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An Analysis of a Video Game on Cognitive Abilities: A Study to Enhance Psychomotor Skills via Game-Play

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ABSTRACT Psychomotor skills are a series of cognitive abilities often linked with physical movement, coordination and speed that individuals use, to progress through cognitive stages in order to demonstrate fine motor skills. This paper investigates whether or not playing a video game could potentially influence and improve the psychomotor skills of adolescents, particularly their eye-hand coordination, visual response and attention competence, the aim being to provide statistical evidence that video games can be potentially used to enhance psychomotor skills. A total of 62 participants were invited to participate in an experimental study where these participants were divided into two groups, the control group and the experimental group. The participants were aged between 16 and 19 years, and they were asked to complete a building block task that is closely associated with using psychomotor skills, and they did not have any prior experience of. A pre – post study design was used in both groups in order to measure participants' level of confidence in using their psychomotor skills. Furthermore, the study investigated if the participants in the experimental group integrated elements of video game play into intentional and automatic real-life reactions within the building block task they undertook. The findings of the study suggest that those participants who played the video game were more confident in using their eye-hand coordination and visual response, and managed to complete the natural building block task faster and more accurately than the participants who did not play the video game.

INDEX TERMS Psychomotor skills, video games, eye hand coordination, game-play and skill acquisition, game-play behavior and cognitive skills.

I. INTRODUCTION

Due to their immersive experiences, video games and video game-based technologies (henceforth referred to as games) have been heavily utilised by researchers, particularly in the fields of Psychology and Computer Science [1]–[3]. Many researchers have shown that games can enhance cognitive abilities in individuals and have latent benefits in addressing social stimulation and abstraction difficulties [4]–[6]. As a result, there is an increasing volume of research that investigates the impact of player engagement, and outcomes that influence the cognitive abilities in players during their game-play [7].

Recent studies in this field provide statistical data to support the premise that people who play video games on a regular basis outperform those who do not play video games/non-gamers specifically in measures of reading abilities, eye-hand coordination, reaction-time, visual response and basic attention [6], [8]. While many studies have investigated psychomotor skills using psychological assessment tests, only a few studies provided empirical evidence regarding video game-play leveraging attention control and eye-hand coordination [9], [10]. Furthermore, many researchers argue that game elements can be used to solve real life issues in support of automatic responses, attention, eye-hand coordination and other cognitive skills particularly in adolescents [8], [11]. The reason why young people are often recruited as the target population of such research studies is because psychomotor development occurs throughout infancy, childhood, and adolescence [12]. Apart from this, most adolescents have the awareness to judge their own behaviour and motor development accurately and objectively as they are closer to adulthood than children [13].

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Research that focuses on the psychological effects of video-games has reported that highly immersive games can become potential tools in supporting attention deficit disorder [14]. Whilst there is some statistical evidence to show that video games can lead to enhancement in cognitive abilities [15], the majority of evidence provided in this area lacks rigorous analysis and is based on anecdotal data [4] [11]. Moreover, recent research in this area suggests that adolescents have a tendency to be immersed in prolonged game-play sessions without any clear agenda [16]. Therefore, it is argued that due to the lack of a clear plan, the prolonged session could potentially lead to a decline in cognitive abilities instead of being enhanced [17].

There is clearly insufficient empirical evidence regarding the effects of gaming on the development of cognitive patterns and visual responses due to the tendency of studies to focus on working memory [9], [15] rather than the impact of core psychomotor skills developed via game-play, on real world activities. In other words, the short and/or long term effects of a potential increase in visual response and eye-hand coordination via game-play, particularly on adolescents, is relatively unexplored because of the need for well-structured and well analysed experiments [18].

For the reasons identified above, this study has taken an approach to build an action game from the ground up in order to observe a potential enhancement to core psychomotor skills, particularly the eye-hand coordination management, visual response and attention of the participants. To clarify, this paper aims to answer the following research questions:

Can a video game-play be designed to enhance core psychomotor skills? If so, what video game-play elements can support the enhancement and confidence of using core psychomotor skills?

In order to answer these questions, two groups of participants were asked to complete a natural task that is taken from the literature and was strongly associated with using psychomotor skills. While both groups completed the natural task, one group was asked to play an *adhoc* game before they completed their task and the other group was not. The *adhoc* game was developed from scratch and was supported with Tobii Eye Tracking Kit [19], with a view to enhance the participants' psychomotor skills during their game-play. The eye-tracking development kit was integrated into the game-play in order to explore when and where the participants were focusing during their game-play. Having developed the game, an extensive analysis was undertaken to assess whether or not the game had an impact on the psychomotor skills of participants in three different categories: *visual response*, *attention* and *eye-hand coordination*.

II. RELATED WORK

Psychomotor skills refer to a range of abilities that establish a relationship between cognitive abilities and physical movement which are often investigated using psychological assessments via natural tasks [6]. Practicing psychomotor skills accelerates motor skills and mental capacities which are majorly affected by task complexity, amount of practice and environmental factors [20]. Additionally, psychomotor learning enhances cognitive functions such as learning, thinking, remembering, problem solving, decision making, and attention. Some of the advantages of developing psychomotor skills include increase of attention span and effective coordination of activities that involve the use of arms, hands and eyes such as *driving* [21]. Additionally, psychomotor skills are often associated with laparoscopic skills which can only be acquired through hands-on training [22].

Older studies in this area focused on static image processing or physical tasks to investigate the development of psychomotor skills, [23] whereas recent studies encourage the use of integrated robotic kits or eye-tracking technologies [24], [25].

It is widely accepted that video games and video game-based technologies engender high levels of motivation, provide immediate feedback, hold rewards, and adjust difficulties according to players' skill and learning pace [26].

The idea of using games and game-like environments for skill development and/or manipulation of behaviours in human subjects is not novel. As an example, Virtual reality exposure therapy (VRET) is an approach perceived as an alternative to standard vivo procedures in psychology [27], [28]. As a practical implication, game-like environments have been used to treat people with extreme fear of heights or other phobias [29]. Moreover, various educational games have been rigorously investigated through studies and proven to be effective tools to increase motivation of participants in learning a specific topic such as computer programming [30]. As serious games hold relatively low risk of experiential learning curves, they are being used in a wide variety of fields from mental health to even crisis management [31], [32]. It is clear that there is a huge potential in using games both as learning tools and a motivator particularly in education, health and training. This is why, many researchers have defended the idea that video games promote effective learning and foster the meta-skill of attention control, which means that video games could be potential tools for developing psychomotor skills [33], [34].

A number of studies have discussed and provided evidence with regard to how video games could potentially enhance visual attention and eye-hand coordination skills particularly among adolescents [16], [26], [35]. A descriptive study in this area revealed that a considerable percentage of game players (74.6%) perceive sensorial awareness and content from video games even after they stop playing games [17]. Another study examined what factors cause prolonged effects of game-play but they did not clearly identified whether or not these effects could potentially enhance players' abilities and visualization skills [14]. A study by Satyen [36] investigated whether or not playing video games could lead to improvement in how attention is divided between tasks, and the reaction time among participants, using a dual task paradigm. Findings of the study suggested that reflex reactions and the reaction time of participants were improved after 6 hours of training but this diminished shortly after players stopped playing the game. Furthermore, Achtman *et al.* [35] examined whether or not action video game play could be used to train participants to take correct decisions faster. Their findings suggested that video game players were able to process information and take correct decisions based on visual and auditory stimuli faster than non-gamers. Franceschini *et al.* [8] investigated the effects of video games on adolescents with dyslexia. Their research was predominantly focused on using a video game in order to improve the attention and reading abilities of 20 adolescents divided into a control and an experimental group. While the overall numbers in each group were low, their findings suggested that video game training could improve the efficiency of focus, and that could drastically reduce the incidence of reading disorders over time. Green & Bavelier [26] undertook similar research using video games in order to examine cognitive benefits and transferable skills that could be drawn from game-play. Although their study was limited to the use of commercial off the shelf (COTS) games, their results indicated that participants who played action video games between 10 to 50 hours spaced over a couple of weeks experienced enhancement in perceptual skills, attention and cognitive flexibility.

In addition to these, studies investigating psychomotor skills and video games argue that the improvement of perceptual skills is beneficial in the area of surgery and surgical training [37]. Other researchers investigated whether playing video games would predict psychomotor performance on surgical training and examined the correlation, if any, with a person's innate abilities [38]–[41]. Research in this area suggests that repetitive and frequent video game-play can improve psychomotor skills, and that a relatively strong correlation between game-play and performance on surgical simulators exists [38]. More recent studies also support this claim and provide semi-structured evidence that video game-play can improve laparoscopic surgical skills [42]–[44].

Despite the overwhelming amount of research in enhancing psychomotor skills and cognitive abilities using games, very few studies directly focus on a structured assessment of how to enhance eye-hand coordination and the visual response of players using games and natural tasks together [18]. More importantly, which transferable skills could be drawn from video game-play and how game-play elements can support the enhancement of these abilities are relatively uncharted research areas.

For the reasons identified above, this study was undertaken to investigate psychomotor skills in three different categories by using an action game developed from scratch. Having done a deep review of the literature in this area, the psychomotor skill categories were divided into *visual response*, *attention* and *eye-hand coordination*. All of these categories were drawn from the recent work available in the literature [9], [10], [25], [31]. It should be noted that these three categories are not the only core psychomotor skills mentioned in the literature as there are many other cognitive and motor processes that are mentioned as part of psychomotor skills such as body control, awareness and anticipation. While there are wide variety of psychomotor skills, not every one of them is objectively quantifiable in a video game environment. A good example to this is *multi-tasking* which is referred as part of psychomotor skills [46] but not necessarily measurable in a video game environment. Most video games are challenging by nature and rely on simultaneous micro management of various tasks at once. Considering this, it is not clear a) what exactly can be defined as a task in a video game environment because players often complete overlapping tasks to win in video games and b) how multi-tasking can be quantifiable is uncertain because micromanagement often happens simultaneously in video games. Moreover, research in this area suggests that effective multi-tasking does not exist but rather should be defined as "*task-switching*" [47]. It is argued that it requires more time to complete the tasks when using *task-switching,* rather than doing one task at a time in order [48]. As a result, *visual response*, *attention* and *eye-hand coordination* were chosen in this study because these are objectively quantifiable in an action video game environment and transferable to real world activities.

TABLE 1. Showing refined research questions, null and alternative hypotheses used in the study.

Research Question	Null Hypothesis (Ho1)	Alternative Hypothesis (Ha1)
Is there a difference in participants' level of confidence in using their psychomotor skills between the pre and the post study both in the control and in the experimental group? *	There is no significant difference in participants' level of confidence in using their psychomotor skills in between the pre and the post study. *	Participants' level of confidence in using their own psychomotor skills significantly changed in between the pre and the post study. *
Is there a difference in participants' *eye-hand coordination* in between their playthroughs?	There is no significant difference in participants' *eye-hand coordination* in between their playthroughs.	Participants' *eye-hand coordination* significantly changed in between their playthroughs.
Is there a correlation between participants' *eye-hand coordination* during their game-plays and their strategies used in completing the given natural task?	There is no significant correlation in participants' *eye-hand coordination* during their game-plays and their strategies used in completing the given natural task.	Participants' *eye-hand coordination* during their game-plays and their strategies used in completing the given natural task were significantly correlated.

* evaluated *eye-hand coordination*, *visual response* and *attention*.

Having identified the psychomotor skills, the research questions were refined in order to fit into a pre-post control-experimental study structure. As shown from Table 1, a null and an alternative hypothesis were added to each refined research question in order to statistically analyse the collected data with the aim of answering these new research questions. Several research papers were reviewed before categorizing and reorganizing the research questions [38], [45], [49]–[51] the aim being to keep the focus of the research on the confidence level of participants as well as the potential psychomotor skill acquisition from the study. Based on the results obtained from these research questions, the aim was to analyse what elements of the game-play could be associated with the enhancement and confidence of psychomotor skills.

III. TASK DESIGN

There are two important tasks that are used in this study. One of them is a natural task taken from the literature in psychomotor research and the other one is an *adhoc* game developed from scratch with which aims to deliver the practice of core psychomotor skills identified above. Both of these tasks are explained in detail below:

A. NATURAL TASK

This study uses a natural task that is taken from the seminal work of Ballard *et al.* [52] as a measure to assess participants' psychomotor abilities. The natural task is based on effectively completing a series of building block activities with provided models, workspace and resource management.

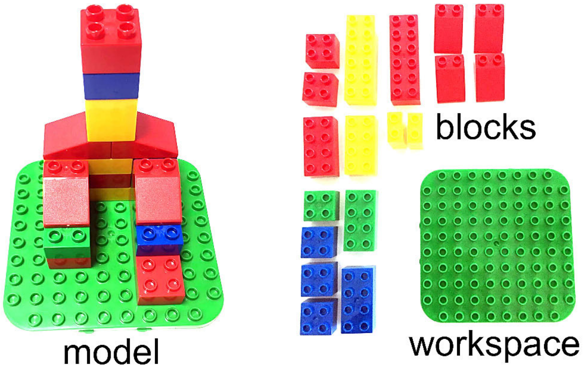

FIGURE 1. Showing one of the natural task models, workspace board and the building block pieces in this study.

Figure 1 shows one of the models that was constructed on the workspace with a variety of building blocks that have different colours. In this natural task, participants are provided a series of models of what they need to construct through using *lego* like building blocks on a workplace. As an assessment, the purpose is to measure how fast and correct participants complete the given building block models without reference to the model diagrams provided. The core idea behind this is that the less participants check the model diagrams to recall the pieces, the faster they can build the provided models. After informing participants about the models which need to be constructed, they are expected to complete the task as fast and accurately as possible within a limited time period.

This natural task is perceived as a simple and an effective way for measuring *eye-hand coordination*, *visual response* and *attention* of participants and as a way of testing the use of short-term memory [50], [53]–[56]. Several appropriate tasks (such as the Grooved Pegboard test, the Digit Symbol Substitution test and the Star Mirror Tracing task) were evaluated in order to identify a method of assessing psychomotor skills before choosing this natural task. Having undertaken some analysis of the assessment methods, the natural task used in this study was chosen because this task predominantly focuses on minimizing the use of short-term memory. Furthermore, the task also focuses on reducing the immediate memory required to perform the activity and is based on serializing eye-hand movement to postpone the gathering of task-relevant information until just before it is required. It is argued that the observed sequences of eye-hand coordination are performed in terms of whether the participants remembered either the colour and/or location of the blocks required without looking at the model provided to them. In other words, the task uses an approach where the sequences participants perform are encoded according to how much they remember about the colour and location of the blocks [52]. Each sequence represents a deeper level of the use of short-term memory. If participants cannot recall both the colour and the location of the blocks and need to look at the model to do this, a Model Pick up Model Drop (MPMD) sequence happens. If only the colour is recalled, a Pick up Model Drop (PMD) sequence should result; and if only the location is known, a Model Pick up Drop (MPD) sequence happens. Finally, if both the location and the colour are known, this results a Pick up Drop (PD) sequence. These sequences can be ordered according to how much participants remember and therefore, these are listed as *sequence ratings* in this study as in the higher participants show that they remember the colour and location of the blocks on the model, the higher rank they get in the task. In this case, this research associates MPMD as 1, PMD as 2, MPD as 3 and finally PD as 4 in terms of sequence ratings. To this day, this natural task is perceived as a seminal work as a way of testing the use of short-term memory in the form of a natural eye-hand task [55], [56].

B. THE GAME

Considering the previous work identified above, a video game was developed from scratch as a test-bed in order to assess *visual response*, *attention* and *eye-hand coordination* of participants. While there are several games available to measure brain activities and awareness such as the BrainHQ framework [57], it was decided to develop an *ad hoc* game for this study because a) the existing brain exercise games were not designed from the ground up to support eye-tracking software, and thus it was difficult to obtain precise information regarding what a participant was looking at during their game-play; b) we needed a game-play that could deliver objectively quantifiable data to investigate, such as log files that keep the score of the game and/or information about the participants' interactions; and finally, c) most existing brain exercise games are designed to measure only one aspect of the psychomotor skills, whereas we needed to have a game that could measure multiple skills simultaneously.

Further to the above, the literature argues that cognitive processes are directly involved in the acquisition of core psychomotor skills [58]. In order to acquire core psychomotor skills, several processes (such as visual response orientation and eye-hand coordination) need to be practiced repeatedly and consistently, in parallel with their integration and execution [59]. A game-play that is aimed at practicing the use of core psychomotor skills needs to consistently encourage players to use their attention, visual response orientation and coordinated physical movement all at once in order to respond to sensations that are caused by different stimuli in the game environment. In other words, players' *attention*, *visual response* and *eye-hand coordination* are among the abilities that need to be utilized in game-play simultaneously in order to assess core psychomotor skills. Therefore, we decided to develop a new game-play that encourages the practice and/or acquisition of these skills.

The game was designed as an action-platform game using the Unity Game Engine. Unity is a popular game engine and has a relatively large community and effective support for game development. Additionally, Unity supports Eye Tracking Software Development Kits (eSDKs) that can be used to track the eye-hand coordination of players when they play a game.

FIGURE 2. **Showing the game-play from the *adhoc* game.**

As shown in Figure 2, the game used in this study was designed to be a 2D endless runner game that consists of a player navigating a robot through a series of platforms. At the beginning of the game, the players are informed that they control a robot that continuously runs ahead moving from the left of the screen to the right. The players are expected to interact with the game so that the robot does not fall off the platforms and/or does not collide with any obstacles. In other words, the aim of the game was to provide control over an endlessly running robot – which is the player character – to run along the platforms, and jump up or down to other platforms without falling off. While the robot is running, the player needs to use the mouse to either get down or jump up to platforms by clicking on to the platforms themselves.

While a left click on a platform would make the robot jump up, a right click would make the robot jump down from the current platform to a lower one. By using this simple game mechanism, it was designed to calculate whether or not the players' gaze is focused on the objects they are clicking hence it was possible to detect whether players are looking at the object the robot is about to try and jump to. In addition to navigating the robot, the players need to pay attention to collect random *power-ups* which appear throughout the game and provide enhancements for the robot such as an extra life or invincibility. Furthermore, the game has traps on the platforms, which players need to avoid. While the platforms are stable, trap locations and *power-ups* are randomized in the game making each play through significantly different. Moreover, as the game goes on, the robot starts moving faster and thus making it harder to predict when to move to a higher or lower platform, or avoid a trap. The game offers three lives to the player initially, however more lives can be obtained via collecting *power-ups*. Should the robot fall, one of the lives is spent and the game will continue from that point. When all lives are spent, the game is over. Finally, the game has a tutorial mode, which allows the player to pause the game at any time and become familiar with, or to refresh their memory of, the game rules and environment.

An endless running game genre was specifically selected in this study because this type of game-play presents a context where the time has a direct effect on the game-play. It provided an environment to assess gradually increasing demands that can be practiced through tasks management with spaced conditions. In other words, as the time goes by, the difficulty of the game progressively increases. However, when a player reaches a certain point in the game, the game-play slows down to offer a spaced condition for players to reflect on their game-play before facing further challenges.

Recent studies examining the effect of skill acquisition and game-play behaviour have shown that individuals practicing in spaced conditions outperform those in massed practice conditions [49], [51]. In other words, a game-play that offers increasingly difficult activities to assess the skill of players with some room to breathe in between these activities could be more beneficial than a gameplay that offers increasingly difficult mass activities that have no break in between. Furthermore, Van Der Vijgh *et al.* [60] argue that digital games particularly action games present a flexible setting for assessing different forms of psychological stressors and that they allow for precise control of these stimuli, because the results can be determined in detail and manipulated in real time. They hint that this type of game-play requires *attention*, *eye-hand coordination* and *visual response*, which are the key areas targeted to be assessed in this study.

As a result, the entire game-play was designed around the idea that players need to use core psychomotor abilities in order to survive in the game environment. Players' *visual responses* were tracked by generating log files which recorded hand movements of players by detecting their interactions in the game environment and the number of times this happened. Tobii Eye Tracking Kit and hardware were used to capture the gaze of players during their game-play. The Eye Tracking Kit detected whether or not the players were precisely looking at the object they interacted with, and thus helped calculate the eye-hand coordination of players. Finally, the attention of the players was matched with how long and how well they survived in the game by implementing a scoring system. The game was designed in a way that the longer the player survived and faced new challenges in the game, the higher the score they would achieve. Finally, when players collected *power-ups* or avoided *traps* successfully, this significantly increased their score and thus provided a basis to measure their *visual response* and *attention*.

IV. RESEARCH DESIGN

A two-group pre-test and post-test design was used in this study. The recruited participants were divided into two groups: the control group and the experimental group. Both groups were asked to complete the natural task taken from the seminal work of Ballard *et al.* [52], but only the experimental group played the *ad hoc* game before completing the task. The participants in the control group were not informed about the game intervention used in the experimental group. Having played the *ad hoc* game, the participants in the experimental group were asked to complete the natural task, whereas the participants in the control group were asked to do the same without playing the game.

The participants of this study were recruited from a school in Cyprus that they were currently studying at, and they were all adolescents with previous video-game playing experience. The participants were selected based on the fact that they had self-reported focus problems as this was the focal point of many studies in this area [8], [9], [26], [35]. However, the extent of participants' focus problems or the classification of their inability to concentrate were not investigated due to the ethical restrictions of the research. The participants themselves claimed that they have a lack of focus and this was known by their teachers. All of the participants were approached and invited in person by their teachers to participate in this study. In other words, their teachers invited the participants based on the target group criteria (i.e. being adolescents, having a lack of focus and playing video games). After accepting this invitation, the procedure and the study structure were explained to the participants through face-to-face meetings. It was clearly explained to them that participation was voluntary.

The study was conducted in a classroom environment within a week period as an after-school activity in Cyprus. The environment was familiar to the participants and they were all informed that their honest answers were vital and valuable for the research. Additionally, they were aware that they all had the option to dropout from the study at any time without providing a reason. The research was confidential and the participants were never asked to reveal any personal information about themselves. As the procedures of the study explained to the participants, they were divided into two as the control and the experimental groups according to their age, gender and ethnicity, for the purpose of keeping these equally split in between the groups.

The participants who were in the experimental group were invited to take an eye-tracking calibration test in order to ensure that their eye-movements would be recorded accurately during their game-play. These participants were made aware that their eye-hand coordination would be recorded during their game-play. All participants in the experimental group were also aware that a series of log files would be generated and used to track their game-play. The participants did the test three times and undertook the same set of calibration tests to make sure that their eye-hand coordination was tracked accurately.

In order to assess the psychomotor skills accurately, a pre-post study design was followed in a control experimental study structure. At the beginning of the study, all participants were asked to take a pre-study activity which involved undertaking a questionnaire to rank their perception of their psychomotor skills before they undertook the natural task described above. All participants were informed about the natural task before they participated in the study. Having done so, participants were asked to rank their psychomotor skills in three areas which were the identified abilities from the literature: *eye-hand coordination*, *visual response* and *attention*. Participants' confidence and their perception of abilities to use psychomotor skills were assessed using a 5-point rating Likert scale in each question. The main reason for using a close ended questionnaire was to make the participants' perception of abilities quantifiable. The Likert scale ranged from one extreme attitude to another from 1 (strongly disagree) to 5 (strongly agree), 3 being the moderate (neutral) point. Furthermore, none of the participants had any experience regarding the natural task, and those who defined themselves as hardcore video gamers were evenly distributed between the two groups.

During the study, the control and the experimental groups did not communicate with one another. The entire study lasted for about two hours and was repeated three times during the week with a day gap between experiments. Moreover, participants undertook multiple and different block building models each time they participated in the study. The majority of the participants managed to finish before the time limit given in each iteration. As the control group was not asked to play the game, they took less time to complete the study than the experimental group who took about twenty to forty minutes to play the game in each iteration so they completed the experiment later than the control group.

The duration provided to the experimental group was decided based on a usability test that was carried out with 12 participants before the actual study. This usability test served as a pilot study both for the game experience and the questionnaire implemented. Having taken feedback from these participants, the answers were examined to evaluate whether or not the defined psychomotor categories were measured. Additionally, the game experience was enhanced based on the feedback provided in this study. None of the participants in the pilot study was invited to participate in the actual research in order to avoid any kind of bias.

During the actual study, the participants in both groups were asked to complete a post-study activity at the end of the third iteration (i.e. end of the week). The post-study questionnaire given to participants was identical to the pre-study questionnaire provided to them at the beginning of the study. The results of the post-study were matched with the results obtained from the pre-study in order to investigate the impact of the natural task and the experimental game factor. As a result, the study involved rigorous investigation of the game-play behaviour and was structured to assess whether or not playing the *ad hoc* game had an impact on the participants' level of confidence and performance in using psychomotor skills in the experimental group.

V. DEMOGRAPHICS

A total of 62 participants were invited to participate in this study and all participants were aged between 16 and 19. Those participants who were younger than 18 were asked to obtain a parental consent in addition to the consent form they were all asked to sign. While all participants were recruited in Cyprus, they came from a wide variety of backgrounds and ethnicities.

Among the 62 participants participated in the study, 4 dropped out and 8 participants completed the pre-study but not the post-study. As a result, only 12 (8%) of the 62 participants dropped out of the study. Of the 50 participants who completed the study, 19 (38%) of them were female; and 31(62%) of them were male. In terms of age, 33 of them (66%) were 16 years old, 7 participants (14%) were 17 years old, and 6 participants (12%) were in the age group of 18. Finally, 2 out of 50 participants (4%) were 19 years old. Regarding the ethnicity groups, 19 (38%) of these participants identified themselves as white, 13 (26%) as black, 11 (22%) as Asian, and lastly 7 (14%) as mixed. As mentioned before, the age, gender and ethnicity groups were broadly split evenly between the control and the experimental groups. The data analysis generated from the obtained statistics is presented below.

VI. RESULTS

Before investigating the results of the study in detail, a series of statistical analyses was undertaken to observe whether or not the distribution of participants among the groups impacted the results of the study. To be more precise, the distribution of male/female ratio, ethnicity, age and participants' level of confidence in using their own psychomotor skills were evaluated in the control and the experimental groups. For this reason, a Man Whitney U Test was used to investigate the age and the perception of the participants, whereas Chi-Square tests were used to analyse the impact of gender and ethnicity in both groups.

TABLE 2. Mann Whitney U test on age and confience in using psychomotor skills.

	Group	N	Mean Rank	Sum of Ranks
Age	Control Group	25	25.08	627.00
	Experimental Group	25	25.92	648.00
	Total	50		
Self-Confidence in using Psychomotor skills	Control Group	25	27.46	686.50
	Experimental Group	25	23.54	588.50
	Total	50		

	Age	Self-Confidence in using Psychomotor skills
Mann – Wthitney U	302	263.5
Wilcoxon W	627	588.5
Z	-0.252	-1.052
Asymp. Sig. (2-tailed)	0.801	0.293

Grouping Variable: Group

Table 2 provides statistics regarding the output of the Mann-Whitney U test specifically showing the mean ranks and the sum of ranks for the two groups tested. As shown in the table, the mean ranks of age were similar in both groups, but the confidence of participants was lower in the experimental group. From this data, it can be concluded neither the age ($U = 302$, p = 0.801) nor the confidence in using psychomotor skills ($U = 263.5$, p = 0.293) had a statistically significant difference between the groups. And as stated above, the confidence of participants in using their psychomotor skills was lower in the experimental group. This means that before completing the natural task, the participants in the control group felt more confident than the participants in the experimental group. Despite these findings, the result of the Mann-Whitney U test did not show any statistical significance between the two groups.

In addition to the Mann-Whitney U Test, several Chi-Square tests for gender, ethnicity and other confounding variables were undertaken. Two of these tests were presented in Table 3 (age distribution and self-confidence among groups). As shown in the table, there is no statistically significant association between gender and the level of self-confidence in using psychomotor skills χ (3) = 4.706, $p = 0.195$; that is, both males and females had similar level of confidence. Additionally, there is no statistically significant association between ethnicity and confidence either χ (9) = 3.929, p = 0.916; which means that ethnicity was not a significant factor affecting the confidence in using psychomotor skills. These results suggest that age, gender and ethnicity of the participants were not significantly

TABLE 3. CHI square tests.

	Value	Df	Asymptotic Significance (2-sided)
Pearson Chi-Square	**4.706**[a]	**3**	**0.195**
Likelihood Ratio	5.376	3	0.146
Linear-by-Linear Association	0.996	1	0.318
N of Valid Cases	50		

Chi-Square Tests for Etnicity and Confidence

	Value	Df	Asymptotic Significance (2-sided)
Pearson Chi-Square	**3.929**[b]	**9**	**0.916**
Likelihood Ratio	4.206	9	0.897
Linear-by-Linear Association	0.205	1	0.651
N of Valid Cases	50		

a. 4 cells (50.0%) have expected count less than 5. The minimum expected count is 0.38.
b. 12 cells (75.0%) have expected count less than 5. The minimum expected count is 0.14.

different between the groups. Other confounding variables such as dropout rates from both groups were also assessed with using same statistical methods but was not shared here due to the iterative analyses. In all measured cases, no statistically significant association was identified that could cause a tendency to overestimate or underestimate the results.

TABLE 4. The test of normality of pre-post study.

Category	W	Df	Sig.
Control Group Eye Hand Coordination	0.893	50	0.013
Experimental Group Eye-Hand Coordination	0.786	50	0.0001
Control Group Visual Response	0.809	50	0.0001
Experimental Group Visual Response	0.809	50	0.0001
Control Group Attention	0.786	50	0.0001
Experimental Group Attention	0.848	50	0.002

Having identified that there is no significant difference between the control and the experimental groups, a test of normality was undertaken to investigate the distribution of data. Table 4 represents the test of normality regarding the pre and post study questionnaire results from the groups. As the sample size used in the study was small ($N = 50$), the Shapiro-Wilk Test was undertaken to assess the normality of the differences of the numeric data collected.

As shown from the Table 4, the Shapiro-Wilk Test results were significant in all categories for both groups ($p<0.05$). In this case the null hypothesis was rejected and the alternative hypothesis accepted, which is that the data significantly deviates from a normal distribution.

Despite the distribution of variables showing a non-linear pattern, the Central Limit Theorem (CLT) establishes that when random variables are added, their means tend toward a normal distribution even if the original variables themselves are not normally distributed [61]. For this reason, a computer simulation was run to estimate the average number on the pre-post differences of collected data in repeated samples. A histogram visualising the distribution on the repeated samples is displayed in Figure 3. As shown in the histogram, the sampling distribution means are much less skewed when compared to the original distribution of data. The Normal Q-Q plots were also analysed in order to ensure a correct interpretation regarding the normality of data distribution and as a result, a linear distribution pattern was observed. Therefore, it is possible to assume that the sampling distribution derived from the normal distribution is implied by the CLT.

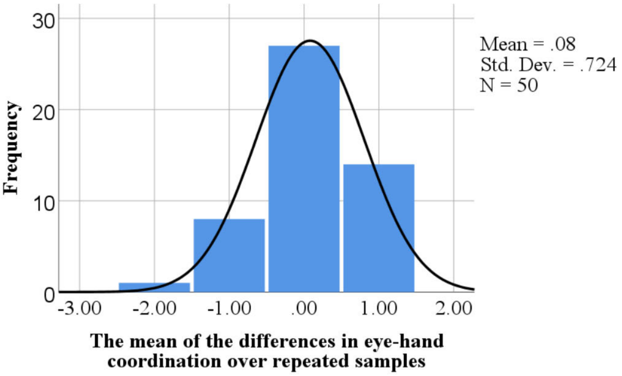

FIGURE 3. Histogram showing the mean of eye-hand coordination distributions.

As the mean of the samples approaches a normal distribution and this was satisfied with CLT, the paired samples T-Test was undertaken to analyse the data obtained from the groups. The original descriptive statistics of pre and the post study (i.e. the Mean and the Std. Deviation) for both groups are presented in Table 5. As shown from the table, the mean values for gender, ethnicity and age were close to each other in both groups. The mean ranks increased in all cases in the post study for both of the groups. However, the participants' perception of their psychomotor skills increased more in the experimental group.

In addition to descriptive statistics, a series of paired-samples t-test was conducted to compare the responses collected from the participants in both groups in order to observe whether or not there was a significant difference between the pre and the post study responses.

A paired-samples t-test was conducted to compare the responses collected from the participants in the control group. As shown in Table 6, there was no significant difference

TABLE 5. **Descriptive statistics for both groups.**

Descriptive Statistics for Control Group

	N	Mean	Std. Deviation
Gender	25	0.60	0.5
Group	25	1.00	0.001
Ethnicity	25	2.16	1.106
Age	25	16.48	0.872
Pre-Study Eye Hand Coordination	25	3.16	0.624
Post-Study Eye Hand Coordination	25	3.36	0.569
Pre-Study Visual Response	25	3.04	0.79
Post-Study Visual Response	25	3.16	0.746
Pre-Study Attention	25	3.08	0.64
Post-Study Attention	25	3.16	0.66

Descriptive Statistics for Experimental Group

	N	Mean	Std. Deviation
Gender	25	0.64	0.49
Group	25	2.00	0.001
Ethnicity	25	2.08	1.077
Age	25	16.52	0.872
Pre-Study Eye Hand Coordination	25	3.12	0.881
Post-Study Eye Hand Coordination	25	3.76	0.663
Pre-Study Visual Response	25	3.04	0.79
Post-Study Visual Response	25	3.76	0.831
Pre-Study Attention	25	3.08	0.64
Post-Study Attention	25	3.72	0.936

in any of the measured categories which were *eye-hand coordination* $(M = -0.20; SD = 0.645)$; *visual response* $(M = -0.12; SD = 0.781)$ and *attention* $(M = -0.4; SD = 0.676)$; $t(24) = -1.549$, $p = 0.134$ for *eye-hand coordination*, $t(24) = -0.768$; $p = 0.45$ for *visual response* and $t(24) = -0.296$; $p = 0.77$ for *attention*.

An identical paired-samples t-test was conducted in the experimental group, and the results showed that there was a significant difference in all of the scores, namely *eye-hand coordination* $(M = -0.64; SD = 0.907)$; *visual response* $(M = -0.72; SD = 1.021)$ and *attention* $(M = -0.64; SD = 0.952)$ conditions; $t(24) = -3.527$, $p = 0.002$ for *eye-hand coordination*, $t(24) = -3.524$; $p = 0.002$ for *visual response* and $t(24) = -3.361$; $p = 0.003$ for *attention*.

TABLE 6. **Paired sample t-test results of the participants' perception of psychomotor skills in the control group.**

Pair	Mean	Std. Deviation	Std. Error Mean	t	df	Sig.
Pre-Eye-Hand Coordination – Post Eye-Hand	-0.20	0.645	0.129	-1.549	24	0.134
Coordination Pre-Visual Response Coordination – Post Visual Response	-0.12	0.781	0.156	-0.768	24	0.45
Pre-Attention Coordination – Post Attention	-0.40	0.676	0.135	-0.296	24	0.77

TABLE 7. **Paired sample t-test results of the participants' perception of psychomotor skills in the experimental group.**

Pair	Mean	Std. Deviation	Std. Error Mean	t	df	Sig.
Pre-Eye-Hand Coordination – Post Eye-Hand	-0.64	0.907	0.181	-3.527	24	0.002
Coordination Pre-Visual Response Coordination – Post Visual Response	-0.72	1.021	0.204	-3.524	24	0.002
Pre-Attention Coordination – Post Attention	-0.64	0.952	0.19	-3.361	24	0.003

These results suggest that there was a statistically significant difference between the pre-study and the post-study results in all three categories in the experimental group but no significant difference identified in the control group. Based on the collected data, the number of positive responses in the experimental group was greater than the number of positive responses given in the control group. The paired sample T-test results suggest that the increase participants felt in the experimental group regarding their *eye-hand coordination*, *visual response* and *attention* was significant. On the other hand, there was no significant difference in the control group between the pre and the post study.

While these findings were useful to determine how groups perceived their psychomotor skills, further assessment was conducted to examine the reasons why experimental group provided more positive and significant feedback when compared to the control group. Considering the fact that both groups contained the same sample size with similar

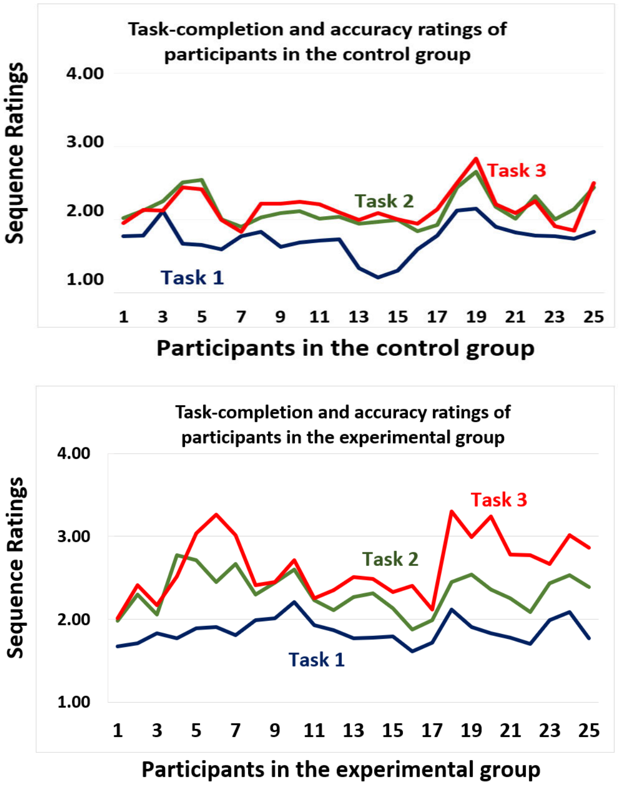

FIGURE 4. Showing task completion and accuracy rating of the participants in both groups.

demographics, we observed the performance of participants in completing the given natural task.

Figure 4 displays the accuracy rating of participants according to Model Pick up Model Drop (MPMD), Pick up Model Drop (PMD), Model Pick up Drop (MPD) and Pick up Drop (PD) sequences proposed by Ballard *et al.* [52]. Furthermore, Table 8 shows the mean ranks of sequences applied by the participants in the control and the experimental groups. Each task is associated with a colour in the figure 4 and each strategy was associated with a rating where the more advanced strategy participants applied the higher rank they obtained.

TABLE 8. Mean ranks of sequence ratings used by participants in the control and experimental groups during their natural task activity.

Group	Task 1	Task 2	Task 3
Control Group Mean Ranks	1.73	2.14	2.17
Experimental Group Mean Ranks	1.86	2.33	2.64

As shown in the Table 8, the mean ranks of the participants in the experimental group were higher than the mean ranks in the control group in each task undertaken. The mean ranks of the experimental group were found as 1.86 for Task 1; 2.33 for Task 2 and 2.64 for Task 3. On the other hand, the mean ranks in the control group were 1.73 for Task 1; 2.14 for Task 2 and 2.17 for Task 3. As stated above, each of these tasks included different building block activities with various models. These findings clearly show that both groups increasingly performed better as they undertook the tasks, and the participants in the experimental group performed better in terms of accuracy in all three tasks than the participants in the control group.

TABLE 9. Independent t-test results regarding how long the groups took to complete the natural task (in minutes).

Group	N	Mean	Std. Deviation
Control Group	25	13.01	1.15
Experimental Group	25	12.15	0.831

		F	Sig.	t	df	Sig.
Total Time Spent in Natural Tasks	Equal Variance assumed	1.784	0.188	3.023	48	0.004
	Equal Variance not assumed			3.023	43.620	0.004

In addition to the sequences applied, the amount of time the participants spent on completing the natural tasks was also investigated. Table 9 shows the results of the independent T-Test undertaken to compare the control group and the experimental group in terms of the time the participants took to complete the given natural tasks. While all participants in both groups managed to complete the tasks, the time they took to do this was widely diverse. The mean in the control group was 13.01, whereas this was 12.15 in the experimental group. The assumption of homogeneity was met as the value of F was not significant. Furthermore, distribution in the two groups differed significantly from each other $t(48) = 3.028; p = 0.004$. From this data, it can be concluded that the control group took significantly more time to complete the tasks than the experimental group. In other words, the participants who played the game completed the building block tasks significantly faster than those who did not play the game.

Based on the obtained data, the participants in the experimental group completed the natural task faster and more accurately than the participants in the control group. Furthermore, participants' perception of their psychomotor abilities was statistically and significantly improved in the experimental group whereas such an improvement was not found in the control group.

In order to investigate whether or not this significant increase is linked to participants' game-play, we examined the game-play behaviour of the participants in the experimental group.

As mentioned before, participants' gaze and game-play were recorded in a series of log files during their game-play. The log files included the data whether the participants' gaze matched with their hand behaviour. The game continually recorded this data by detecting whether the participants' gazes matched with their hand movements through noticing the game objects participants pointed at with the mouse. A pattern was then generated for assessment where 1 indicated a successful gaze with the hand behaviour, and 0 indicated that participant's gaze did not match with the mouse interaction. This pattern was recorded each time a participant interacted with the game. When the participants died in the game, the game stopped matching these patterns and hence the *eye-hand coordination* data for the game-play groups were generated.

In order to make this pattern useful, a percentage of eye-hand coordination was estimated by counting the numbers of 1s within the game-play of each participant. Based on this, a success percentage for each game-play was calculated. Additionally, the game-play time, the score achieved by the players, and the total number of interactions in the game, were also recorded.

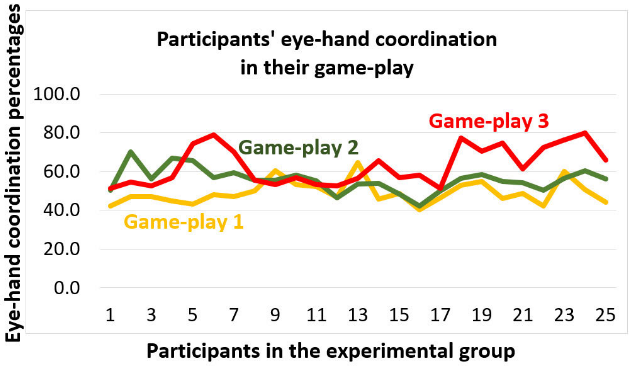

FIGURE 5. Eye-hand coordination percentages of participants in all three game-play in the experimental group.

Figure 5 shows a distribution of participants' eye-hand coordination percentages during their game-play in the experimental study. The yellow line in the above line graph shows the first game play while the green and the red lines indicate the second and the third for each participant respectively. As shown from the figure, the obtained data suggests that as the players played the game, their eye-hand coordination was improved. It is clear that there is some increase in eye-hand coordination of players between Game-play 1 and Game-play 2 and also in between Game-play 2 and Game-play 3. While the exact reasons for this increase is not known, this could be because of the increased focus of the players and decrease of the pace of learning how to play the game.

Table 10 shows the descriptive statistics regarding eye-hand coordination of participants on game-plays. Based on the mean ranks generated, the eye-hand coordination of participants increased when they played the game the second and the third times. As shown in the table, with each new game-play the accuracy of eye-hand coordination increased. While the difference between Game-Play 1 and Game-Play 2 was found to be 8.91, the difference between Game-Play 2 and Game-Play was 9.23. A one-way analysis of variance (ANOVA) was performed to investigate whether there is a statistically significant difference between the groups.

TABLE 10. Descriptive statistics regarding eye-hand coordination of participants during their game-play in the experimental group.

	N	Mean	Std. Deviation
Game-Play 1	25	46.74	7.41
Game-Play 2	25	55.65	6.12
Game-Play 3	25	64.88	9.84
Total	75	55.76	10.81

%95 Confidence Interval for Mean

TABLE 11. The output of ANOVA analysis of eye-hand coordination among game-play groups.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4113.330	2	2056.665	32.590	0.0001
Within Groups	4543.786	72	63.108		
Total	8657.117	74			

As displayed in Table 11, there was a statistically significant difference between groups as determined by a one-way ANOVA test (F(2,72) = 32.59, p =.00001). In other words, there was a statistically significant difference in the mean of eye-hand coordination measured between the game-play groups. In order to find which of the specific game-play group(s) differed, a Tukey post hoc test was undertaken.

As shown in Table 12 all of the groups differed from each other. The Tukey post test revealed that eye-hand coordination was statistically and significantly higher after game-play 2 (55.65 ± 6.12, p = 0.001) and game-play 3 (64.88 ± 9.84, p = 0.0001) compared to game-play 1 (46.74 ± 7.41). Additionally, there was a statistically significant difference between game-play 2 and game-play 3 (p = 0.0001) and game-play 1 and game-play 3 (p = 0.0001). These results clearly display that participants' eye-hand coordination gradually and significantly increased during their game-play.

TABLE 12. Tukey HSD post-hoc test comparision of eye-hand coordination among game-play groups.

Game-Play Group	Game-Play Group	Mean Difference	Sig.
Game-Play 1	Game-Play 2	-8.90560*	0.001
	Game-Play 3	-18.13920*	0.0001
Game-Play 2	Game-Play 1	8.90560*	0.001
	Game-Play 3	-9.23360*	0.0001
Game-Play 3	Game-Play 1	18.13920*	0.0001
	Game-Play 2	9.23360*	0.0001

The mean difference is significant at the 0.05 level.

In addition to the eye-hand coordination, a one-way ANOVA test was undertaken to analyse whether or not a statistically significant change happened between the *game-time* participants spent in each iteration of the play.

TABLE 13. Descriptive statistics and ANOVA alaysis of the participants' game time among the game-play groups (in minutes).

	N	Mean	Std. Deviation
Game-Play 1	25	22.84	8.41
Game-Play 2	25	26.75	6.98
Game-Play 3	25	32.92	9.30
Total	75	27.50	9.18

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	1291.291	2	645.646	9.387	0.0001
Within Groups	4552.109	72	68.779		
Total	6243.4	74			

%95 Confidence Interval for Mean

The ANOVA results revealed that there was a statistically significant difference between the groups with regard to the time participants spent during their game-play (F(2,27) = 9.387, p = 0.0001). The results displayed in Table 13 show that at least two of the groups were significantly different from one another. Furthermore, a Tukey post hoc test revealed that there was no statistically significant difference between the time participants spent in game-play 1 and game-play 2 (p = 0.225). However, the post hoc test results showed that there was a statistically significant difference between game-play 2 and game-play 3 (p = 0.028) and game-play 1 and game-play 3 (p = 0.0001). As shown in Table 14, the results of the post-hoc test provided some evidence that participants spent significantly more time in the game environment with each playthrough particularly in between game-play 1 and game-play 3.

TABLE 14. Tukey HSD post-hoc test comparision of the participants' play time among the game-play groups.

Game-Play Group	Game-Play Group	Mean Difference	Sig.
Game-Play 1	Game-Play 2	-3.91187	0.225
	Game-Play 3	-10.08*	0.0001
Game-Play 2	Game-Play 1	3.91187	0.225
	Game-Play 3	-6.16813*	0.028
Game-Play 3	Game-Play 1	10.08*	0.225
	Game-Play 2	6.16813*	0.028

The mean difference is significant at the 0.05 level.

A series of one-way ANOVA tests were conducted for the *power-ups* collected and the total *game score* participants obtained during their game-plays. Similar to *eye-hand coordination* and *game-time*, there was a statistically significant difference between the groups in terms of *power-ups* collected (p = 0.015) and *game score* obtained (p = 0.0001). However, when post-hoc test results were investigated, it was found that the only statistically significant difference in terms of *power-ups* collected was between game-play 1 and game-play 3 (p = 0.013). In other words, no statistically significant difference was identified between game-play 1 and game-play 2 (p = 0.135), and game-play 2 and game-play 3 (p = 0.591) in terms of *power-ups* collected. Furthermore, the Tukey post test undertaken to investigate the *game score* revealed that there was a statistically significant difference between game-play 1 and game-play 3 (p = 0.0001) and game-play 2 and game-play 3 (p = 0.036). However, there was no significant difference between game-play 1 and game-play 2 (p = 0.184).

The results gathered from the study analysis showed somewhat mixed results particularly in power-ups collected, game-time and the game-score distribution among the game-play groups. Regardless of this, there are strong reasons to believe that participants' *eye-hand coordination* significantly increased as they continued to play the game.

It is important to point out that a significant increase occurred in all the categories measured but none of these were cumulative. As a matter of fact, participants' eye-hand coordination was the only category that significantly changed in between the game-plays groups. In other words, participants' *game-time*, the number of *power-ups* collected and the total *game-score* were diverse between the game-plays, and these did not increase progressively each time they played the game.

A final investigation was conducted to analyse the correlation between the eye-hand coordination percentages during the game-plays and the sequence ratings of natural task completion in the experimental group. As a linear distribution pattern was observed in the means of the variables and a normal distribution was implied by the central limit theorem, Pearson's Product-Moment Correlation was used to investigate the data sets. The aim was to use the Pearson's correlation to find whether there is an association between participants' eye-hand coordination during their game-play and the sequences they applied to build the natural task in the experimental group. As shown in Table 15, there was a strong, positive correlation between eye-hand coordination percentages in the game-plays and the accuracy ratings in the natural tasks, which were statistically significant in all cases. Results of the Pearson correlation indicated that there was a significant positive association between Game-Play 1 and Task 1, (r = 0.427, n = 25, p = 0.033), for Game-Play 2 and Task 2 (r = 0.767, n = 25, p = 0.0001), and for Game-Play 3 and Task 3 (r = 0.869, n = 25, p = 0.0001). These associations clearly showed that with each game-play, the relationship between the eye-hand coordination and the natural task accuracy significantly increased. As a result, the findings provided strong and significant evidence that as the eye-hand coordination of participants improved during their game-play, so did their accuracy in performing the given natural task.

TABLE 15. **Pearson coefficient correlations between the game-plays and the natural task completed in the experimental group.**

Group		Game-Play 1	Task 1
Game-Play 1	Correlation Coefficient	1.000	0.427*
	Sig. (2-Tailed)	.	0.033

Group		Game-Play 2	Task 2
Game-Play 2	Correlation Coefficient	1.000	0.767**
	Sig. (2-Tailed)	.	0.0001

Group		Game-Play 3	Task 3
Game-Play 3	Correlation Coefficient	1.000	0.869**
	Sig. (2-Tailed)	.	0.0001

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

VII. DISCUSSION

Having analysed the results in great detail, the refined research questions in this paper can be answered as follows: Q1) Participants' level of self-confidence in using their psychomotor skills significantly increased in the experimental group between the pre and the post study. However, this did not significantly change in the control group; Q2) Participants' eye-hand coordination in the experimental group significantly increased in between their playthroughs; and Q3) There is a strong and significant relationship between participants' eye-hand coordination during their game-play and the strategies they applied while completing the natural tasks.

While this research sheds some light on understanding whether or not the game improved the psychomotor skills of individuals, the study also had room for improvement. First of all, this study is conducted under the assumption that the given natural task is an adequate activity to measure all psychomotor skills identified. While various studies reference the used task as a homogeneous measurement, there is no absolute evidence to prove that the given natural task (i.e. *building block activity)* is a standard assessment for measuring psychomotor skills [56], [62]. Secondly, because of its complex structure and analysis, this study was conducted with a limited number of participants. Several iterations and investigations were done on the eye-hand coordination of participants both in the completion of the natural task and during their game-play. Furthermore, various calibration tests were run on the participants in order to track their eye-hand coordination. Tracking the sequences participants followed in the natural task and investigating their eye-hand coordination were rigorously difficult and complex. Additionally, it was imperative to ensure participants had similar demographics, background in games and no explicit experience regarding the natural task.

Keeping the numbers at a manageable level helped the analysis of the gaze patterns and data collection but this might have caused some potential threats to internal validity. *Maturation* and *experimental mortality* were among the factors that could potentially biased the results of this study. *Maturation* effects raise due to short- and long-term changes such as subject tiredness, boredom, hunger and inattention. *Experimental mortality* becomes a serious threat to internal validity when dropout rates are unequal between the groups and if a large number of participants drop out from one group before completing the post-study.

Several precautions were taken to minimize the possible threats to internal validity in this study. For example, all participants were made aware that they always had the option to withdraw at any time if they felt tired, and participating in the research or not would have no adverse effect on their studies. The majority of the dropouts happened at the beginning of the study. Moreover, the number of participants in both groups were equal and they were randomly allocated. The impact of *resentful demoralization* was minimized by preventing the groups to communicate during the study. However, as the sample size was small, the opportunity to include covariates which could be possible threats to internal validity, was reduced. This is why it is important to repeat this study with larger numbers to observe if the results would be duplicated before generalizing the results.

Finally, this study only investigated the impact of game-play on short-term memory usage. While three iterations were conducted within a week time, the study only investigated the correlation between task completion and game-play focusing predominantly on minimizing the use of short-term memory in terms of *eye-hand coordination*, *visual response* and *attention*. In other words, the long-term effects of this type of game-play on psychomotor skills are still an uncharted area.

At the beginning of this paper two research questions were defined to investigate whether or not a game could be designed to enhance psychomotor skills via game-play and if so, what game elements could potentially impact skill enhancement. The statistical results obtained from this study were encouraging as there was a strong correlation between the game-play behaviour and the sequences applied by the participants in the experimental group. As the results obtained from the study were statistically significant, we argue that the *ad hoc* game developed for this research was indeed beneficial to enhance participants' psychomotor abilities during the study. Furthermore, the findings of this study suggest that a balanced game-play between puzzle solving and action that implements a meaningful reward system where eye-hand coordination was an integral part of game-play can support the enhancement and the level of confidence in using core psychomotor skills because the findings suggest that *eye-hand coordination* patterns were significantly correlated to the sequences applied by the participants.

Based on these results, we argue that a game-play aimed to enhance psychomotor skills should incorporate a) eye-hand coordination as an integral part of the game-play; b) a meaningful reward system that rewards players according to how well they demonstrate their psychomotor skills and c) task(s) management with spaced practice conditions rather than increasingly difficult mass activities.

VIII. CONCLUSION AND FUTURE WORK

This research predominantly focused on developing a game to investigate whether or not playing it improves participants' ability to complete a natural building block task taken from the literature. A control and an experimental group were established in order to investigate whether or not the gaming experience of the participants could have an impact on how fast and accurate they complete the given natural task. The scope of the research was limited on a number of psychomotor skills namely *visual response eye-hand coordination* and *attention.* Each of these categories was reviewed deeply in the published literature before being used in the study.

The results obtained from this study clearly demonstrate that there is a significant improvement in the experimental group in terms of the participants' perspective of their psychomotor skills, whereas the same improvement did not significantly happen in the control group. Additionally, the participants in the experimental group completed the natural task faster and more accurately than the participants in the control group. A statistical analysis on the game-plays in the experimental group revealed that the participants' eye-hand coordination improved as they repeatedly played the game. Furthermore, it was revealed that there is a strong and significant correlation between how accurately participants completed the natural task and the eye-hand coordination of participants during their game-play in the experimental group. These results provide strong reasons to believe that the game positively and significantly improved the participants' eye-hand coordination. While the exact reasons for this is arguable, it is clear that because of playing the game, the participants' brain was in a heightened state of alertness, hence why they performed higher sequences and accuracy in the experimental group.

Whilst this study put forward a strong premise and statistical evidence that the designed game has the potential to improve psychomotor skills, there were some limitations with the study which are all argued in the discussion section.

As future work, it is planned to address these limitations and re-conduct the study with a larger sample size and with multiple tasks both before and after participants play the game. Additionally, multiple eye-hand coordination patterns can be applied in this study in order to investigate how participants' gaze and interactions are divided to handle the quick transition of eye-hand coordination. As the difficulty of the game increases, participants' gazes can be divided on the running robot, the interactable objects, the platforms, and/or quick transition between all of these. Hence generating multiple eye-hand coordination criterion could potentially capture individual behavioural differences in this particular gaming task.

The ad hoc game developed in this research is very different from the popular games in the market as many commercial off the shelf (COTS) games offer multi-player, battle arenas, competition and/or team working. The focus of this study was observing whether three identified psychomotor skill categories could be enhanced with a single player game experience without considering the social factors such as cooperation or competition. As the results of this study were positive, the research can now be progressively expanded to investigate how psychomotor skills can be affected by multi-player games when competition and cooperation are integrated into the game-play. The impact of different type of games can also be investigated by forming multiple game groups. As an example, a different set of natural tasks could be asked to be completed multiple times both before and after playing a series of games in order to investigate which games impact participants' abilities better in which tasks.

An important note from this study is that there was a strong and significant correlation between participants' natural task strategies and participants' game-play in the experimental group. These findings show that the game has an impact on how accurately participants completed the provided natural task. While it is essential to enhance the game experience as well as the overall study design, the findings clearly showed that there is a great potential in using games to enhance psychomotor skills of individuals.

A series of well-structured game-play in the future will aim to investigate both short- and long-term effects of the game-play that would potentially reinforce new ways to address people particularly to those who have attention deficit or lack of focus problems that prevent the use of motor abilities. The overall experience has shown that much more research is necessary in this field and highlighted the difficulties how game-play can be used to support enhancement of a limited number of psychomotor abilities.

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