58	3.20	3.39	8	1.14	0.51	0.83
F	3.3	3.7	3.5	10	5	5	3.04	4.85	3.95	9	0.24	-1.11	-0.44
M	7.9	7.3	7.6	6	2	4	5.22	5.91	5.56	9	2.70	1.40	2.05
M	18.0	15.9	17.0	6	3	3	10.22	19.84	15.03	4	7.78	-3.91	1.94
F	4.54	5.75	5.14	10	5	5	1.94	2.77	2.35	9	2.60	2.98	2.79
F	3.48	3.38	3.43	10	5	5	1.94	3.02	2.48	9	1.53	0.36	0.95
F	8.03	8.64	8.33	6	2	4	5.59	7.15	6.37	10	2.44	1.48	1.96
M	11.43	10.49	10.96	7	4	3	9.44	9.34	9.39	7	1.99	1.15	1.57
F	7.60	7.14	7.37	8	4	4	3.14	3.68	3.41	9	4.47	3.46	3.96
F	8.10	9.46	8.78	5	5	5	4.96	5.05	5.01	6	3.13	4.41	3.77
M	7.51	8.21	7.86	9	5	4	10.47	8.48	9.48	9	-2.96	-0.28	-1.62
M	4.62	6.16	5.39	9	4	5	3.16	3.42	3.29	9	1.46	2.73	2.09
M	6.52	7.47	7.00	10	5	5	5.35	5.00	5.17	10	1.18	2.47	1.82
F	4.80	5.00	4.90	9	5	4	2.63	3.19	2.91	7	2.17	1.82	2.00
F	4.64	6.25	5.44	10	5	5	4.28	3.95	4.11	9	0.36	2.30	1.33
F	11.85	14.11	12.98	4	2	2	9.78	8.37	9.08	5	2.07	5.74	3.91
F	5.75	3.64	4.69	3	4	3	5.18	5.83	5.51	6	0.57	-2.19	-0.81
F	6.75	7.83	7.29	7	3	4	3.75	3.31	3.53	9	3.00	4.52	3.76
M	4.60	4.82	4.71	9	5	4	5.46	4.12	4.79	9	-0.86	0.70	-0.08
M	7.58	11.56	9.57	8	5	3	5.03	4.00	4.52	8	2.55	7.56	5.06
	6.98	**7.39**	**7.18**	**7.53**	**4.06**	**3.78**	**5.42**	**5.83**	**5.62**	**8.25**	**1.56**	**1.56**	**1.56**
	3.37	**3.21**	**3.19**	**2.11**	**1.12**	**1.02**	**2.34**	**3.36**	**2.71**	**1.44**	**2.36**	**2.63**	**1.99**

EXPERIMENTAL CONDITIONS					
ACTION GAME	SCORE	RT	NON-ACTION GAME	SCORE	RT
Action-1	100	11.74	No Action-1	100	8.45
Action-1	120	7.64	No Action-1	120	8.21
Action-1	120	8.68	No Action-1	60	6.29
Action-1	70	7.69	No Action-1	90	6.38
Action-1	80	5.89	No Action-1	70	9.74
Action-1	80	12.35	No Action-1	110	3.66
Action-1	120	11.23	No Action-1	90	5.73
Action-1	60	6.74	No Action-1	130	4.05
Action-1	130	5.03	No Action-1	90	11.13
Action-1	90	10.95	No Action-1	130	5.59
Action-1	80	11.22	No Action-1	110	9.67
Action-1	60	24.31	No Action-1	100	7.98
Action-1	100	11.41	No Action-1	130	7.04
Action-1	90	7.57	No Action-1	80	11.83
Action-1	90	6.04	No Action-1	120	7.67
Action-1	90	8.51	No Action-1	120	6.74
Action-2	110	11.65	No Action-2	90	13.08
Action-2	140	7.72	No Action-2	110	9.81
Action-2	120	10.56	No Action-2	90	6.96
Action-2	100	6.23	No Action-2	100	9.78
Action-2	120	6.54	No Action-2	60	10.91
Action-2	140	8.12	No Action-2	120	5.44
Action-2	90	7.13	No Action-2	130	3.96
Action-2	70	11.45	No Action-2	80	8.63
Action-2	130	6.93	No Action-2	120	7.22
Action-2	150	8.03	No Action-2	110	7.52
Action-2	90	5.36	No Action-2	110	4.67
Action-2	100	10.97	No Action-2	60	11.00
Action-2	120	10.28	No Action-2	70	3.08
Action-2	100	10.95	No Action-2	120	6.61
Action-2	70	12.27	No Action-2	100	4.86
Action-2	100	6.03	No Action-2	90	7.48
Mean	100.94	9.29	***Mean***	100.31	7.54
SD	23.50	3.53	***SD***	21.28	2.50

Appendix E: List of results per case – survey

se l.	Experience with games in general						Experience with these prime number games								Attitudes towards games								
	1 – How much do you enjoy playing video games in general?	2 – How much do you use video games for learning?	3 – How much do you use video games for fun?	4 – How much are you engaged by action video games?	5 – How much are you engaged by learning games?	6 – How good do you think you are at playing video games?	1 – How much did you enjoy playing these video games?	2 – How much do you think these video games are useful for learning?	3 – Qualify your level of engagement with the movement game.	4 – Qualify your level of engagement with the non-movement game.	5 – Qualify your level of learning with the movement video game.	6 – Qualify your level of learning with the non-movement video game.	7 – How easy was to play with the movement video game?	8 – How easy was to play with the non-movement video game?	1 – I think action video games lead to violent behaviour.	2 – I believe learning games are generally boring.	3 – I think playing video games isolates people from society.	4 – I think video games are an excellent opportunity to develop skills.	5 – Video games can damage your brain eventually.	6 – Video games can damage your vision eventually.	7 – Video games can become an addiction.	8 – Video games are only for children.	Condition preferred
	5	4	5	4	4	4	5	5	5	5	5	5	5	4	3	1	3	4	4	4	5	1	movement
	5	3	4	5	3	4	3	4	5	4	3	3	5	4	2	2	2	5	1	3	4	1	movement
	1	1	1	1	1	4	4	4	4	3	3	4	4	4	4	3	4	3	3	4	4	1	movement
	4	2	4	2	5	3	3	5	4	3	4	5	3	4	4	1	3	5	2	2	4	1	movement
	3	2	3	2	2	3	2	2	3	3	3	3	5	5	2	2	2	4	3	3	3	2	indifferent
	5	4	5	4	4	4	3	4	4	3	4	4	4	5	1	1	1	5	1	1	3	1	movement
	5	5	5	5	3	5	5	3	5	2	5	1	5	1	4	3	5	1	4	5	5	1	movement
	5	2	4	4	2	4	4	4	3	4	3	4	4	4	2	3	1	4	1	2	4	1	no-movement
	5	3	5	5	3	3	4	5	5	3	5	3	5	5	3	1	2	3	2	2	4	1	movement
0	3	2	4	4	2	3	3	3	4	3	4	4	2	4	3	3	2	3	2	3	3	2	movement
1	1	3	1	2	4	2	3	4	4	3	5	3	4	5	2	1	1	3	1	2	4	2	movement
2	2	3	1	1	3	2	4	4	5	4	5	4	5	5	2	2	2	4	3	3	3	1	movement
3	2	1	1	1	1	1	3	5	4	3	3	2	3	4	1	2	3	4	1	1	2	1	movement
4	2	2	4	2	3	2	4	3	4	2	4	4	2	4	3	2	2	2	2	2	4	2	movement
5	2	2	1	1	2	2	3	5	5	4	4	4	5	5	3	2	3	3	3	4	4	3	movement
6	3	1	1	2	1	1	4	4	5	5	3	5	4	5	2	1	4	3	2	1	3	2	no-movement
7	3	1	2	3	2	2	3	4	4	3	4	4	2	4	2	2	3	2	1	2	2	3	movement
8	4	3	4	4	3	4	4	4	5	3	5	4	3	5	2	2	2	4	3	3	4	2	movement
9	4	2	3	2	2	3	4	4	4	3	4	3	4	5	1	1	3	3	1	2	5	1	movement
0	3	2	4	1	2	3	4	3	4	2	3	3	5	5	4	4	2	4	3	5	5	1	movement
1	3	2	4	3	3	4	4	4	4	4	4	4	4	4	4	2	5	4	4	4	5	1	movement
2	3	4	3	1	4	3	3	5	5	4	3	3	4	3	3	1	2	3	1	1	3	2	movement
3	5	1	3	2	1	3	3	1	3	5	3	5	3	4	1	5	5	1	2	5	4	1	non-movement
4	4	3	4	4	3	3	3	2	4	3	4	3	5	5	2	4	2	5	1	3	5	1	movement
5	4	4	5	4	4	4	2	3	3	2	3	3	4	5	1	4	2	5	1	3	5	1	indifferent
6	4	2	4	2	4	3	4	4	3	4	4	4	3	5	2	4	2	4	1	2	3	1	movement
7	4	2	4	3	1	3	3	5	4	2	5	3	3	5	4	2	4	3	2	3	3	2	movement
8	1	1	1	1	1	2	4	5	5	4	4	4	5	5	1	3	2	3	1	1	3	1	movement
9	2	2	1	2	2	1	2	3	2	2	3	2	4	2	5	3	5	3	3	4	5	2	movement
0	3	2	2	3	3	1	3	4	4	4	4	4	3	4	3	2	3	4	2	2	3	1	movement
1	3	1	2	2	2	2	4	3	3	2	3	4	4	3	2	3	3	2	2	1	4	1	movement
2	4	3	4	3	3	4	4	4	4	3	3	4	3	5	4	3	2	3	1	3	4	1	movement

Appendix F: List of results – answers to open-ended questions

Case N.	Gnd.	Condition preferred	1 - Reasons for preferred condition
1	F	movement	active; more attention
2	F	movement	active; attention
3	F	movement	concentrated to the moving answer
4	F	movement	more alert to see the change of number
5	F	indifferent	movement did not affect my actions
6	F	movement	more actiona
7	M	movement	interact with people in the games
8	M	no-movement	concentrate better
9	M	movement	more alert and attentive; non-movement reminded me of traditional school test and caused me anxiety.
10	F	movement	more action; less boring
11	F	movement	more awareness and attention
12	F	movement	more concentration; more fun
13	F	movement	more attention
14	F	movement	more attentive
15	M	movement	more action
16	M	no-movement	gave more time to learn and memorise easier
17	F	movement	more focus
18	F	movement	more activity in catching the number
19	F	movement	more stressed made me more comptitive
20	M	movement	more action and thinking
21	F	movement	more alert
22	F	movement	action
23	M	non-movement	better focus
24	M	movement	motor skill associated with thinking
25	M	indifferent	maybe movement made me more accurate with the mouse
26	F	movement	attention and thinking while trying to learn Pr numbers
27	F	movement	more concentration so as not to miss the correct answer
28	F	movement	not boring; makes you think quickly
29	F	movement	more time to think and answer
30	F	movement	engaging and difficult
31	M	movement	more challenging
32	M	movement	more concentration in different tasks

Case N.	Gnd.	Condition preferred	2 - Missing element to make it more engaging
1	F	movement	other shapes
2	F	movement	music, sound effects, more attractive graphics
3	F	movement	sound
4	F	movement	hints or guidelines to not make mistakes more than twice
5	F	indifferent	some sounds
6	F	movement	sound
7	M	movement	audio
8	M	no-movement	timer as sometimes I missed an option because the number changed
9	M	movement	different colours for the numbers; music; sounds; an image of a trophee at the end to boost confidence of tne player
10	F	movement	extra rewards; different scores according to difficulty
11	F	movement	increase speed and level
12	F	movement	increase speed to increase the sense of competition and fun
13	F	movement	sound; different shapes
14	F	movement	sound effects
15	M	movement	different levels of difficulty
16	M	no-movement	better graphics
17	F	movement	more appealing graphics
18	F	movement	more than one number on the screen to increase difficulty
19	F	movement	bigger screen; modern graphics but may not help in focusing on the content
20	M	movement	colours; sound
21	F	movement	sound and movement when game is over
22	F	movement	multiple squares
23	M	non-movement	building and testing an algorithm like Eratosthene's shiere
24	M	movement	increase point score with higher number assertions
25	M	indifferent	more distracting conditions;music, different layers of visualisation
26	F	movement	better layout, seems old fashion game; faster movement
27	F	movement	sound; additional feedback; a fun element
28	F	movement	nothing
29	F	movement	time given
30	F	movement	element of competition but it may be more stressful as well
31	M	movement	different kinds of movement
32	M	movement	bigger moving boxes to make it easier to catch them

Case N.	Gnd.	Condition preferred	3 - How much will you remember?
1	F	movement	around 50%
2	F	movement	strategy of the game and some prime numbers
3	F	movement	a lot. Still thinking of the missing PR during the game
4	F	movement	quite much
5	F	indifferent	a few things
6	F	movement	definetively remember some pr numbers
7	M	movement	most of it
8	M	no-movement	a fair bit
9	M	movement	procedure of the game; some prime numbers
10	F	movement	pr numbers for quite a while
11	F	movement	depends on how much i play in a week/month. I dont have a good memory
12	F	movement	Pr numbers a lot and the mistakes I made, especially with bigger numbers
13	F	movement	not much because i usually dont work with numbers
14	F	movement	80%
15	M	movement	many things (mathematical skills) for a long time
16	M	no-movement	at least i will knowwhat is a Pr N
17	F	movement	i will remember what i've learned from it.
18	F	movement	larger pr numbers
19	F	movement	a lot; especially the wrong answers. Explanations in different colour helped remember it.
20	M	movement	pr numbers and the ones I failed.
21	F	movement	all Pr numbers I got wrong
22	F	movement	some prime numbers
23	M	non-movement	nothing
24	M	movement	just two or three pr numbers
25	M	indifferent	most of it
26	F	movement	a lot from colours to some answers
27	F	movement	mistakes for long, especially the ones i did wrong more than once
28	F	movement	pr numbers and wont forget what they are.
29	F	movement	more about prime numbers
30	F	movement	57 is not a Pr number
31	M	movement	maybe some numbers
32	M	movement	a lot, especially mistakes

Appendix G: Informed consent form

University of BRISTOL

Informed Consent Form

Project: Effects of video games in learning

Please read and tick the boxes as confirmation of your understanding:

☐ I understand that my participation in this project will involve taking part in an experiment using video game in which data about my performance will be collected by the computer. I also understand that I will be required to answer a survey after playing the game as well as the completion of a second post-test after a week of the experiment.

☐ I understand that participation in this study is completely voluntary and that I can withdraw from the study at any time until a week after I have participated in the study and without the need of providing further explanation.

☐ I understand that the information provided by me will be treated confidentially, such that only the researcher can track this information back to me individually, and that individual performance in the experiment will be made public using a pseudonym of my choosing.

☐ I understand that I am free to ask any questions at any time and to discuss my concerns with the researcher and/or research supervisor.

☐ The information will be retained for further studies and publication. I understand that I can ask for the information I provide to be deleted/destroyed at any time and, in accordance with the Data Protection Act, I can have access to the information at any time.

☐ I also understand that at the end of the study I will be provided with additional information and feedback about the purpose of the study and its findings.

☐ I have understood all the above mentioned information and given the opportunity to ask questions if necessary.

I, ___________________________________ (NAME) consent to participate in the study conducted by Carolina Gordillo at Graduate School of Education, University of Bristol.

Signed: ______________________________

CONTACT DETAILS

Date of Birth (DD/MM/YY): ____________________________ **Gender:** ___________
E-mail address: ____
Pseudonym: _________________

Appendix H: Information sheet

University of BRISTOL

Information Sheet

Project: Effects of video games in learning

You are invited to take part in a voluntary study to explore the relationship between video games and learning. As a participant, you will be asked to complete 4 tasks in a personal computer interface plus an additional one a week after this session.

Every task in the computer should take no longer than 2 minutes. Once the tasks have been performed, you will need to complete a brief survey on your experience as game user. Your participation in total will not be longer than 30 minutes.

The data collected from participants will be analysed in order to obtain information about the influence of video games on learning automaticity. All data will be treated anonymously and it will be not linked to any other information related to you. However, you will be asked to provide your date of birth and gender for data analysis purposes, and a pseudonym to receive results if desired.

All testing will take place at the Graduate School of Education, University of Bristol. Your participation is voluntary and every participant has the right to withdraw from the study at any moment during the experiment until a week after participation in the study without providing further explanation.

Shall you have any further inquiries related to this study you can always contact the researcher and/or supervisor.

Carolina Gordillo: carolina.gordillo.2013@my.bristol.ac.uk (Researcher)

Paul Howard-Jones: paul.howard-jones@bristol.ac.uk (Research Supervisor)

I appreciate the time you take to contribute to my research.

Carolina Gordillo

Researcher

Appendix I: Verbal instructions to participants

University of BRISTOL

Information to provide verbally to participants

In this experiment, you will be asked to play a computer game in which you will have to guess the prime numbers.

A prime number is one that can be divided evenly by itself and by 1 only.

You will be pre tested on these numbers before playing the first game. This pre-test consists of 10 questions. For this purpose you will use the computer keyboard. The keys are marked with the symbols representing the alternatives in the game. You should press the corresponding key when you know the answer. There is a bar time on the right side of the screen

Once the pre-test is completed, you will play the first game according to the distribution list. In this game you will need to use the mouse or key pad as desired. There are 15 questions in each game.

Once finished, you will play a second game with a variation in the conditions.

Once the two conditions have been tested, you will perform a post-test to prove how much you have learned.

Finally, you will be asked to complete a survey on your experience as video game player.

You will be asked to come in for a second session to complete a second post-test.

).

The survey and open questions were also piloted and revised by volunteers who were not participating in the experiment. Minor content corrections were applied to the survey statements and the questions.

The game reliability was checked by piloting it on several people who obtained similar results on every occasion they played the game.

3.6 Procedure

This study was conducted in two phases. Firstly, an exploratory study was carried out to devise the corpus for the game (prime numbers). Secondly, the main study took place over a period of three weeks.

3.6.1 Exploratory study

In order to make the input more authentic, a brief preliminary exploratory study was carried out to compile the prime numbers most remembered as well as the most common errors.

An opportunity sample of eight students (4 females; 4 males) at the University of Bristol between 23 and 31 years of age (*M* = 26 *SD* = 3 years) were each given one minute to list aloud any prime numbers they could think of. They were sound recorded for obtaining the time response afterwards. These participants remained anonymous with only their date of birth recorded alongside their scores.

Figure 7 displays the numbers (not all of them prime numbers) listed by participants, along with the average time taken for each one. A significant correlation (*N*= 34, *r* = .432, *p* = .011) between number size and time taken for recalling was found with this set of numbers.

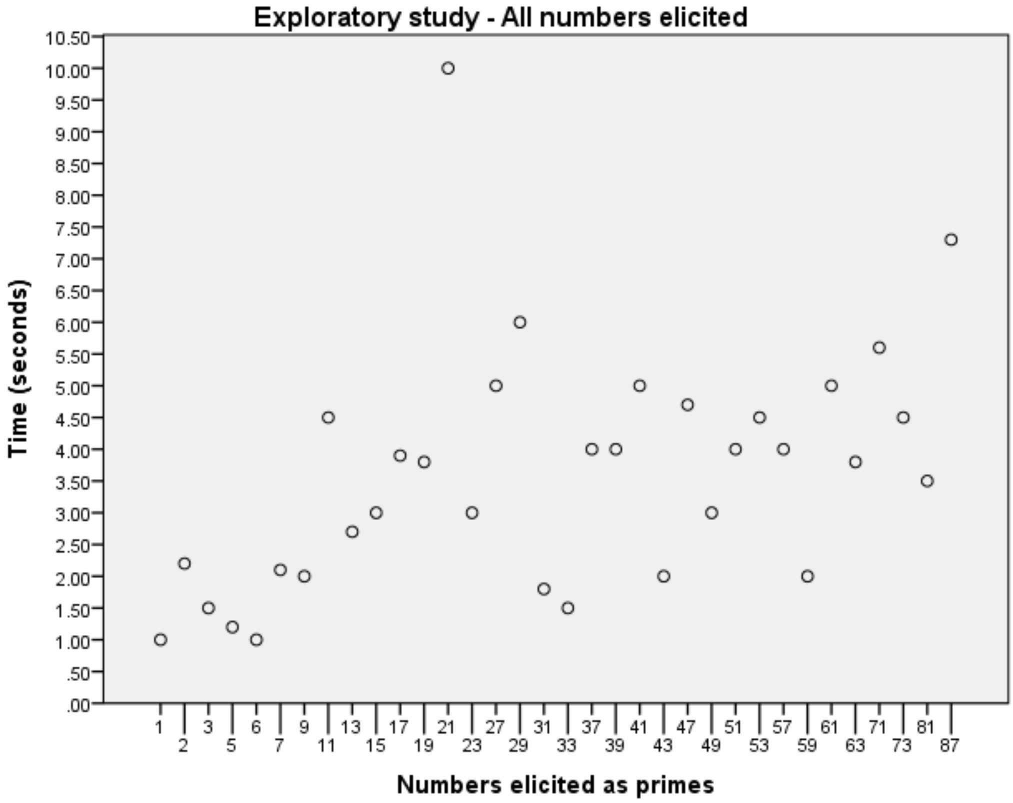

Figure 7: Elicited prime numbers in one minute (not all number were primes).

This correlation persists when isolating the actual elicited prime numbers (*N* = 20, *r* = .530, *p* = .016) which suggested that difficulty in eliciting a prime was roughly dependent on the size of the prime number (Zagier, 1977) (Figure 8). This was used as the rationale for creating two new 'more challenging' new prime number corpora, as the original ones appeared to be too easy in the pilot. The new corpora comprised larger numbers but maintained the difference between the corpora as shown in Table 1.

Table 1: Total sum of prime numbers per corpus.

	Corpus	Sum of prime numbers	Difference between corpora
Original	1	123	50
	2	173	
New	1	156	49
	2	205	

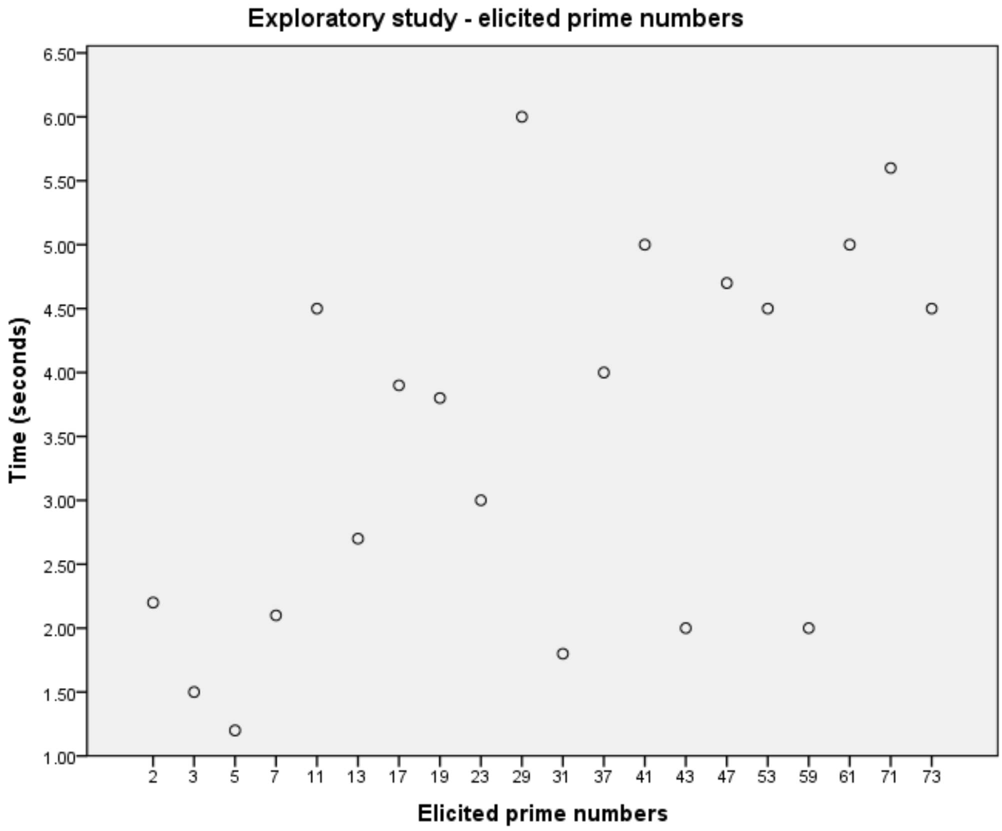

Figure 8: Actual prime numbers elicited.

3.6.2 Main study

In order to avoid preparation on prime number knowledge, participants were not told about the content of the game in the information sheet sent with the invitation to take part in the study. They were informed about the content and consulted about their understanding at the beginning of the session (Appendix H: Information sheet and I). There was a sheet with the rule and an illustrated example of a prime and non-prime numbers.

The main study comprised five tasks for all participants.

a) Pre-test on prime numbers
b) First experimental condition
c) Second experimental condition
d) Post-test on prime numbers
e) Retention post-test on prime numbers (applied after one week)

All these tasks but letter *e)* were completed on a single session which lasted not longer than 35 minutes per participant. A week later, participants took the retention post-test. However, due to seasonal reasons (summer holidays) it was not always possible to adhere to this rule strictly and therefore the interval between post-test and R-post-test for the 32 participants varied between 6 and 14 days.

As explained, the study comprised the two sets of corpus (see **¡Error! No se encuentra el origen de la referencia.**) for the VG based on the information obtained from the exploratory study on prime numbers. Each corpus contains 5 sets of 4 different numbers each. Only one from those four numbers is a prime. Hence, there is a total of 10 prime numbers in the video game. This group of numbers was distributed in two different tests for each condition: Game (Action-1 and Action-2) and No Game (No action-1 and No action-2).

In order to counterbalance the participation in both conditions (Dancey and Reidy, 2004) and avoid possible practice and fatigue effects, the four groups were distributed according to the testing design in Table 2.

Table 2 Experimental conditions distribution design.

Group	Pre-test	Condition 1	Condition 2	Post-test
A	X	Action-1	No Action -2	X
B	X	No Action -1	Action -2	X
C	X	Action -2	No Action -1	X
D	X	No Action -2	Action -1	X

The experiment was conducted on an individual basis. Each participant started with a pre-test on the computer. This was a time-based task with a maximum duration of 4.30 minutes. After the pre-test, participants underwent the two conditions according to their designated group. Instructions on how to play the game were given. Each condition had 15 questions and a maximum duration of 7 minutes. Once the final condition was applied, participants were asked to complete the experiential survey. This activity was not time-based and took approximately 5 to 7 minutes to be completed. After the survey (to introduce a short break), the post-test (same as pre-test) was applied.

The retention post-test was applied under the same environmental conditions of the first session, one week later.

3.7 Data handling

Data was collected about participants' date of birth, gender, a pseudonym and answers to survey. Data from computer-based tasks was automatically saved via the software design. Once numbers had been transcribed to an Excel spread sheet, data was transferred to University of Bristol server to maintain security standards.

3.8 Data analysis

Descriptive analysis addressed the concepts of accuracy and RT obtained in pre- and post-tests and in the conditions. Inferential statistical analysis used was correspondent with the within-participants design. Hence, paired-samples *t*-tests were applied for mean comparisons and Pearson correlation when the relationship of two variables needed to be established (Creswell, 2014).

Survey results were collated and grouped to show percentages of preference. The five-scale point was collapsed into three parameters for analysis purposes. The responses to open questions were treated with content analysis to devise categories and their frequencies.

3.9 Ethics

A research ethics form (Appendix B: Ethics discussion form) was completed and discussed with two fellow researchers. This research did not imply any physical or psychological harm to participants. All ethics requirements were fulfilled with participants who, after being invited and informed about the experiment, participated voluntarily and signed an informed consent in advance (Appendix G: Informed consent form). Data handling followed UK Data Protection Act (1998) principles. Participants' anonymity and confidentiality of data was guaranteed.

Chapter 4 Analysis and Results

This chapter first portrays the participants' demographics, characteristics and habits towards VGP. Then the pre- and post-tests and experimental conditions are compared for both participant accuracy and RTs. Finally, the relationship between self-reported aspects and performance is analysed together with a summary of the additional information. Appendix D: List of results per case – RT and accuracyAppendix E: List of results per case – surveyand Appendix F: List of results – answers to open-ended questionscontain lists of results per case.

4.1 Participants

32 participants volunteered for this experiment. The age range was 23-42 years of age (*M* = 28.3, *SD* = 5.5 years). All participants were students at the University of Bristol pursuing studies in diverse areas and levels. The cohort included participants from South Korea, Singapore, Hong Kong, Taiwan, Chile and various European countries. Gender distribution was 34.4% male (11 participants) and 65.6% female (21 participants).

Information collected through a Likert-scale survey portrayed participants' habits and attitudes towards VGs. The results were as follows:

4.1.1 General experience with video games

Table 3 addresses the level of enjoyment, use and engagement of video games in general, learning video games and action video games.

Table 3: Participants' answers in the domain of experience with video games in general.

Experience with video games in general	low/little	moderate/indifferent	high/very much
1 – How much do you enjoy playing video games in general?	25.0%	28.1%	46.9%
2 – How much do you use video games for learning?	62.5%	21.9%	15.6%
3 – How much do you use video games for fun?	34.4%	12.5%	53.1%
4 – How much are you engaged by action video games?	53.1%	15.6%	31.3%
5 – How much are you engaged by learning games?	46.9%	31.3%	21.9%
6 – How good do you think you are at playing video games?	34.4%	34.4%	31.3%

Only 25% of participants declared low enjoyment of VGs and 75% as moderate or high. 62.5% declared a low usage of video games for learning while 53.1% expressed high use of video games for fun. Around half the participants expressed not feeling engaged by either AVGs (53.1%) or learning games (46.9%). Finally, when asked for their ability for playing video games, responses divided quite evenly between low, moderate and high.

4.1.2 Attitudes towards playing video games

The survey also aimed to elicit participants' opinions and attitudes towards playing video games.

Table 4: Participants' answers in the domain of attitudes towards playing video games.

Attitudes towards video games	low/little	moderate/indifferent	high/very much
1 – I think action video games lead to violent behaviour.	53.1%	21.9%	25.0%
2 – I believe learning games are generally boring.	59.4%	25.0%	15.6%
3 – I think playing video games isolates people from society.	53.1%	25.0%	21.9%
4 – I think video games are an excellent opportunity to develop skills.	15.6%	37.5%	46.9%
5 – Video games can damage your brain eventually.	68.8%	21.9%	9.4%
6 – Video games can damage your vision eventually.	46.9%	28.1%	25.0%
7 – Video games can become an addiction.	6.3%	31.3%	62.5%
8 – Video games are only for children.	93.8%	6.3%	0.0%

Table 4 shows that most participants may be easily identified as pro video game playing even when they reported being lower users. 93.8% of participants thought that video games are not only for children, implying that they would value video games for adults. Many participants believed video games may help develop skills. Most participants did not think that video game might have negative effects on behaviour or health. However, 62.5% believed that VGP could become addictive.

4.2 Response time

Paired-samples t-tests were conducted to determine the statistical significance of the mean differences between RTs in pre- and post-tests and experimental conditions. The scores mean differences were computed and analysed for normality of distribution using Shapiro-Wilk's test of normality (recommended for samples < 50) and for outliers inspection (values greater than 1.5 box-lengths from the edge of the box as defined by SPSS). Violations to the assumptions (normality and outliers) were reported when corresponded. However, since *t*-test is a robust test and tolerates well violation of normality, no changes of statistical test were required in case of lack of normal distribution. The case with outliers was different as the use of a non-parametric test, Wilcoxon-signed-rank test, was preferred if the mean score to be analysed violated this assumption.

4.2.1 Pre- and post-tests

Response times showed a significant difference between baseline and the post-test. Figure 9 depicts mean RTs per test, including the R-post-test. In the computation of the mean difference between pre- and post-test RTs, one outlier was detected as assessed by inspection of a boxplot but as its value was not extreme, it was kept for the analysis. The assumption of normality was not violated, as assessed by Shapiro-Wilk's test ($p = .078$).

Participants were faster in recognising prime numbers in the post-test ($N = 32$ $M = 5.42$ $SD = 2.78$) in comparison to the pre-test ($N = 32$ $M = 7.18$ $SD = 3.24$), with a statistically significant mean decrease of -1.76 seconds, 95% CI [-2.52, -1.00], $t(31) = -4.73$, $p < .001$, $d = .84$.

Retention of learning after some time had a slight increase in RT following several days without practice ($N = 32$ $M = 5.62$ $SD = 2.75$). Compared to pre-test, participants experienced a statistically significant mean decrease of -1.56 seconds, 95% CI [-2.29, -.83], $t(31) = -4.38$, $p < .001$, $d = .77$, suggesting a learning effect over time as measured by RT.

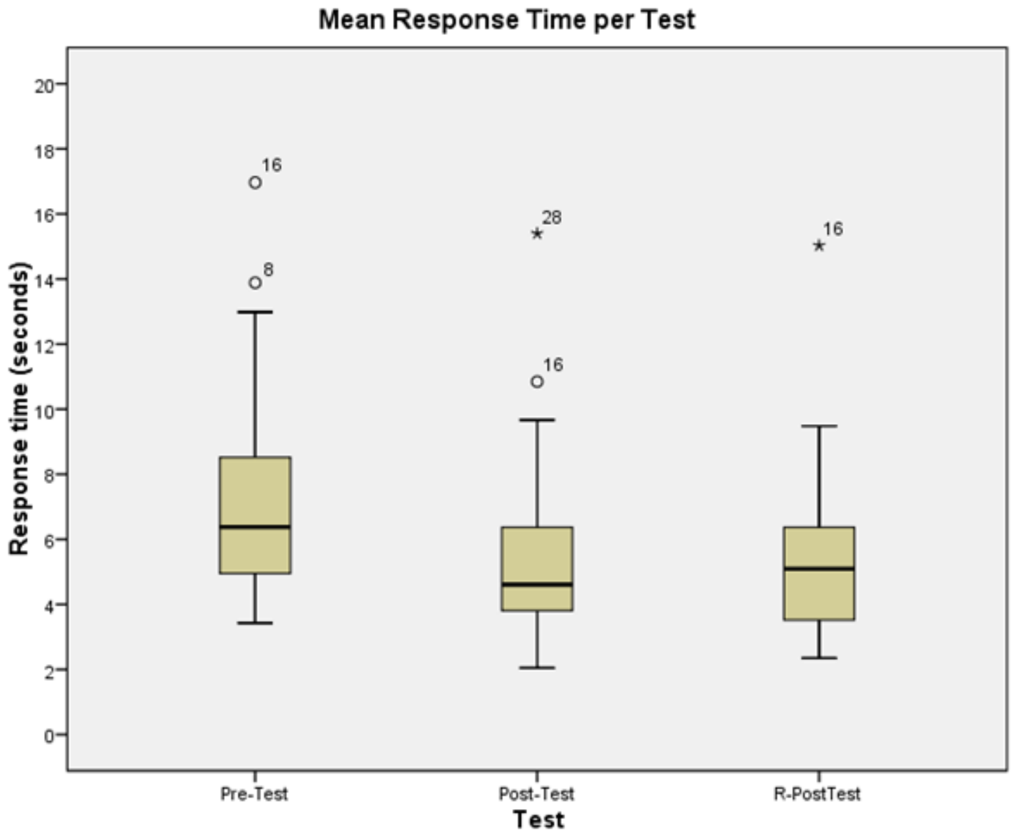

Figure 9: Mean response times for pre-, post- and retention post-tests.

Individual corpus analysis showed that both corpora had similar gains in RT in the post-tests as measured by Wilcoxon signed-rank test. Corpus 1 post-test elicited a statistically significant median decrease in RT (*Mdn* = 5.19 seconds) compared to the corpus 1 pre-test (*Mdn* = 6.11 seconds), $z = -3.39$, $p < .001$. Likewise, corpus 2 post-test also showed a statistically significant median decrease in RT (*Mdn* = 4.86 seconds) compared to the corpus 2 pre-test (*Mdn* = 6.72 seconds), $z = -3.72$, $p < .001$. Of the 32 participants, 25 showed an increase in their speed for recognising prime numbers in each of the corpora.

4.2.2 Game and No Game

A paired-samples *t*-test was conducted to determine whether there was a statistically significant mean difference between RTs when participants played the action game in comparison to the non-action game (Figure 10). By computing the mean difference between the conditions, no outliers were detected as assessed by inspection of a boxplot. The assumption of normality was not violated, as assessed by Shapiro-Wilk's test (p = .409). Participants' mean RTs were higher in the Game condition (N = 32 M = 9.29 SD = 3.58) as opposed to the No Game condition (N = 32 M = 7.54 SD = 2.54), a statistically significant mean difference of 1.75 seconds slower, 95% CI [.23, 3.28], $t(31)$ = 2.34, p = .026, d = .41.

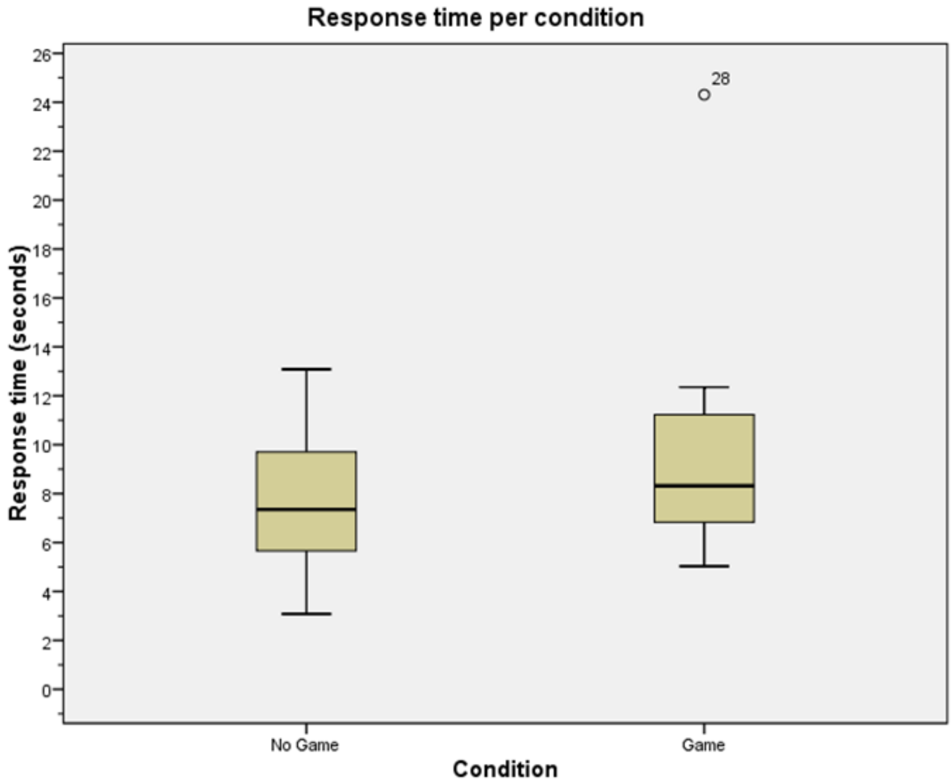

Figure 10: Response time per condition.

4.3 Accuracy

4.3.1 Pre- and post-tests

The pre- and post-tests comprised ten prime numbers (from both corpora). Hence, the range of possible scores on each test was between zero and ten.

As expected, post-test mean scores (N = 32 M = 8.31 SD = 1.26) were higher than the pre-test scores (N = 32 M = 7.53 SD = 2.14). A paired-samples t-test revealed a small but statistically significant mean difference of .781 points, 95% CI [.27, 1.30], $t(31) = 3.09$, $p = .004$, $d = .55$. These results indicated that, on average, participants' accuracy of responses was significantly higher in the post-test than in the pre-test. This implies that learning about prime numbers took place, which can be attributed to video game playing.

Figure 11 depicts a boxplot showing identical medians (Mdn = 8) between pre-test and post-test but an increment of the lower quartile in the post-test can be observed. Those scoring lower in the pre-test improved, whilst those scoring higher maintained their performance in the post-test. And there was further improvement in the r-post-test (higher median).

The post-test scores show a more symmetrical distribution than the pre-test scores, which are distributed more asymmetrically and bunched towards the maximum score possible. However, there is a clear ceiling effect here with a maximum possible score of 10. Whilst those initially scoring poorly could show improvement in the post-test, it was more difficult for those initially scoring highly to demonstrate learning by an improved score.

One outlier occurred in the post-test with a score of 5.

Mean score in the retention post-test (*N* = 32 *M* = 8.25 *SD* = 1.46) was also higher than mean pre-test score, but slightly lower than that of the post-test, possibly as a consequence of time spent without practice (Figure 11). A paired-samples *t* test showed a statistically significant mean difference of .719 points, 95% CI [.08, 1.36], *t*(31) = 2.281, *p* = .030 between the pre-test and the retention post-test mean scores, so learning was retained, even after a week.

There were two outlier cases in the r-post-test with scores of 5 and 4.

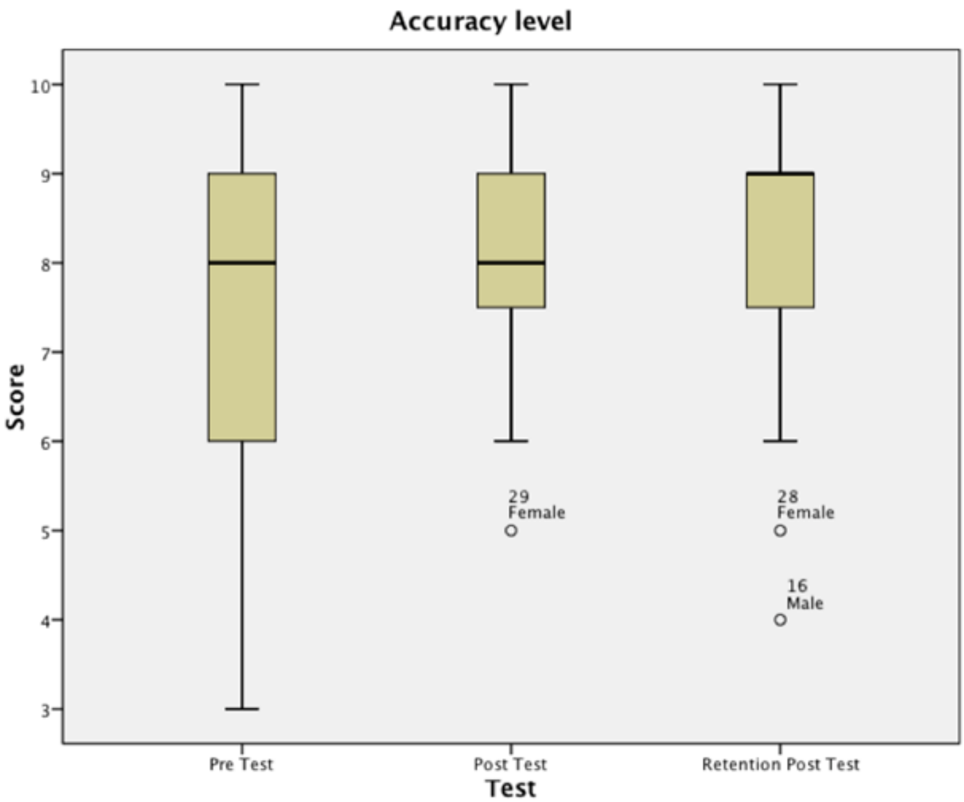

Figure 11: Participant's accuracy level on pre-, post- and retention post-test.

As a ceiling effect was detected by the results in pre- and post-tests, a second analysis using only those low-achieving cases (score ≤ 5) in the pre-test was run in order to understand better the possible effects of the intervention. The paired-samples *t*-test showed that post-test mean scores (*N* = 5 *M* = 6.6 *SD* = 1.14) were higher than the pre-test ones (*N* = 5 *M* = 3.8 *SD* = .84), with a larger statistically significant mean difference of 2.8 points, 95% CI [1.18, 4.42], *t*(4) = 4.80, *p* = .009, *d* = 2.15. When compared with the R-post-test (*N* = 5 *M* = 6.6 *SD* = 1.52), the mean difference between test scores was maintained at 2.8 points, 95% CI [.58, 5.02], *t*(4) = 3.50, *p* = .025, *d* = 1.57 (Figure 12).

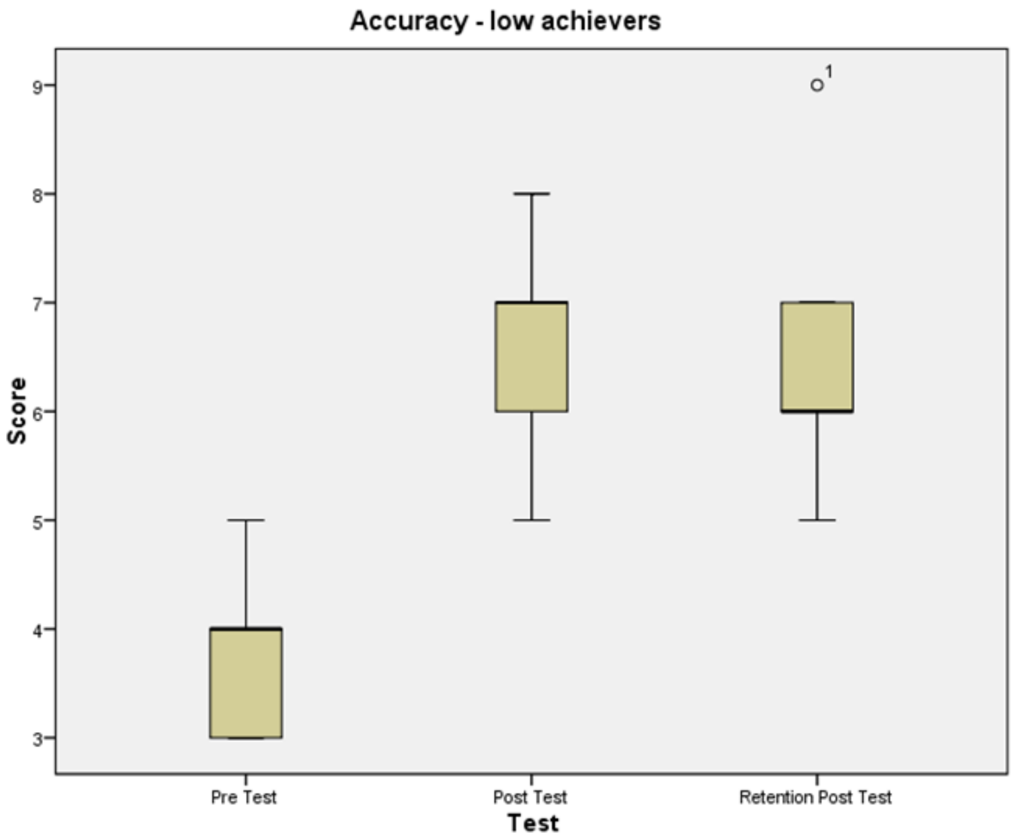

Figure 12: Accuracy of low achievers in pre-, post- and r-post-tests (*N* = 5).

4.3.2 Game and No Game

Accuracy of responses in the conditions was subjected to the number of correct responses out of 15 questions. Each correct response scored 10 points, reaching a maximum of 150.

Analyses were conducted to determine whether there was a statistically significant mean difference between accuracy of responses when participants played the action game in comparison to the non-action game. The computation of the mean difference between the conditions showed no outliers as assessed by inspection of a boxplot. The assumption of normality was not violated, as assessed by Shapiro-Wilk's test (p = .958).

Participants showed an almost unnoticeable difference in performance between the Game condition (N = 32 M = 100.94 SD = 23.88) and the No Game condition (N = 32 M = 100.31 SD = 21.63) scores. Neither the action nor the non-action video games made a significant difference in performance with a mean difference of .625 points, 95% CI [-9.57, 10.82], $t(31)$ = .125, p = .901.

Figure 13 depicts a similar median in both conditions but different distribution with the Game condition looking more symmetrical. Likewise, the upper quartile in the Game condition seemed to have reached higher scores.

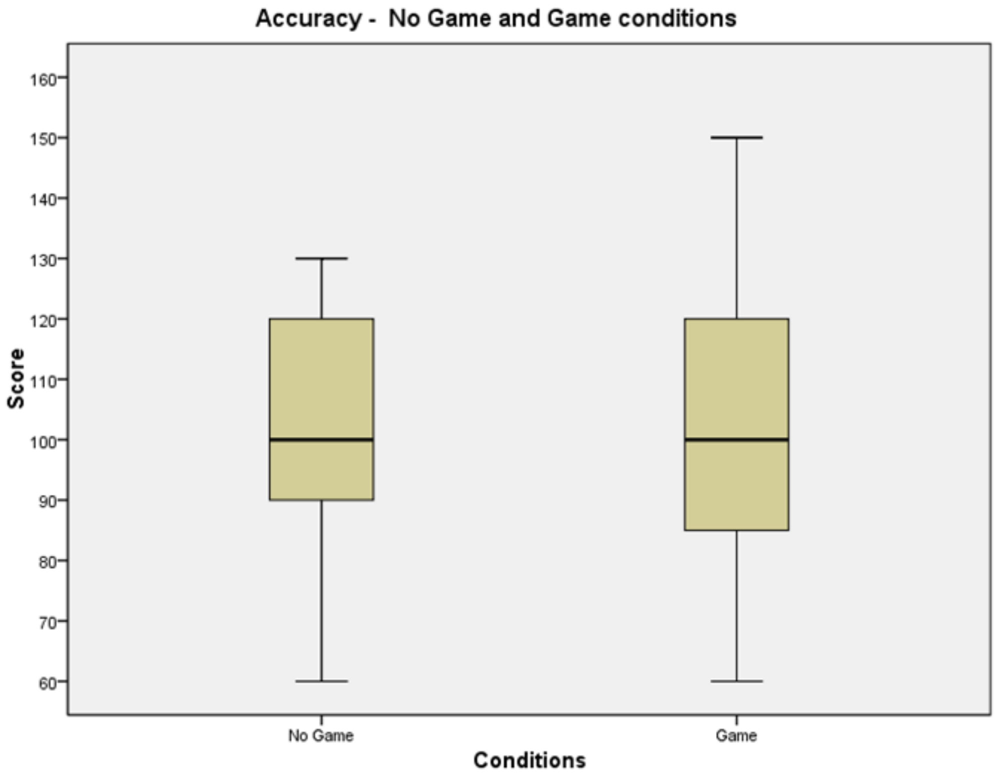

Figure 13: Accuracy of responses. Comparison between No Game and Game conditions

The aforementioned results cannot allow the claim that adding a cue-directed action to a video game would improve the learning, in this case, of prime numbers.

However, the further analysis carried with 5 lower-achiever cases mentioned in section 4.3.1 showed that participants had higher performance in the Game condition (N = 5 M = 88 SD = 17.9) than in the No Game one (N = 5 M = 72 SD = 13.04) with a statistically significant mean difference of 16 points, 95% CI [1.84, 30.16], $t(4) = 3.14$, $p = .035$, $d = 1.40$ (Figure 14). However, it is important to mention that this is a small proportion of the total sample and due to its small size, these results are not to be generalised.

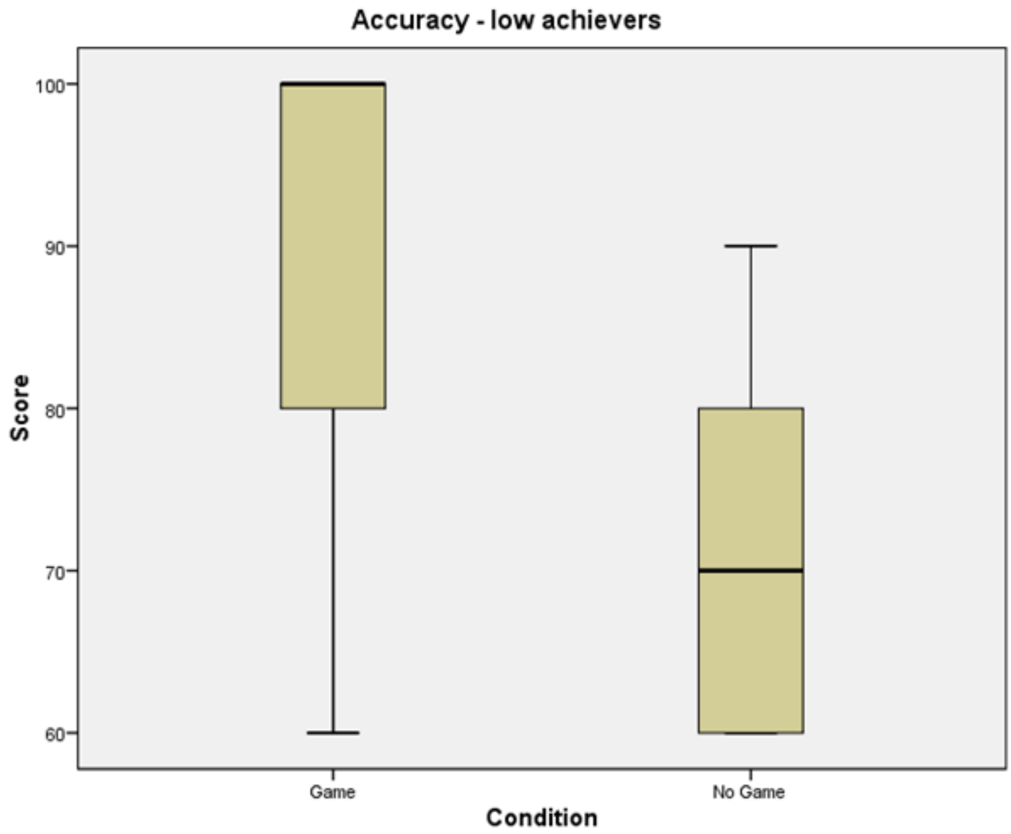

Figure 14: Accuracy level in the conditions for low achievers (N = 5).

4.4 Self-reported level of engagement/learning and performance

When the experiential domain regarding this particular VG was surveyed, self-reported measures of participant's engagement and learning were obtained. Table 5 shows the percentages of responses in each category.

Table 5: Participants' answers in the domain of experience with prime number game.

Experience with these prime number games	low/little	moderate/indifferent	high/very much
1 – How much did you enjoy playing these video games?	9.4%	40.6%	50.0%
2 – How much do you think these video games are useful for learning?	9.4%	21.9%	68.8%
3 – Qualify your level of engagement with the movement game.	3.1%	18.8%	78.1%
4 – Qualify your level of engagement with the non-movement game.	21.9%	40.6%	37.5%
5 – Qualify your level of learning with the movement video game.	0.0%	40.6%	59.4%
6 – Qualify your level of learning with the non-movement video game.	9.4%	31.3%	59.4%
7 – How easy was to play with the movement video game?	9.4%	25.0%	65.6%
8 – How easy was to play with the non-movement video game?	6.3%	6.3%	87.5%

Half of the participants enjoyed playing these VGs and 68.8% thought they were useful for learning. Participants felt mostly engaged with the Game condition (78.1%) and only 3.1% estimated their engagement level with this condition as low. However, the level of learning was equally rated highly with 59.4% for both conditions. However, there was no significant correlation between the level of engagement/learning and performance in the corresponding condition as measured by scores. The self-reported engagement with the non-action game correlated with RT in the corresponding condition (N = 32, r = .435, p = .013) (Table 6).

Table 6: Correlations (Pearson) between self-reported engagement/learning and performance.

		Self-reported engagement		Self-reported learning	
		Game	No game	Game	No game
No Game Score	*r*	.213	-.061	.251	.211
	p	.242	.738	.165	.247
Game Score	*r*	.233	-.343	.168	-.191
	p	.200	.055	.357	.295
No game RT	*r*	.183	.435*	-.057	.065
	p	.315	.013	.756	.722
Game RT	*r*	.081	.197	.156	.066
	p	.660	.279	.395	.718

Participants were asked to rate the level of difficulty of both conditions in order to control for the familiarisation of the game interface. 87.5% of participants rated the non-action game as very easy to play while 65.6% thought the same for the action game. The additional feature made it more engaging but at the same time represented an increased level of difficulty.

4.5 Additional information to explain unexpected findings

4.5.1 Content analysis of answers to open questions

Participants were asked three open-ended questions that required a brief answer in a few words or one or two sentences. Table 7 shows the theme categories identified from participants' answers to the experiential survey. One aim was to encourage participants to consider their reasons for preferring a particular condition, which might reveal hints about the learning implied in this task. Another was to understand possible weaknesses or flaws (missing elements in game) that may have impeded performance. Additionally, the question about how much they would remember was included to enhance awareness of the learning element of the experiment.

Table 7 Categories identified from participants' answers.

Reasons for preferred condition	Missing elements in game	How much will be remembered
Attention – alertness	Graphics	Content (prime numbers)
Focus	Audio	Mistakes
Engagement - action	Competition	Strategy for playing
Challenge	Support	Estimates
Time	Reward	Graphics

The following are the findings of this section presented per question. A frequency of the themes is stated in parenthesis.

4.5.2 Question 1: Reasons for preferred condition

Participants were first asked for their preferred experimental condition (Game [moving object] or No Game [static object]) and to provide the reasons for their choice. 27 participants reported preferring the Game (movement) condition over 3 who opted for the No Game. Two participants reported no preference. Amongst the reasons given for the Game preference, being more **alert** and **attentive** to the task was mentioned 9 times. Interestingly, being more **focused** and **concentrated** in the task was attributed as a reason for both Game (6) and No Game (2) conditions. The concepts of **action** and **engagement** were attributed to the Game condition (7). **Challenge** or the idea of **competitiveness** and **difficulty** represented in the Game condition was only mentioned on 3 occasions. The concept of **time** was also another reason mentioned for both conditions (one for each) as having more time to learn or to think.

4.5.3 Question 2: Missing elements in the game

With the proviso that this software was a computer game created for the experiment and lacked the sophisticated graphic features of the commercially-produced games, participants were asked for elements that they would have liked to experience in the game. Aside from improved **graphics** (8), participants also mentioned the following points.

The theme of **sound** or **music** (categorised under audio) was widely cited (13). Different sounds and their speed would act as cues for directing attention which in this case could have been confounded with the moving object as an attention-directing cue. Another theme referred to the concepts of **challenge** or **competition** (12) and in relation to this one the **rewards** (6) expected as a player. These themes are related mainly to the way scores were assigned and the possibility of earning more points by chance rather than knowledge itself. Finally, the concept of **support** (6) was elicited as part of the way games have to teach people how to learn to play in order to win more.

4.5.4 Question 3: How much will be remembered

This question aimed to elicit an estimate of the perceived learning after the game experience. However, they interpreted it in different ways giving rise to the themes mentioned in Table 7. Primarily, participants gave **estimates** about how much they will remember being '*a lot*' (8) a common answer amongst them and some numerical estimates (2) in percentages also referring to higher level of remembering. However, there were 3 occasions in which '*nothing'* was elicited from the question. Another highly prompted theme was the one referring to the remembering of the **content** itself (13) with participants being general or specific and referring to prime and non-prime numbers. Interestingly, **mistakes** (7) was a category prompted as part of what should be remembered in order to learn. Alongside, **graphics** (2) in this case was referred to colours that helped remember right from wrong answers. Finally, another category of remembered items referring to the *what* more than to the *how much* was **strategy for playing** (2) reflecting on the awareness about the process of learning something new and how to do it.

4.6 Summary of findings

In brief, findings in this study can be summarised as follows.

Participants' profile

This group of participants in general stated a moderate to high enjoyment for VG playing. Almost half of them used VG mainly for fun because in their opinion, VG are not just for children and there are some skills that may be developed through VG playing. However, the majority do not use VG for learning because they do not feel sufficiently engaged by them. Perceptions of their VG skill levels were mixed. Regarding their attitudes towards VG, they seem to be in favour of VGP as they do not support most common anti-game stances. However, they do believe that they may become an addiction.

Response time and accuracy

A significant increase in speed for recognising prime numbers occurred after the conditions were experimented as measured by pre-test-post-test mean RT difference. This was accompanied as well by an increased accuracy of responses in the post-test. Both improvements in speed and accuracy were maintained after a week when learning retention was measured.

In the experimental conditions, participants were faster in responding in the NAVG as opposed to the action one. However, there was virtually no difference in scores between the two conditions. Therefore, the learning about prime numbers cannot be differentially attributed to the two conditions in this experiment.

Due to the detection of a ceiling effect in the testing, an analysis using low-achieving sample was conducted and it showed significant mean difference in accuracy of responses for the action game as compared with the non-action. However, caution needs to be taken with these results as only 5 cases were considered.

Action or non-action

Regarding the experience with the experimental conditions, participants widely showed preference for the action game as they felt more engaged and active according to their own record of answers. They expressed their views on missing elements that would have helped in their level of engagement with the game such as auditory cues, more challenging routes to rewards, improved graphics and support mechanisms. Nonetheless, the majority would use their game of preference again. Finally, among the most remembered items from the game, the concept of prime numbers, strategy for playing and the mistakes made were mostly mentioned by participants.

Chapter 5 Discussion and conclusions

The main purpose of this study was to investigate the effect of cue-directed actions on learning in a video game environment. A computer-based task tested the impact of cue-directed action in a game scenario on the learning of prime numbers. Improvements in accuracy of responses and RT were taken to be indicative of learning. Additionally, improvement in focused attention, awareness and engagement were reported by participants when cue-directed action was present in the game. Motivation levels are reached through the features and elements contained in the video game which, according to the reviewed literature, prompt the neurochemical release in the brain (dopamine and acetylcholine) that support the reward theory (Berridge and Kringelbach, 2008) and action theory (Bavelier et al., 2012a) respectively.

The study was unable to find conclusive evidence in support of the main research question as no significant difference in scores was found between the experimental conditions. Therefore, any influence on the learning revealed by the post-tests can be attributed to either the reward element alone or to the combination of action and reward (action game), but it was not shown that cue-directed action makes a significant difference to learning in this specific context.

The results lead to the postulation that despite an improvement in scores and speed after VGP, there is no direct evidence that the action game led to these improvements. Hence, the hypothesis:

H1_*A video game with a cue-directed action improves adult engagement and learning of prime numbers*

cannot be supported.

Learning after VG playing

Post-test mean scores were significantly higher than pre-test means, meaning that actual learning of prime numbers occurred after playing VGs. These results support two of the hypothesis proposed for this study, namely:

H2_*Accuracy of recognising primes as measured by score in pre-test, post-test will be significantly higher in post-test compared with pre-test,* and

H3_*Speed of recognising primes as measured by RT in pre-test, post-test will be significantly higher in post-test compared with pre-test.*

One interesting fact is that this increase in speed did not compromise accuracy which is normally the rule in the absence of training (speed-accuracy trade-off). Nonetheless, literature has reported this joint enhancement in avid AVGPs (Dye et al., 2009b). Surprisingly, half of the sample reported not feeling particularly engaged with AVGs, despite the fact that they enjoyed VGs in general. However, participants did feel mostly engaged with the action game so there might be some features that caught their attention, such as the action implied in the movement as reported by the themes emerged from their answers. This may have contributed to an increased focus and attention during the action game.

Furthermore, despite the low number of trials in the current study, this increased performance was even maintained a week later.

The learning of prime numbers through the games needed to apply a rule and some mathematical computations that required the use of working memory in the initial stages, e.g. for remembering tables of multiplication in order to know whether the number was a prime or not. However, after several trials and given feedback for correct and incorrect responses, participants may have been able to recall some of those prime numbers from memory (in this case, episodic memory). Therefore, the increase in speed and accuracy could possibly be explained by the action of neuromodulators in the brain areas related to memory formation (acetylcholine) and learning as a result of performing a task which involved engagement and motivation (dopamine) through specific elements. The question that arises now is which of those elements was responsible for this learning.

Action or non-action

Higher RTs in the action game were contrary to expectations. These data could not support the following hypothesis initially stated for the research question:

> **H5**_*Pre-test – post-test differences in RT will be significantly greater in the Game condition compared with the No Game condition*.

Also, there was no significant difference in the scores between conditions and therefore, it was difficult to determine whether one of the conditions had a greater influence over the other in the post-test. Again, these data could not support the following hypothesis:

> **H4**_*Pre-test – post-test differences in score will be significantly greater in the Game condition compared with the No Game condition*.

However, caution needs to be applied to these results as the testing indicated a ceiling effect which represented a potential threat to internal validity. In terms of accuracy, scores could not get higher than 10. Regarding RTs, it should have been possible for those responses to get faster, but they did not. So in both **H4** and **H5**, there is a limit to how much learning a participant could demonstrate without a change of design in the study.

The additional analysis on 5 low-achieving participants (score ≤ 5) showed a significant difference in accuracy for the action game as compared with the non-action. Nonetheless, it needs to be considered that, although these results help dispelling doubts regarding the ceiling effect of the testing, they are based only on the lowest-scoring five cases and may not be generalizable to the rest of the sample.

From the two games played under the experimental conditions it was the action game that was prominently preferred. This finding supports the hypothesis,

> **H6**_*Participants will prefer the game containing the action feature*.

However, it needs to be noted that preference for a specific game type was not significantly correlated to enhanced performance in this case. Other studies have also shown that preference for learning through VG as opposed to traditional methods did not make any difference in performance (Sward et al., 2008).

In fact, participants reported their level of engagement and learning to be higher when they referred to the Game condition. This was interesting as participants enjoyed playing VGs in general but did not feel particularly engaged with AVG or learning games. These data endorse what the learning VG industry has experienced in terms of the lack of engagement with learning games and consequently one of the reasons why they have not proved to be effective for learning yet (Zimmerman and Fortugno, 2005). However, the fact that they preferred the action game and felt more engaged by it shows an affective and motivational reaction to the elements of action added to that condition.

Nonetheless, the preference or the self-reported engagement and learning were not correlated with performance. Previous research (Howard-Jones and Demetriou, 2009), results revealed that there was no significant correlation between self-reported engagement and the actual learning. Hence, hypotheses:

> **H7_***Learning achieved in the action and non-action games will be correlated with self-reported engagement*, and
>
> **H8_***Learning achieved in the action and non-action games will be correlated with self-reported learning*

cannot be supported by the evidence obtained.

Additionally, the fact that there is a marked preference for the action game but no significant difference was found in mean scores in relation to the non-action game leads to believe that there might be elements of the game itself that may have not been well designed from a technical perspective. This may have well influenced the outcomes in a different way according to the game model proposed by the study.

Results and neuroscience research

Although this study was not designed to observe brain activity or track neuromodulators to check for levels of engagement and learning with the tasks, a functional correlate between the learning occurred (as shown by RT and score) and a change in the biological function as a result of engagement and motivation could be assumed here. Both dopamine and acetylcholine contribute to memory consolidation and retrieval and seem to have a putative role in learning due to the brain regions where they are projected (Gold, 2003; Shohamy et al., 2008). The learning that took place after playing the VGs and the posterior demonstration of retention of such learning may lead to infer, perhaps speculatively, that there was an influence of dopamine and acetylcholine in this process, as a result of video game playing.

Certainly, further and deeper research is needed to consolidate the findings from studies in the interface of neuroscience and education

5.1 Limitations to the study

Although the experience of playing VGs contributed to the learning of prime numbers in the participants, there were limitations to the study.

Firstly, it was observed a lack of sensitivity in the pre- and post- tests which produced a ceiling effect. If a participant scored 9 or 10 correct answers in the pre-test, there was little they could do to demonstrate learning in the post-test. This threat to internal validity placed a limit on the extent to which participants could demonstrate learning. During the piloting of materials, the lack of challenge was detected by the testers but it was attributed to the small size of prime numbers used in the corpora and not to the small number of questions (10) used to test participants. Despite the improved corpora, the ceiling effect could still be observed.

A second limitation was related to the game used for the experiment. In the survey, participants mentioned some elements they missed in the game, such as sound or a more challenging or competitive environment that would induce to a higher level of engagement. The lack of challenge or competition revealed by the themes was related to the way in which scores were assigned once a correct answer occurred irrespective of the number of previous incorrect attempts.

Other limitations related to the sample indicate that although sample size was not small, it counted as a minimum for statistical analysis. Further sub-group analyses needed to be treated cautiously before generalising findings due to sample size matters. Regarding the characteristics of this sample, the group showed to be not particularly engaged with AVG or learning games. However, this study did not initially consider relevant asking for the type of game of their preference following Herz's taxonomy (1997). Perhaps this piece of information would have added more insight about participants' interest or preference for a particular type of VG. The inclusion of this piece of information may have repercussions in the design as it may lead to the identification of different groups to apply the experimental conditions.

Finally, there was a minor limitation related to the time of the year for conducting the experiment. As most students were travelling due to their summer break, there was a variation in the time between the post- and retention post-test. Most of them could adhere to the 7-day span, but flexibility was needed due to this contingency.

5.2 Recommendations for future research

A future research in this line may wish to consider minimising or eliminating some of the limitations of the present study. Balancing the difficulty in the testing by increasing the number of questions or the size of the prime numbers would solve the ceiling effect. Regarding the gaming interface, an incremental scoring according to the number of attempts to answer would be an aspect to consider for adding the feature of competition in further studies. This would also make RT and accuracy for responses more precise and will help discriminate better the nature of the response, either by knowledge, by chance or by mistake. Regarding the design, one simple modification to the actual one would be to add more trials in time per condition and intermediate post-tests. This would certainly increase the covariance so a within-participants design should be maintained.

An extension of research in this line may require variations to the design, making it quasi-experimental in order to test in real context such as a school. This would require the inclusion of more trials or tailoring the materials by adding more simultaneous elements to test for automaticity of learning over time. This might be relevant for determining factors that contribute to the transfer from declarative to non-declarative processes in learning. However, as Ashby et al. (2010) noted, even when studies in automaticity require more time and hence more resources, further practice leading to automatic learning, may also continue producing changes in neural representations. Therefore a new training time may be needed to achieve automaticity.

In terms of real-life learning this may imply that even when people master an ability or knowledge to a certain point, once that occurs a new and more complex level of representation will be formed, requiring time to become automatic again. An example of this could be well represented by second language learning in which learners reach a level of mastery after some practice. In fact, most language learning programmes known use levels such as the ones established by the CEFR (Common European Framework of Reference) for languages. After a level has been attained, deeper and more complex structures of the language are expected, restarting the cycle of mastering this new level of representations. In this sense, prime numbers used for this experiment can be analogous to a content to be learned as part of a more global domain of knowledge, such as irregular verbs or prepositions in a second language; the tables of multiplication; or the components of a piece of machinery to be manipulated. All of them are elements that complement the body of knowledge required for a superior skill to be mastered.

Future topics for research on the acquisition of learning and its progress to automaticity through VGs are related to the study of the reversion of learned mistakes once this learning has become automatic. Also important would be the transfer of knowledge or skills to different settings. Findings in these areas would contribute to increase understanding of how we learn and also to help validate the use of VGs in educational contexts.

5.3 Conclusions

There are 3 major conclusions that can be drawn from this study. The first one is that when playing a learning video game featuring elements of reward and action, these students improved their learning of prime numbers as assessed by their increased accuracy and speed of responses, and this learning was maintained after a week. The second is that this improvement in learning cannot be attributed to any one particular feature of the VG (reward or action). The third conclusion is that there seems to be a preference for AVG over NAVG as a result of the engagement they produce although this does not seem to be related to performance.

The results from this study support what has been claimed by other research (Dye et al., 2009b) about the acceleration of reaction time in VG players and the accuracy of responses. However, it was not possible to infer which condition influenced mostly the gain in accuracy and speed as a result of playing both video games. It is important to note that AVGs used in other experiments are off-the-shelf VGs, thus most of the features of action and reward are included in a defined graphical fashion. Furthermore, most of those games which are not intended for education are the ones that have produced different kinds of motor and cognitive enhancements in their users (Greenfield et al., 1994). The challenge for future research consists then in creating an interface as real as possible with an educational purpose to generate enthusiasm and motivation leading to the acquisition of new skills or knowledge.

Certainly this attempt to conjointly test both reward and action features in a VG to produce higher levels of learning represents a challenging endeavour that is worth further development. Whereas this study does not offer a great deal of conclusive evidence to the makers of educational VGs, it may help other researchers to improve designs and materials in order to conduct further studies on the topic. Thus, the importance of a collaborative participation from different stakeholders involved in the use and manipulation of games remains essential.

This exploratory-level study may be considered an initial step for further developments aiming at challenging the limitations of pedagogical VGs by adding features rooted in neuroscientific findings of how the brain engages in learning. Future studies in this line could contribute more about human learning in educational contexts and in a technological era. Applying these ideas more broadly, research endeavours in this area could inform how educators can connect and adapt their practices based on what is known about human cognition, so that the main learning comes firstly from the interaction with another human rather than with a machine.

Appendices

Appendix A: Experiential survey on video games

University of BRISTOL

What is your experience with games?

In order to complement your data, please complete the following survey. Mark your preference accordingly. Number 1 on the scale represents the lowest score and number 5 the highest.

Experience with games in general	1	2	3	4	5
1 – How much do you enjoy playing video games in general?					
2 – How much do you use video games for learning?					
3 – How much do you use video games for fun?					
4 – How much are you engaged by action video games?					
5 – How much are you engaged by learning games?					
6 – How good do you think you are at playing video games?					

Experience with these prime number games	1	2	3	4	5
1 – How much did you enjoy playing these video games?					
2 – How much do you think these video games are useful for learning?					
3 – Qualify your level of engagement with the movement game.					
4 – Qualify your level of engagement with the non-movement game.					
5 – Qualify your level of learning with the movement video game.					
6 – Qualify your level of learning with the non-movement video game.					
7 – How easy was to play with the movement video game?					
8 – How easy was to play with the non-movement video game?					

Attitudes towards video games	1	2	3	4	5
1 – I think action video games lead to violent behaviour.					
2 – I believe learning games are generally boring.					
3 – I think playing video games isolates people from society.					
4 – I think video games are an excellent opportunity to develop skills.					
5 – Video games can damage your brain eventually.					
6 – Video games can damage your vision eventually.					
7 – Video games can become an addiction.					
8 – Video games are only for children.					

Please answer the following questions:

1 – Which of the two games did you find more engaging? Please give a reason.

2 – What element did you miss in the game of your preference to make it even more engaging?

3 – With the game of your preference, do you feel you would like to play it again?

4 – How much do you think you will remember from this game after a while?

Thanks for your participation!

Appendix B: Ethics discussion form

Date: 23/6/2014

Prompt	Comment
Researcher access/ exit	Access is needed to 32 young adults, most of them expected to be university students from the city of Bristol. Snowballing technique will be used to contact participants as well as publicising via massive email.
Information given to participants	Participants will be provided a hand-out with information regarding general instructions and purpose for this study when contacted via email. Onsite, there will be a hard copy of the hand-out plus instructions (in a protocol format) to read aloud to participants.
Participants right of withdrawal	It will be emphasized in the informed consent form that they have the right of withdrawal at any point of the experiment. Shall this be the case, data collected will not be accounted for and more participants will need to be contacted. However, the procedure for contacting will as well emphasize the relevance of their participation in order to avoid withdrawal.
Informed consent	An informed consent sheet will be requested to be signed by participants.
Complaints procedure	Researcher and supervisor's email address will be provided in the information sheet delivered to participants.
Safety and well-being of participants/ researchers	Due to the nature of this study, participants will not be exposed to physical risks or psychological harm.
Anonymity/ confidentiality	No personally identifying material will be held. Participants will only be identified by date of birth and gender. A pseudonym and an email address will be required in case they would like to know their particular result.
Data collection	Quantitative data will be collected in a personal laptop computer hosting the game. Qualitative data will be collected via a paper version of a Likert-scale survey right after the gaming. Data will be collected at GSoE facilities.
Data analysis	Data will be analysed using SPSS.
Data storage	Data from the game will be collected in a personal laptop and retrieved after every participant and saved in the university server. Data from the paper-based survey will be collated and stored in university server.
Data Protection Act	This study meets all the 8 main data protection principles behind the DPA
Feedback	Participants may ask for a personal feedback on their game results after all sample has been collected. At the end of the study and once it has been officially reported, a briefing will be sent with the findings and scope of the study.
Responsibilities to colleagues/ academic community	This aspect has been responsibly covered.
Reporting of research	This research will be reported in my master's degree dissertation and possibly further publications. All contacted participants will be sent a summary of the results and scope of the findings once research has been finalised.

Signed: Silvia Carolina Gordillo (Researcher)
Signed: Carolina Caffarenna-Barcenilla and Antonios Petropolous (Discussants)

Appendix C: Prime number corpora

Original game corpora

Corpus 01 prime numbers			
4	5	6	8
7	8	9	10
30	31	32	33
36	37	38	39
42	43	44	45

Corpus 02 prime numbers			
8	9	10	11
12	13	14	15
20	21	22	23
27	28	29	30
47	48	49	50

Modified game corpora used in this study

Corpus 1 prime numbers			
4	2	6	8
17	12	15	27
28	29	33	39
44	47	49	51
57	61	63	69

Corpus 2 prime numbers			
6	9	10	13
15	19	21	27
33	40	42	43
49	51	59	63
71	75	81	87

Appendix D: List of results per case – RT and accuracy

	PRE-TEST					POST-TEST						DIFFERENCE POST-TEST - PRE-TEST			
est 1	RT Pre-test Corpus 2	Mean C. 1&2 Pre-test	Score Pre-test	correct Corpus 1	correct Corpus 2	RT Post-test Corpus 1	RT Post-test Corpus 2	Mean C. 1&2 Post-test	Score Post-test	correct Corpus 1	correct Corpus 2	difference score	Diff. RT Corpus 1	Diff. RT Corpus 2	Learning from pre- and post-test (RT)
.06	5.99	6.02	9	4	5	4.40	4.61	4.51	9	5	4	0.00	1.65	1.38	1.52
.07	5.92	5.00	9	5	4	3.40	4.16	3.78	10	5	5	1.00	0.67	1.77	1.22
.86	4.96	3.91	7	4	3	4.85	3.65	4.25	8	4	4	1.00	-1.99	1.31	-0.34
.84	7.08	6.46	8	5	3	5.36	7.40	6.38	7	4	3	-1.00	0.48	-0.31	0.08
.03	5.63	5.83	4	3	2	6.75	6.62	6.69	6	3	3	2.00	-0.73	-0.99	-0.86
.94	13.97	11.95	8	4	4	8.02	7.80	7.91	10	5	5	2.00	1.92	6.16	4.04
.75	5.27	5.01	10	5	5	1.89	2.80	2.34	10	5	5	0.00	2.86	2.47	2.66
.35	12.42	13.88	6	4	2	4.73	6.50	5.62	8	3	5	2.00	10.62	5.91	8.27
0.4	7.0	8.7	6	3	3	6.16	5.16	5.66	7	4	3	1.00	4.23	1.84	3.03
4.0	3.5	3.7	10	5	5	2.38	2.41	2.40	10	5	5	0.00	1.58	1.09	1.34
6.2	6.4	6.3	7	4	3	4.51	5.59	5.05	8	4	4	1.00	1.65	0.84	1.25
6.2	7.7	6.9	3	1	2	4.03	5.12	4.58	8	3	5	5.00	2.16	2.58	2.37
4.7	3.7	4.2	8	5	3	3.99	3.98	3.98	9	5	4	1.00	0.74	-0.26	0.24
3.3	3.7	3.5	10	5	5	2.55	2.44	2.50	9	5	4	-1.00	0.73	1.29	1.01
7.9	7.3	7.6	6	2	4	6.10	5.76	5.93	8	4	4	2.00	1.82	1.55	1.69
8.0	15.9	17.0	6	3	3	8.02	13.68	10.85	7	3	4	1.00	9.99	2.25	6.12
.54	5.75	5.14	10	5	5	2.64	4.35	3.49	9	5	4	-1.00	1.90	1.40	1.65
.48	3.38	3.43	10	5	5	1.59	2.51	2.05	10	5	5	0.00	1.89	0.87	1.38
.03	8.64	8.33	6	2	4	4.63	7.60	6.12	9	4	5	3.00	3.40	1.04	2.22
.43	10.49	10.96	7	4	3	8.43	10.91	9.67	8	3	5	1.00	3.00	-0.42	1.29
.60	7.14	7.37	8	4	4	6.18	6.54	6.36	9	5	4	1.00	1.42	0.60	1.01
.10	9.46	8.78	5	5	5	4.11	4.44	4.27	7	4	3	2.00	3.99	5.03	4.51
.51	8.21	7.86	9	5	4	9.84	8.46	9.15	9	5	4	0.00	-2.33	-0.25	-1.29
.62	6.16	5.39	9	4	5	5.16	4.36	4.76	9	5	4	0.00	-0.54	1.80	0.63
.52	7.47	7.00	10	5	5	2.63	3.45	3.04	9	4	5	-1.00	3.89	4.02	3.96
.80	5.00	4.90	9	5	4	2.88	3.88	3.38	8	4	4	-1.00	1.92	1.12	1.52
.64	6.25	5.44	10	5	5	3.45	4.23	3.84	10	5	5	0.00	1.18	2.03	1.61
.85	14.11	12.98	4	2	2	12.64	18.15	15.40	7	4	3	3.00	-0.79	-4.04	-2.41
.75	3.64	4.69	3	4	3	3.91	5.38	4.65	5	3	2	2.00	1.84	-1.74	0.05
.75	7.83	7.29	7	3	4	4.60	3.69	4.15	8	3	5	1.00	2.15	4.13	3.14
.60	4.82	4.71	9	5	4	4.86	3.90	4.38	8	5	3	-1.00	-0.26	0.92	0.33
.58	11.56	9.57	8	5	3	5.15	7.65	6.40	7	3	5	-1.00	2.44	3.91	3.17
.98	**7.39**	**7.18**	**7.53**	**4.06**	**3.78**	**5.00**	**5.85**	**5.42**	**8.31**	**4.19**	**4.16**	**0.78**	**1.98**	**1.54**	**1.76**
.37	**3.21**	**3.19**	**2.11**	**1.12**	**1.02**	**2.36**	**3.28**	**2.74**	**1.24**	**0.81**	**0.83**	**1.41**	**2.65**	**2.08**	**2.07**

	PRE-TEST						R-POST-TEST				DIFFERENCE R-POST-TEST - PRE-TEST		
Gender	RT Pre-test Corpus 1	RT Pre-test Corpus 2	Mean C. 1&2 Pre-test	Score Pre-test	correct Corpus 1	correct Corpus 2	RT R-post-test Corpus 1	RT R-post-test Corpus 2	Mean C. 1&2 R-post-test	score	Diff. RT Corpus 1	Diff. RT Corpus 2	Retention of learning from pre- and post-test (RT)
F	6.06	5.99	6.02	9	4	5	6.92	5.38	6.15	8	-0.87	0.61	-0.13
F	4.07	5.92	5.00	9	5	4	3.37	3.64	3.51	10	0.70	2.28	1.49
F	2.86	4.96	3.91	7	4	3	3.93	4.42	4.17	9	-1.07	0.55	-0.26
F	5.84	7.08	6.46	8	5	3	5.19	5.22	5.21	9	0.65	1.86	1.26
F	6.03	5.63	5.83	4	3	2	7.37	10.02	8.70	9	-1.35	-4.39	-2.87
F	9.94	13.97	11.95	8	4	4	5.36	7.08	6.22	8	4.58	6.88	5.73
M	4.75	5.27	5.01	10	5	5	5.07	3.52	4.30	10	-0.32	1.74	0.71
M	15.35	12.42	13.88	6	4	2	6.84	9.81	8.32	8	8.51	2.61	5.56
M	10.4	7.0	8.7	6	3	3	9.10	9.51	9.30	9	1.29	-2.50	-0.61
F	4.0	3.5	3.7	10	5	5	3.22	1.86	2.54	9	0.75	1.64	1.19
F	6.2	6.4	6.3	7	4	3	6.06	5.56	5.81	7	0.10	0.87	0.48
F	6.2	7.7	6.9	3	1	2	6.67	6.06	6.37	7	-0.48	1.64	0.58
F	4.7	3.7	4.2	8	5	3	3.58	3.20	3.39	8	1.14	0.51	0.83
F	3.3	3.7	3.5	10	5	5	3.04	4.85	3.95	9	0.24	-1.11	-0.44
M	7.9	7.3	7.6	6	2	4	5.22	5.91	5.56	9	2.70	1.40	2.05
M	18.0	15.9	17.0	6	3	3	10.22	19.84	15.03	4	7.78	-3.91	1.94
F	4.54	5.75	5.14	10	5	5	1.94	2.77	2.35	9	2.60	2.98	2.79
F	3.48	3.38	3.43	10	5	5	1.94	3.02	2.48	9	1.53	0.36	0.95
F	8.03	8.64	8.33	6	2	4	5.59	7.15	6.37	10	2.44	1.48	1.96
M	11.43	10.49	10.96	7	4	3	9.44	9.34	9.39	7	1.99	1.15	1.57
F	7.60	7.14	7.37	8	4	4	3.14	3.68	3.41	9	4.47	3.46	3.96
F	8.10	9.46	8.78	5	5	5	4.96	5.05	5.01	6	3.13	4.41	3.77
M	7.51	8.21	7.86	9	5	4	10.47	8.48	9.48	9	-2.96	-0.28	-1.62
M	4.62	6.16	5.39	9	4	5	3.16	3.42	3.29	9	1.46	2.73	2.09
M	6.52	7.47	7.00	10	5	5	5.35	5.00	5.17	10	1.18	2.47	1.82
F	4.80	5.00	4.90	9	5	4	2.63	3.19	2.91	7	2.17	1.82	2.00
F	4.64	6.25	5.44	10	5	5	4.28	3.95	4.11	9	0.36	2.30	1.33
F	11.85	14.11	12.98	4	2	2	9.78	8.37	9.08	5	2.07	5.74	3.91
F	5.75	3.64	4.69	3	4	3	5.18	5.83	5.51	6	0.57	-2.19	-0.81
F	6.75	7.83	7.29	7	3	4	3.75	3.31	3.53	9	3.00	4.52	3.76
M	4.60	4.82	4.71	9	5	4	5.46	4.12	4.79	9	-0.86	0.70	-0.08
M	7.58	11.56	9.57	8	5	3	5.03	4.00	4.52	8	2.55	7.56	5.06
	6.98	**7.39**	**7.18**	**7.53**	**4.06**	**3.78**	**5.42**	**5.83**	**5.62**	**8.25**	**1.56**	**1.56**	**1.56**
	3.37	**3.21**	**3.19**	**2.11**	**1.12**	**1.02**	**2.34**	**3.36**	**2.71**	**1.44**	**2.36**	**2.63**	**1.99**

EXPERIMENTAL CONDITIONS					
ACTION GAME	**SCORE**	**RT**	**NON-ACTION GAME**	**SCORE**	**RT**
Action-1	100	11.74	No Action-1	100	8.45
Action-1	120	7.64	No Action-1	120	8.21
Action-1	120	8.68	No Action-1	60	6.29
Action-1	70	7.69	No Action-1	90	6.38
Action-1	80	5.89	No Action-1	70	9.74
Action-1	80	12.35	No Action-1	110	3.66
Action-1	120	11.23	No Action-1	90	5.73
Action-1	60	6.74	No Action-1	130	4.05
Action-1	130	5.03	No Action-1	90	11.13
Action-1	90	10.95	No Action-1	130	5.59
Action-1	80	11.22	No Action-1	110	9.67
Action-1	60	24.31	No Action-1	100	7.98
Action-1	100	11.41	No Action-1	130	7.04
Action-1	90	7.57	No Action-1	80	11.83
Action-1	90	6.04	No Action-1	120	7.67
Action-1	90	8.51	No Action-1	120	6.74
Action-2	110	11.65	No Action-2	90	13.08
Action-2	140	7.72	No Action-2	110	9.81
Action-2	120	10.56	No Action-2	90	6.96
Action-2	100	6.23	No Action-2	100	9.78
Action-2	120	6.54	No Action-2	60	10.91
Action-2	140	8.12	No Action-2	120	5.44
Action-2	90	7.13	No Action-2	130	3.96
Action-2	70	11.45	No Action-2	80	8.63
Action-2	130	6.93	No Action-2	120	7.22
Action-2	150	8.03	No Action-2	110	7.52
Action-2	90	5.36	No Action-2	110	4.67
Action-2	100	10.97	No Action-2	60	11.00
Action-2	120	10.28	No Action-2	70	3.08
Action-2	100	10.95	No Action-2	120	6.61
Action-2	70	12.27	No Action-2	100	4.86
Action-2	100	6.03	No Action-2	90	7.48
Mean	100.94	9.29	***Mean***	100.31	7.54
SD	23.50	3.53	***SD***	21.28	2.50

Appendix E: List of results per case – survey

se l.	Experience with games in general						Experience with these prime number games								Attitudes towards games								
	1 – How much do you enjoy playing video games in general?	2 – How much do you use video games for learning?	3 – How much do you use video games for fun?	4 – How much are you engaged by action video games?	5 – How much are you engaged by learning games?	6 – How good do you think you are at playing video games?	1 – How much did you enjoy playing these video games?	2 – How much do you think these video games are useful for learning?	3 – Qualify your level of engagement with the movement game.	4 – Qualify your level of engagement with the non-movement game.	5 – Qualify your level of learning with the movement video game.	6 – Qualify your level of learning with the non-movement video game.	7 – How easy was to play with the movement video game?	8 – How easy was to play with the non-movement video game?	1 – I think action video games lead to violent behaviour.	2 – I believe learning games are generally boring.	3 – I think playing video games isolates people from society.	4 – I think video games are an excellent opportunity to develop skills.	5 – Video games can damage your brain eventually.	6 – Video games can damage your vision eventually.	7 – Video games can become an addiction.	8 – Video games are only for children.	Condition preferred
	5	4	5	4	4	4	5	5	5	5	5	5	5	4	3	1	3	4	4	4	5	1	movement
	5	3	4	5	3	4	3	4	5	4	3	3	5	4	2	2	2	5	1	3	4	1	movement
	1	1	1	1	1	4	4	4	4	3	3	4	4	4	4	3	4	3	3	4	4	1	movement
	4	2	4	2	5	3	3	5	4	3	4	5	3	4	4	1	3	5	2	2	4	1	movement
	3	2	3	2	2	3	2	2	3	3	3	3	5	5	2	2	2	4	3	3	3	2	indifferent
	5	4	5	4	4	4	3	4	4	3	4	4	4	5	1	1	1	5	1	1	3	1	movement
	5	5	5	5	3	5	5	3	5	2	5	1	5	1	4	3	5	1	4	5	5	1	movement
	5	2	4	4	2	4	4	4	3	4	3	4	4	4	2	3	1	4	1	2	4	1	no-movement
	5	3	5	5	3	3	4	5	5	3	5	3	5	5	3	1	2	3	2	2	4	1	movement
0	3	2	4	4	2	3	3	3	4	3	4	4	2	4	3	3	2	3	2	3	3	2	movement
1	1	3	1	2	4	2	3	4	4	3	5	3	4	5	2	1	1	3	1	2	4	2	movement
2	2	3	1	1	3	2	4	4	5	4	5	4	5	5	2	2	2	4	3	3	3	1	movement
3	2	1	1	1	1	1	3	5	4	3	3	2	3	4	1	2	3	4	1	1	2	1	movement
4	2	2	4	2	3	2	4	3	4	2	4	4	2	4	3	2	2	2	2	2	4	2	movement
5	2	2	1	1	2	2	3	5	5	4	4	4	5	5	3	2	3	3	3	4	4	3	movement
6	3	1	1	2	1	1	4	4	5	5	3	5	4	5	2	1	4	3	2	1	3	2	no-movement
7	3	1	2	3	2	2	3	4	4	3	4	4	2	4	2	2	3	2	1	2	2	3	movement
8	4	3	4	4	3	4	4	4	5	3	5	4	3	5	2	2	2	4	3	3	4	2	movement
9	4	2	3	2	2	3	4	4	4	3	4	3	4	5	1	1	3	3	1	2	5	1	movement
0	3	2	4	1	2	3	4	3	4	2	3	3	5	5	4	4	2	4	3	5	5	1	movement
1	3	2	4	3	3	4	4	4	4	4	4	4	4	4	4	2	5	4	4	4	5	1	movement
2	3	4	3	1	4	3	3	5	5	4	3	3	4	3	3	1	2	3	1	1	3	2	movement
3	5	1	3	2	1	3	3	1	3	5	3	5	3	4	1	5	5	1	2	5	4	1	non-movement
4	4	3	4	4	3	3	3	2	4	3	4	3	5	5	2	4	2	5	1	3	5	1	movement
5	4	4	5	4	4	4	2	3	3	2	3	3	4	5	1	4	2	5	1	3	5	1	indifferent
6	4	2	4	2	4	3	4	4	3	4	4	4	3	5	2	4	2	4	1	2	3	1	movement
7	4	2	4	3	1	3	3	5	4	2	5	3	3	5	4	2	4	3	2	3	3	2	movement
8	1	1	1	1	1	2	4	5	5	4	4	4	5	5	1	3	2	3	1	1	3	1	movement
9	2	2	1	2	2	1	2	3	2	2	3	2	4	2	5	3	5	3	3	4	5	2	movement
0	3	2	2	3	3	1	3	4	4	4	4	4	3	4	3	2	3	4	2	2	3	1	movement
1	3	1	2	2	2	2	4	3	3	2	3	4	4	3	2	3	3	2	2	1	4	1	movement
2	4	3	4	3	3	4	4	4	4	3	3	4	3	5	4	3	2	3	1	3	4	1	movement

Appendix F: List of results – answers to open-ended questions

Case N.	Gnd.	Condition preferred	1 - Reasons for preferred condition
1	F	movement	active; more attention
2	F	movement	active; attention
3	F	movement	concentrated to the moving answer
4	F	movement	more alert to see the change of number
5	F	indifferent	movement did not affect my actions
6	F	movement	more actiona
7	M	movement	interact with people in the games
8	M	no-movement	concentrate better
9	M	movement	more alert and attentive; non-movement reminded me of traditional school test and caused me anxiety.
10	F	movement	more action; less boring
11	F	movement	more awareness and attention
12	F	movement	more concentration; more fun
13	F	movement	more attention
14	F	movement	more attentive
15	M	movement	more action
16	M	no-movement	gave more time to learn and memorise easier
17	F	movement	more focus
18	F	movement	more activity in catching the number
19	F	movement	more stressed made me more comptitive
20	M	movement	more action and thinking
21	F	movement	more alert
22	F	movement	action
23	M	non-movement	better focus
24	M	movement	motor skill associated with thinking
25	M	indifferent	maybe movement made me more accurate with the mouse
26	F	movement	attention and thinking while trying to learn Pr numbers
27	F	movement	more concentration so as not to miss the correct answer
28	F	movement	not boring; makes you think quickly
29	F	movement	more time to think and answer
30	F	movement	engaging and difficult
31	M	movement	more challenging
32	M	movement	more concentration in different tasks

Case N.	Gnd.	Condition preferred	2 - Missing element to make it more engaging
1	F	movement	other shapes
2	F	movement	music, sound effects, more attractive graphics
3	F	movement	sound
4	F	movement	hints or guidelines to not make mistakes more than twice
5	F	indifferent	some sounds
6	F	movement	sound
7	M	movement	audio
8	M	no-movement	timer as sometimes I missed an option because the number changed
9	M	movement	different colours for the numbers; music; sounds; an image of a trophee at the end to boost confidence of tne player
10	F	movement	extra rewards; different scores according to difficulty
11	F	movement	increase speed and level
12	F	movement	increase speed to increase the sense of competition and fun
13	F	movement	sound; different shapes
14	F	movement	sound effects
15	M	movement	different levels of difficulty
16	M	no-movement	better graphics
17	F	movement	more appealing graphics
18	F	movement	more than one number on the screen to increase difficulty
19	F	movement	bigger screen; modern graphics but may not help in focusing on the content
20	M	movement	colours; sound
21	F	movement	sound and movement when game is over
22	F	movement	multiple squares
23	M	non-movement	building and testing an algorithm like Eratosthene's shiere
24	M	movement	increase point score with higher number assertions
25	M	indifferent	more distracting conditions;music, different layers of visualisation
26	F	movement	better layout, seems old fashion game; faster movement
27	F	movement	sound; additional feedback; a fun element
28	F	movement	nothing
29	F	movement	time given
30	F	movement	element of competition but it may be more stressful as well
31	M	movement	different kinds of movement
32	M	movement	bigger moving boxes to make it easier to catch them

Case N.	Gnd.	Condition preferred	3 - How much will you remember?
1	F	movement	around 50%
2	F	movement	strategy of the game and some prime numbers
3	F	movement	a lot. Still thinking of the missing PR during the game
4	F	movement	quite much
5	F	indifferent	a few things
6	F	movement	definetively remember some pr numbers
7	M	movement	most of it
8	M	no-movement	a fair bit
9	M	movement	procedure of the game; some prime numbers
10	F	movement	pr numbers for quite a while
11	F	movement	depends on how much i play in a week/month. I dont have a good memory
12	F	movement	Pr numbers a lot and the mistakes I made, especially with bigger numbers
13	F	movement	not much because i usually dont work with numbers
14	F	movement	80%
15	M	movement	many things (mathematical skills) for a long time
16	M	no-movement	at least i will knowwhat is a Pr N
17	F	movement	i will remember what i've learned from it.
18	F	movement	larger pr numbers
19	F	movement	a lot; especially the wrong answers. Explanations in different colour helped remember it.
20	M	movement	pr numbers and the ones I failed.
21	F	movement	all Pr numbers I got wrong
22	F	movement	some prime numbers
23	M	non-movement	nothing
24	M	movement	just two or three pr numbers
25	M	indifferent	most of it
26	F	movement	a lot from colours to some answers
27	F	movement	mistakes for long, especially the ones i did wrong more than once
28	F	movement	pr numbers and wont forget what they are.
29	F	movement	more about prime numbers
30	F	movement	57 is not a Pr number
31	M	movement	maybe some numbers
32	M	movement	a lot, especially mistakes

Appendix G: Informed consent form

University of BRISTOL

Informed Consent Form

Project: Effects of video games in learning

Please read and tick the boxes as confirmation of your understanding:

☐ I understand that my participation in this project will involve taking part in an experiment using video game in which data about my performance will be collected by the computer. I also understand that I will be required to answer a survey after playing the game as well as the completion of a second post-test after a week of the experiment.

☐ I understand that participation in this study is completely voluntary and that I can withdraw from the study at any time until a week after I have participated in the study and without the need of providing further explanation.

☐ I understand that the information provided by me will be treated confidentially, such that only the researcher can track this information back to me individually, and that individual performance in the experiment will be made public using a pseudonym of my choosing.

☐ I understand that I am free to ask any questions at any time and to discuss my concerns with the researcher and/or research supervisor.

☐ The information will be retained for further studies and publication. I understand that I can ask for the information I provide to be deleted/destroyed at any time and, in accordance with the Data Protection Act, I can have access to the information at any time.

☐ I also understand that at the end of the study I will be provided with additional information and feedback about the purpose of the study and its findings.

☐ I have understood all the above mentioned information and given the opportunity to ask questions if necessary.

I, ___________________________________ (NAME) consent to participate in the study conducted by Carolina Gordillo at Graduate School of Education, University of Bristol.

Signed: ______________________________

CONTACT DETAILS

Date of Birth (DD/MM/YY): _____________________________ **Gender:** ____________
E-mail address: ____
Pseudonym: __________________

Appendix H: Information sheet

Information Sheet

Project: Effects of video games in learning

You are invited to take part in a voluntary study to explore the relationship between video games and learning. As a participant, you will be asked to complete 4 tasks in a personal computer interface plus an additional one a week after this session.

Every task in the computer should take no longer than 2 minutes. Once the tasks have been performed, you will need to complete a brief survey on your experience as game user. Your participation in total will not be longer than 30 minutes.

The data collected from participants will be analysed in order to obtain information about the influence of video games on learning automaticity. All data will be treated anonymously and it will be not linked to any other information related to you. However, you will be asked to provide your date of birth and gender for data analysis purposes, and a pseudonym to receive results if desired.

All testing will take place at the Graduate School of Education, University of Bristol. Your participation is voluntary and every participant has the right to withdraw from the study at any moment during the experiment until a week after participation in the study without providing further explanation.

Shall you have any further inquiries related to this study you can always contact the researcher and/or supervisor.

Carolina Gordillo: carolina.gordillo.2013@my.bristol.ac.uk (Researcher)

Paul Howard-Jones: paul.howard-jones@bristol.ac.uk (Research Supervisor)

I appreciate the time you take to contribute to my research.

Carolina Gordillo

Researcher

Appendix I: Verbal instructions to participants

University of BRISTOL

Information to provide verbally to participants

In this experiment, you will be asked to play a computer game in which you will have to guess the prime numbers.

A prime number is one that can be divided evenly by itself and by 1 only.

You will be pre tested on these numbers before playing the first game. This pre-test consists of 10 questions. For this purpose you will use the computer keyboard. The keys are marked with the symbols representing the alternatives in the game. You should press the corresponding key when you know the answer. There is a bar time on the right side of the screen

Once the pre-test is completed, you will play the first game according to the distribution list. In this game you will need to use the mouse or key pad as desired. There are 15 questions in each game.

Once finished, you will play a second game with a variation in the conditions.

Once the two conditions have been tested, you will perform a post-test to prove how much you have learned.

Finally, you will be asked to complete a survey on your experience as video game player.

You will be asked to come in for a second session to complete a second post-test.

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