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A Digital Future in Virtual Reality — Insights for Training

Completed Research Paper

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Abstract

Virtual reality is now being used throughout various sectors. It is a tool which is being increasingly relied upon to support cost-effective and safe opportunities to build skills development. There has, however, been little research into whether a virtual environment provides the same effectiveness as a real-world environment.

For virtual reality to be an effective tool, we must better understand the impact of using it. To determine this, we investigate whether there is an additional cognitive load when operating in a virtual environment and we measure whether such a load impacts upon an individual's performance.

Through the use of a 'quadrant' study in both real and virtual environments and with both the presence and absence of a secondary task, we identified that there is no significant cognitive load added when working within the virtual environment, and so the use of virtual reality can indeed be effective in terms of comparative performance with the real-world.

This research was conducted with approval of the Human Research Ethics Committee (Tasmania) Network; the reference number for the study is: H0018156.

Keywords: virtual reality, cognitive load, DRT, training

1 Introduction

Virtual reality (VR) has experienced a broadening in application over the last few years and with this, has expanded beyond gaming and into mainstream society (Madary and Metzinger 2019). An indicator of this is the range of available devices including Sony PlayStation VR, Oculus Rift, Oculus Go, HTC Vive, Google Cardboard, Samsung Gear, Microsoft HoloLens, Lenovo Mirage Solo, Asus VR, and many others (Ippolito 2019; Sawh 2018; Sarmad 2019).

Virtual reality allows for the mirroring of real-life situations within physically safer or cheaper contexts and, as such, is well suited to the application of training and simulation. It has been applied in contexts ranging from school education to professional development and skills training (Weyhe et al. 2018; Sourin et al. 2000; Dyer et al. 2018; Grochowska et al. 2019).

The benefits of virtual reality to enhance education and skills training have been noted by many, including for example (Chaos Theory Games 2020): 40% fewer mistakes being made by surgeons who are trained in virtual reality rather than in conventional methods at the University School of Medicine in Atlanta (Wilson 2016), 80% savings in the training time of Walmart staff, and the ability to safely expose learners to virtual chemical and construction environments, thus reducing health and safety concerns. Stanford University and the Technical University Denmark (Wilson 2016) found that learners recall more when using virtual teaching methods than with traditional methods, resulting in a 76% increase in learning effectiveness, and so, perhaps unsurprisingly, we see increased interest in virtual reality as a training tool. According to ABI Research (Chaos Theory Games 2020), the enterprise virtual reality training market generated US$216 million in 2018 and is currently (2020) valued at US$15.1 billion. This investment is underpinned by an inherent assumption that virtual reality will enhance the learning experience, and provide improved learning outcomes for learners, and that learning is not inhibited in this virtual context.

It is claimed (Kaplan-Rakowski and Wojdynski 2018; Chaos Theory Games 2020) that virtual reality improves retention and engagement, minimises risks to people, and that it can contextualise and immerse learners in their training (Young 2020), and yet very few studies have investigated the effects that virtual reality has upon the individual's ability to perform when in the virtual environment, and whether they are capable of thinking and acting in the way they would outside of that virtual environment in the real-world. Would a surgeon using virtual reality to complete an operating procedure be helped or hindered by the immersive environment? In other words, is there a cognitive load to working in virtual reality which would make the environment less effective or perhaps dangerous to work in? Or is the cognitive load of the real-world reduced within virtual reality? These questions have not been explored.

We therefore need to test the assumption that virtual reality does not inhibit practice. If we do not understand the impacts on performance that virtual reality brings, we may be developing solutions that are not enhancing the practice or learning experience, and may in fact be detrimental to those involved if the persons immersed in virtual reality are becoming distracted by, or confused in, the virtual environment.

This paper reports on research into whether virtual reality offers an effective learning environment in order to either add confidence to its use in training and beyond, or conversely, to provide evidence that there should be limits placed upon its use. The research question posed by this study is: *Does the use of virtual reality technology increase the cognitive load of an individual as they undertake a task?* To this end, we measure the cognitive load of individuals while they are engaged in a primary task within virtual reality and in the real-world. We add a contemporaneous secondary task as a proxy for cognitive load and report our findings.

2 Background

2.1 Virtual Reality

Virtual reality sits firmly within the domain of Computer Science as a technology which allows people to interact multimodally (Foloppe et al. 2018). From its origins in Morton Heilig's Sensorama system in the late 1950s (Andreoli 2018; Adams and Merklinghaus 2014), the use of virtual reality has expanded beyond gaming — Sega introduced the Sega virtual reality headset for the Sega Mega Drive console (Book News Inc. 2011) — and virtual reality technologies are now being used and researched as viable tools within a variety of institutions, industries, and for beneficial applications (Madary and Metzinger 2019). Virtual reality is widely used in physical, cognitive, and psychological interventions: for rehabilitation, for education/training in expensive and/or dangerous domains such as aerospace, military, medicine, and for therapy (Bortone et al. 2018; Massetti et al. 2018).

2.2 Applications of VR to Simulation and Training

Simulation based training and assessment is an important role in training and virtual reality simulators are used to improve comfort and proficiency in many training fields including science, medicine, and the military (Wilson 2016).

Virtual reality based learning tools are used in the training of medical professionals (Aksoyet al. 2019) with robotic systems and robot arms in virtual surgical applications (Almusawi et al. 2019).

Peterson et al. (2018) studied the effect of balance beam walking (including real-world and virtual reality) tasks. Their findings indicated that virtual reality provided realistic experiences that induced psychological stress, as well as impairing the physical and cognitive loading performances during the process of maintaining balance.

Using immersive virtual reality and a self-avatar, Steed et al. (2016) conducted experiments on the impact a self-avatar would have on cognitive load by creating a series of demanding tasks for participants to complete. The trials consisted of virtual reality immersion with and without a self-avatar. The researchers concluded that those participants with a self-avatar were better at recall and concluded that "a self-avatar is important, not just for direct manipulation but also to reduce the cognitive overhead of performing a broader class of tasks that involve cognitive processing." (Steed et al. 2016, p.7).

As we can see from these studies, virtual reality offers a great opportunity to support training and skills development, as long as it offers an appropriate proxy for the real-world, and does not inhibit the cognitive load of learner.

2.3 Cognitive Load

Cognitive skills include problem-solving and decision-making and complex decision-making can be developed in simulated environments — for example by eye tracking technology (Tichon 2016; Meriem et al. 2018). *Cognitive load* is the concentration level or mental workload used to retain information in the working or short-term memory. Hart and Staveland (1988) define mental workload as the "...relationship between the amount of mental processing capability or resources and the amount required by the task".

There are three types of cognitive load: intrinsic, extraneous, and germane. Extraneous cognitive load refers to the unnecessary, ineffective cognitive load that is determined by the way the information is presented (Hasler et al. 2007). Germane cognitive load is the work put in to create a permanent store of knowledge or schema (Sweller 2010). This research will focus on intrinsic cognitive load — the effort put in for a specific task or topic and how dual tasking may impact that effort.

There is a wealth of research which has been conducted on measuring cognitive load in experiments. The experiments include web-based environments, instructional animations versus static-picture, immediate and delayed ratings of problems, divided attention during multimedia learning, Mobile Remote Presence operation, and driving a car with distractions from peers and instructors. The reader is referred to Björnfot et al. (2018), de la Torre et al. (2016), Gray et al. (2015), and Park and Brünken (2014).

Measuring intrinsic cognitive load is achieved through the use of a Detection Response Task (DRT) — a tool originally created to measure driver distraction (ISO:17488, 2016) by the International Organisation for Standardisation (ISO) that assesses cognitive loading associated with primary and secondary tasks (ISO:17488, 2016) which can be implemented outside of driving.

Bird et al. (2019) used an ISO:17488 recommended standardised device to research how having to lie in a narrative affects the cognitive load of participants. The results showed that they "...found strong support for an increase in cognitive load when producing a narrative lie, as measured by both slowed DRT responses and increased response omissions...." (Bird et al. 2019, p.936)

Castro et al. (2019) investigated cognitive load using experiments in which participants undertook four pursuit tracking activities using a driving simulator steering wheel to track a ball that moved continuously on the screen. The DRT device was a dash-mounted light of two intensities of red which was presented as a stimulus occurring randomly. The response devices were two micro-switches attached to both thumbs. The response times (RT) and response omissions were both automatically captured by the software. They found that "it is a fundamental characteristic of human cognition that dividing attention between two or more tasks results in performance decrements (i.e. slower and more error prone behaviour) compared to when each task is performed separately." (Castro et al. 2019, p.33).

3 Methodology

3.1 Experimental Objective

Our goal was to discern whether there was a cognitive load to the use of virtual reality. To do so we needed to measure the cognitive load of a real world task and the cognitive load of the same task when completed within virtual reality and compare them.

There are a number of variables that we need to control:

- it is possible that prior experience of the task will yield better performance for some individuals than for others;
- could there be demographic differences — for example youth or experience of gaming consoles or virtual reality — which may give rise to better performance;
- is it possible that an individual's performance may increase the more time they spend completing the task which might mask cognitive load; and
- is it possible that an individual's performance may increase the more time they spend immersed in virtual reality again masking the inherent cognitive load.

Each of these was addressed in the experimental design.

3.2 Experimental Design

The primary task was to play *TetrisEffect® (The Deep)* to the best of the participants' ability for a ten minute period (which was the recommended time to spend within virtual reality (Dyer et al.2018)). High scores were recorded so that improvement over time could be measured, and a per-individual base-line obtained. Figure 1 illustrates the user's view of the game.

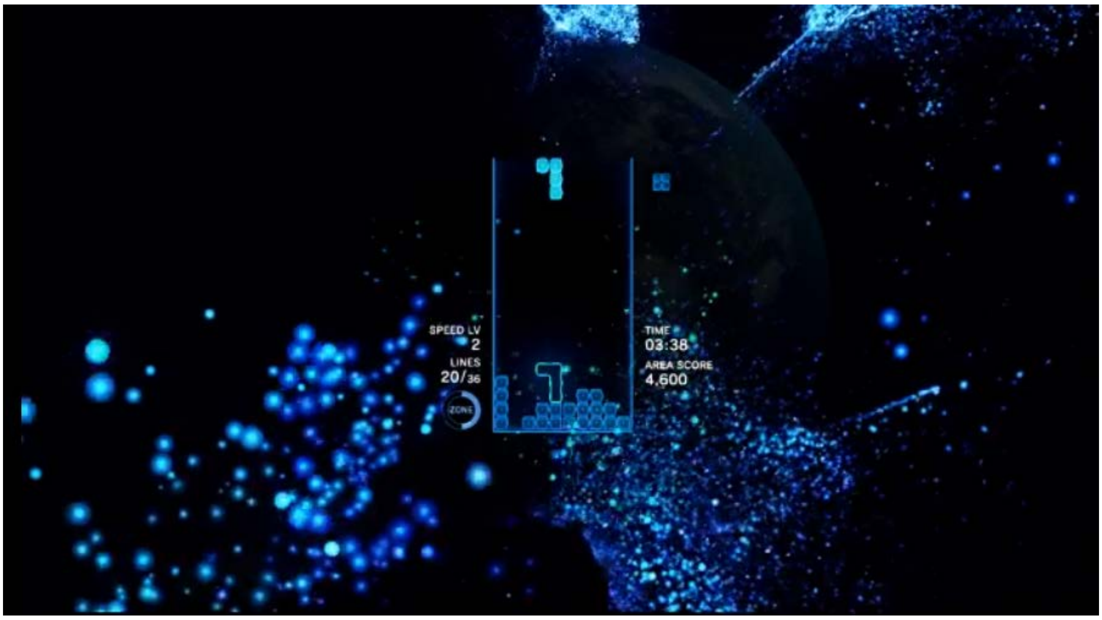

Figure 1: Sample image of TetrisEffect® (The Deep) during virtual reality task.

Tetris® was developed in 1984 by Alexey Leonidovich Pajitnov (Gerasimov 1994–2003). The game consists of seven differently shaped tile pieces with each tile piece consisting of four segments each. The tiles drop from the top of the screen at random and when they can drop no further, they create a pile and when the pile reaches the top of the screen the game ends. Researchers have used Tetris® to study developmental disorders, visuospatial working memory, trauma, cravings, and medical conditions. Young (2020) expounds its use in other studies (Bikic et al. 2017; Lau-Zhue et al. 2017; Pilegard and Mayer 2018; Holmes et al. 2010; Skorka-Brown et al. 2014) and its utility as an appropriate tool is supported by Lindstedt and Gray (2015, p.947): "...as a cognitive task, Tetris® hits the sweet spot of being simple to comprehend and tractable to analyse, but complex enough to remain cognitively interesting and rewarding to master."

To measure cognitive load, a stimulus — a detection response task — was introduced as a secondary task. When the DRT device activated, the participants were required to respond to it while continuing to play the game. The average time taken to respond was used as a proxy for cognitive load: the quicker the responses the lower the cognitive load, the slower the responses the higher the cognitive load felt by the individual. The participants undertook the task of playing Tetris® four times:

- once on a PC (non-VR) without the interruption of a DRT;
- once when immersed in VR without the interruption of a DRT;
- once on a PC (non-VR) with the interruption of a DRT; and
- once when immersed in VR with the interruption of a DRT.

The results of these four rounds were measured and compared to identify any changes in DRT response time due to the introduction of the virtual reality context. To address the possibilities of improvement due to time spent on the task or adjustment to the environment, a variation in the order of completion of the task in the real-world and when immersed in virtual reality was required. Similarly, to address the possibility of adjustment to the secondary task, variation in the order of completion in the real-world and in virtual reality was required.

There are 4! = 24 possible combinations in the 'quadrant' outlined above and we allocated these randomly to participants in order to eliminate the effect of the primary task, secondary task, and environment upon the results. Differences in response were calculated to ensure comparisons were made per individual rather than across the population, and demographic information was collected in order to discern trends amongst participants sharing characteristics.

Figure 2: The DRT equipment (with stimulus at top left with white tape and foot pedal at top right).

Experimental Procedure

Each participant was asked to complete a demographic survey and was then offered a one-hour time slot to complete the four tasks. The virtual reality environment was a Sony PlayStation 4.

Shown in Figure 2, the DRT device used conformed to ISO standards (ISO 2016), and generated a tactile stimulus which was attached to each participant's clavicle; it vibrated at random intervals ranging from 3–5 seconds for approximately 100ms duration. Participants were required to respond to the secondary stimulus as quickly as possible using a foot pedal (see Figures 2 and 3 (right)). Each response (pedal push) or omission (no response within one second) was captured. Timing was recorded at millisecond accuracy.

Figure 3 shows a volunteer — not a participant in the study — wearing the equipment for the virtual reality DRT (Young, 2020) with a close-up of the foot pedal on the right.

Figure 3: Volunteer demonstrating the use of the equipment.

Once gathered, the results were analysed. First, quantile–quantile probability plots (Q-Q plots) were used to determine whether the results were from Normal distributions. Once this had been established, Student's t-tests were conducted to determine whether there was any statistically significant difference between the response times to the secondary stimulus within virtual reality.

4 Results

4.1 Demographics

28 participants were recruited and 25 completed the survey and all four activities. Of these respondents:

- 72% were male, 24% were female and 4% preferred not to say;
- 52% were aged 18–25, 44% were aged 26–35, and 4% were aged 46 or older;
- 40% had played video games in the past, 4% still played sometimes, 40% still played often, and 16% still played very often;
- Most respondents had played games on multiple devices. The most responses were for computers (24 participants) and mobile devices (23) with a PlayStation used by 15;
- The controllers with which the participants were most familiar were keyboards (23 participants), touch screens (22), and mice (22);
- 28% had never played Tetris®, 60% had played in the past, 4% continued to play sometimes, and 8% played often; and
- 9 participants had never used virtual reality, 12 had used virtual reality in the past, 3 still did sometimes, and 1 still did often. When asked how often, one said that they used virtual reality once or twice a week, one used virtual reality once or twice a fortnight, and one used virtual reality once or twice a month.

4.2 High Scores and Performance

Table 1 illustrates the High Scores achieved by the participants in the four environments.

Participant Number	Virtual Reality DRT Score	Virtual Reality Score	PC (Non-VR) DRT Score	PC (Non-VR) Score
121	13088	6334	8116	10110
131	12594	13024	9006	15036
141	12305	18341	13796	14790
151	8679	10566	10866	15132
161	3820	1751	1246	3018
171	2656	2175	2446	960
191	8526	8990	6317	7882
212	13706	13445	11710	8307
222	2807	3725	1707	3028
232	11448	7844	12160	14131
242	15311	17160	10601	14005
252	19201	20996	16610	18139
262	16010	16848	13577	16809
272	11727	19725	15731	16325
292	12360	9270	1588	11519
303	3269	1049	3873	1755
313	8341	11837	6460	11402
323	5885	10190	9086	10156
333	8953	10988	8183	6162
363	29136	27582	19784	12446
373	4661	9647	12416	11108
383	11522	7646	13969	8954
414	10216	5857	13029	8785
454	9987	7033	4796	9690
464	33780	17256	23572	27864

Table 1: Total Scores for each task per participant.

The mean high scores together with standard deviation, minima, and maxima are shown in Table 2. Quantile-quantile probability plots confirmed the values were normally distributed. All participants' scores generally improved in Tetris® the more they played (Young, 2020). Although not significant, this trend supports the decision to systematise the presentation of the four activities.

Detailed analysis can be found in (Young, 2020) but for brevity:

- Those aged 26–35 performed better in Tetris® than the other age-groups;
- Those participants who had never played Tetris® scored more consistently throughout the four tasks; and

- Those participants who had played Tetris® in the past achieved the highest scores throughout the four tasks.

The existence of these differences supports the decision to compare the performances of individuals.

	Virtual Reality DRT Scores	Real-World DRT Scores	Virtual Reality Scores	Real-World Scores
Mean	11599.52	10025.80	11171.16	11100.52
St Dev	7231.60	6438.86	5641.77	5770.72
Min	2656	1049	1246	960
Max	33780	27582	23572	27864

Table 2: Descriptive statistics for total scores per task.

4.3 Cognitive Load

After determining — again with quantile-quantile probability plots — that the results were normally distributed, two-tailed T-Tests were conducted for each like-for-like pair (with DRT, without DRT, real-world, Virtual Reality) to measure whether there is a statistically significant difference to achievement under virtual reality. These are shown in Table 3.

Sample 1	Sample 2	t	df	p
Real-World DRT Scores	Virtual Reality DRT Scores	0.840	24	0.404
Real-World Scores	Virtual Reality Scores	0.040	24	0.968
Real-World DRT Scores	Real-World Scores	-0.652	24	0.517
Virtual Reality DRT Scores	Virtual Reality Scores	0.216	24	0.829

Table 3: Simple Paired Sample T-Tests — results for scores.

For statistical significance, the two-tailed T-Test p-values would need to be < 0.05. Hence there is no significant difference in scores across the different activities.

Next, we consider the secondary stimulus (DRT) in detail. A summary of the population's results is shown in Table 4. An omission is registered when a response to the secondary stimulus was not provided within one second.

	Real-World Responses (ms)	Virtual Reality Responses (ms)	Real-World Omissions (Count)	Virtual Reality Omissions (Count)
Mean	644.22	635.76	76.96	75.44
St Dev	109.07	101.02	43.68	42.74
Min	445.71	426.39	7	3
Max	870.95	815.05	147	160

Table 4: Descriptive statistics of real-world and virtual reality responses and omissions

Once again, two-tailed T-Tests were conducted on the response times and the omission times. Results, shown in Table 5 also illustrate that there is no statistical difference between the responses to the secondary task in the two environments.

Sample 1	Sample 2	t-value	df	p-value
Real-World Responses	Virtual Reality Responses	0.700	24	0.490
Real-World Omissions	Virtual Reality Omissions	0.372	24	0.713

Table 5: Simple Paired Sample T-Tests results for both responses and omissions.

5 Conclusions

The use of virtual reality has expanded beyond gaming into training and use in a variety of work and therapy-based sectors. This has occurred without an investigation into the cognitive load of doing so. We have sought to determine whether a virtual reality environment used for training and professional activities allows an individual to perform as they would in the real-world or whether there is an additional cognitive load when immersed in virtual reality.

To discover this, 25 participants completed the same task within the real-world and within virtual reality. We have found that their performances are not significantly different (see Table 5).

Additionally, we have investigated the cognitive load in the two environments through the use of a secondary task. Again, we have found that their performances are not significantly different (see Table 3).

We have observed that an external stimulus, imposed as a secondary task to serve as a proxy for cognitive load, does not impact in a statistically significant way upon the concentration level of a primary task and that that primary task is performed as well within virtual reality as it is outside of virtual reality.

We can therefore conclude that there is no additional cognitive load when completing a task while immersed in virtual reality. And that as such, virtual reality is not different from the real-world in its cognitive demand and that virtual reality is an effective proxy for more costly or potentially dangerous training environments.

This new finding provides confidence to those utilising virtual reality beyond gaming that its application is not impacting upon the safety of those involved, nor is it detrimental to the abilities of those immersed in the virtual environment. This research may in fact, illustrate that further adoption of virtual reality should occur and that transition to a digital future in virtual environments may be accelerated.

5.1 Further Work

Although the primary and secondary tasks used in this study were found (through relevant literature) to be appropriate and fit-for-purpose, we recognise that the tasks used may not be representative of all activities conducted in virtual reality. We also recognise that 25 participants — although sufficient to cover the 4! combinations — is a small study.

In further work, therefore, we would like to expand participation and would like to investigate whether differing primary and secondary tasks reinforce our results. Additionally, we have not as yet investigated the impact on segments of the population. Our study was too small to make conclusions based around demographic differences. We would like to explore this aspect in the future also.

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