IJHSR
ijhighschoolresearch.org
RESEARCH ARTICLE

Ecological Validity in CPTs via VR for use in ADHD Research

Russell H. Kwok

Ngee Ann Polytechnic, 535 Clementi Rd, Singapore, 599489, Singapore; russellhkwok@gmail.com

ABSTRACT: Continuous performance tasks (CPT) such as the traditionally formatted task (TFT) and the sustained attention to response task (SART) have been used extensively in attention-deficit hyperactivity disorder (ADHD) research due to their function in assessing symptoms of sustained attention and inhibition via several metrics (e.g. Task performances, reaction times, and brain activity). These tasks, however, poorly reflect daily tasks. This weakens the generality of identified behaviors and their associated metrics. Hence, to further investigate these metrics and to improve the ecological validity of these tasks, the SART and TFT were conducted in a virtual reality (VR) environment with 17 healthy individuals (Mean age: 21.86; SD: 2.061; 11 Males and 6 Females) and 16 people with ADHD traits (Mean age: 23.69; SD: 3.386; 9 Males and 7 Females). Results expressed poorer task performances, increased reaction times, and increased reaction time variabilities in the ADHD group for both tasks, though to an insignificant degree. These results suggest that introducing elements that improve the ecological validity of the TFT and SART via VR (E.g. Lifelike scenarios, interactive environments, distractors) reduce the tasks' demands for the executive functions of sustained attention and inhibition, though further investigation is required.
KEYWORDS: Behavioral and Social Sciences; Clinical and Developmental Psychology; ADHD; Continuous performance tasks; Ecological validity.

Introduction

ADHD:

Attention-deficit hyperactivity disorder (ADHD), as defined by the American Psychiatric Association,[1] is a neurodevelopmental disorder characterized by consistent showings of inattention, hyperactivity, and impulsivity. They cite inattentive behaviours to include failing to sustain prolonged attention towards a task or failing to follow through or complete an activity, whilst citing hyperactive and impulsive behaviours to include constant fidgeting or finding difficulty in waiting in turn for something. As such, they reason that such behaviors result in the impairment of function or development. The severities of these symptoms are also not consistent among those with ADHD, because they are experienced across a spectrum.[1,2]

ADHD is usually first identified in children during preschool via hyperactive behaviors; then, inattentive features, which become more prominent and impairing with time.[1,3] Some symptoms, however, may diminish later in life, during adolescence and adulthood.[1,3,4]

ADHD traits are often assessed with the use of scales such as the Adult ADHD Self-Report Screening Scale (ASRS), which vary in forms (short-form / long-form) and are continually updated in accordance with new editions of the diagnostic and statistical manual of mental disorders by various researchers such as Ustun *et al.*[5] They have designed the ASRS to use questions, different sections, and scoring systems. By stimulating conversation pertaining to a patient's symptoms of ADHD, professionals can diagnose patients with high levels of certainty.[5-7]

Continuous Performance Tasks & Executive Function:

Executive functions (EF), refer to the mental processes required in order to perform tasks that require concentration, such as unfamiliar tasks.[8,9] Examples of EFs include working memory and inhibition, which may be trained and developed over one's lifetime. EFs are, however, subject to impairment via mental disorders, such as ADHD, which might consequently affect other aspects of life.[9,10]

Various tasks have been developed to measure and assess particular EFs.[11,12] A widely used measure of response inhibition and sustained attention are continuous performance tasks (CPT). Examples of which include traditionally-formatted tasks (TFT; high no-go, low-go) and the sustained attention to response task (SART; low no-go, high go).[9,13] Hence, CPTs are relevant in the study of ADHD as deficits in sustained attention and response inhibition are characteristic of those diagnosed with the condition.[1]

The CPT-X (a TFT) was originally designed by Rosvold *et al.*[14] to show differences in sustained attention performances between brain-damaged and control subjects because event-related brain potentials (ERPs) observed in brain-damaged individuals suggested deficits in sustained attention. Their task involved presenting a random sequence of single letters at approximately 1-second intervals for a period of 10 minutes. Targets were the letter 'X', and non-targets were any other letter. A variant of this task, the CPT-AX, is similar to the aforementioned task in most ways except that participants were to only respond to the letter 'X' if it was preceded by the letter 'A'. Differences in task performance between groups in both CPTs ultimately demonstrated the tasks' ability to assess sustained attention deficits.[14] In light of improving sensitivity or to better suit specific interests, variations of the CPT-X have been developed. They change factors that affect demand on executive functions like memory load.[15,16] While it is unclear if performance in the CPT and its variations purely measure

DOI: 10.36838/v6i9.13

sustained attention or if it is confounded with factors like inhibition, there is still strong support that these tasks measure attentional problems in general.[15,17] To better mitigate this issue, Smid *et al*.[18] recommended using multiple CPT variants to better isolate and study their sustained attention components.

The SART was designed by Robertson *et al*.[19] as an alternative format to TFTs as a sustained attention task. They originally used it to investigate sustained attention in patients affected by Traumatic Brain Injury (TBI), which typically affects areas of the brain associated with attentional problems like the frontal lobe. They also argued that TFTs are highly vulnerable to automatization, which is unlike the controlled and effortful processing of actions that should be present in a sustained attention task. To prevent this, they changed targets to non-targets and non-targets to targets to hypothetically increase the attentional load of their task. Hence, unlike TFTs, the SART involves frequent key presses to non-targets and the need to withhold a response in the case of a target. The SART used single digits from 1 to 9 that were presented in a random sequence over ~4 minutes with the target being the number '3', which occurred 25 times out of 225 trials. Each digit was presented for 250ms and then masked for 900ms during which subjects would respond.[19] Research on the SART, however, has suggested that instead of measuring sustained attention, the SART is more of a compound measure of sustained attention and response inhibition, or inhibition alone.[13,20-22]

With CPTs being used in various studies, several measures beyond task accuracies have been investigated. In an effort to differentiate errors of inattention and inhibition via scores during the CPT-AX, Overtoom *et al*.[23] conducted the task whilst recording participants' ERPs. They defined inattention scores to be missed targets or slow reaction times to the letter 'X' that were not preceded by the letter 'A' and impulsivity scores to be reflected via fast reaction times to letters other than 'X' preceded by the letter 'A' or the letter 'A' alone. Differences in scores at the experiment's end were supported by presence of corresponding ERPs.[23] Hence, their study provides a method for scoring participants in terms of inattention or impulsivity during a CPT.

In another study by Levy *et al*.[24], the relationship between CPT reaction time variability (RTV) as a measure of sustained attention with participants diagnosed with ADHD on and off medication was investigated. They explained that increased lapses of attention and slow responses generally lead to increased reaction time variability during a CPT. A possible explanation for these lapses of attention in ADHD children is that they don't typically suppress introspective thoughts during demanding tasks. As such, it was theorized that they would show increased reaction time variabilities during a CPT performance. Through this study, it was found that CPT-X RTV corresponded to ADHD clinician severity. Hence, the study's results suggest that measuring RTV during a CPT-X is helpful in ADHD screening tests or in assessing attentional problems.[24]

Brain activity in various frequency bands is also a measurement of interest in the study of ADHD, generally represent different states of mind. Loo & Makeig[25] explain that theta band activity (4-7 Hz) typically represents rest and daydream, that alpha activity (8-12 Hz) is negatively associated with arousal, and that beta activity (13-25 Hz) is associated with mental concentration. Hence, it's unsurprising that ADHD individuals generally exhibit increased theta band and decreased beta band activities during rest states when compared to controls.[25] Alpha activity, however, does not reliably provide support for ADHD symptoms due to inconsistent findings in literature. Nevertheless, such activity may be explained by the maturational lag theory.[25,26] In healthy individuals, the posterior regions of the brain generally develop faster than the anterior regions.[27] Such differences in regional development reflect observed differences in theta and beta activity between ADHD and healthy individuals.[26,28] Hence, the theory reasons that a dysfunction in brain maturation results in frontal lobe dysfunction. This theory has been substantiated via multiple studies, which have found increased theta activity and decreased beta activity in all regions measured in ADHD children and adolescents, but only increased theta activity in the anterior region for ADHD adults.[26-28] Therefore, there has been support that ADHD symptoms may be studied by observing the frontal lobe's theta and beta activity.[25,26]

Despite extensive findings in ADHD research via the TFT and SART, however, Tucha *et al*.[29] argue that these CPTs fail to reflect daily tasks accurately. They mention that unlike the TFT and SART, daily tasks require higher activation levels, frequent interactions, and flexible switching between tasks. This highlights the issue that most CPTs and their associated findings might be ecologically invalid compared to tasks from daily life.

Virtual Reality & Ecological Validity:

Ecological validity is a term often used to describe how well a test measures real-world performance or reflects the behaviour of its actual population, allowing for generalization.[30,31] For high ecological validity, Musso *et al*.[30] state that test environments, stimuli used during testing, and behavioral responses should closely resemble their real-world counterparts. That being said, it is both difficult to conduct an ecologically valid test and to objectively measure ecological validity due to broad definitions, the multitude of factors present in the context of every different experiment, and the need to maintain control over said experiment.[30,32,33] It is often suggested that virtual environments could provide an appropriate middle ground to overcome the issues above.[30]

Vince[34] and Lowood[35] define virtual reality (VR) as computer models and simulations that enable users to interact with an artificial environment. They cite examples of such environments as 3D visual ones or those of other senses. Users are typically immersed in VR via headsets and controllers that act as inputs, outputs, or both.[34-36]

VR has been adopted across many different fields, including behavioral sciences research. In 2010, a study investigating the ecological validity of VR environments demonstrated complex social behaviours in participants, such as the bystander effect and time pressure via simple games.[37] VR has also been successfully utilized in many other studies that include but are

DOI: 10.36838/v6i9.13

not limited to spatial navigation, the body transfer illusion, and findings in neuroscience related to the autism spectrum disorder.[38]

The success and adoption of VR simulations within research may be accredited to its many appealing features. Firstly, VR allows for the practice of potentially dangerous activities to be conducted in a safely.[39] Next, inciting and controlling multiple stimuli becomes possible in VR, allowing experimenters to simultaneously provide realism to a simulation and to account for uncontrollable variables found in the real world.[38,40] Through VR simulations, it's also possible to record user data such as brain activity.[38] With reasons as such, VR often provides a middle ground between a controlled environment and contextual stimuli.[38,40] Hence, with all its past successes and powerful potential uses, VR has proven that it could be incredibly useful and ecologically valid in research when employed correctly.

The Present Study:

The present study aims to improve the ecological validity of CPTs via VR use. In doing so, the study aims to substantiate existing research regarding potential diagnostic markers for ADHD.

Through the use of a VR system and by taking into account the suggestions and findings of previous studies,[13,18,23,29,41] we therefore, propose making use of multiple CPT variations such as a Traditionally-Formatted Task (TFT) and the SART to better isolate various components related to its performance, such as sustained attention; differentiate errors due to lack of sustained attention and inhibition via omission and commission errors respectively; modify tasks to better reflect daily tasks; and to record brain for greater insight into the subject.

By additionally considering consistent findings between independent studies, compared to an adult control group, hypotheses regarding people with ADHD traits performing the TFT and SART were made: (H1) They would have poorer performance scores for each CPT;[14,19,23,24,29,42] (H2) exhibit deficits in attention via omission errors;[14,19,23,24,29,42] (H3) exhibit deficits of inhibition via commission errors only in the SART (High-Go) and not in the TFT (Low-Go) due to the SART's increased demand for inhibition;[13,20-23,42] (H4) have heightened RTVs;[24,42] (H5) have heightened theta activity in frontal regions.[25-28]

Methods

Participants:

17 controls (Mean age: 21.860; SD: 2.061; 11 Males and 6 Females) and 16 people with ADHD traits (Mean age: 23.690; SD: 3.386; 9 Males and 7 Females) were recruited via the University College London (UCL) SONA for this study. Participants within the ADHD trait group self-reported symptoms of ADHD. The study was approved by the UCL Research Ethics Committee (6252/002). Additionally, all participants received £15 for participation and had their travel expenses covered if they were within the M25 area. Before the start of the experiment, each participant received an information sheet regarding the nature of their tasks and signed a consent form.

Materials:

The Adult ADHD Self-Report Scale Screener5 (ASRS-5) was used by participants for ADHD self-reporting. A virtual environment made with the use of Unity was employed in order to conduct the tasks for this study. The environment was a lecture hall with a main screen. It was filled with students as well as a lecturer. The participant is seated within the hall with a book in front of them. A paper plane would also fly once across the hall to act as a distractor within the environment. The paper plane, the hall's screen, and all human avatars were animated and produced ambient noise. Human avatars and their animations were created and imported respectively from DAZ3D. Sounds were similarly imported from https://freesound.org/. All other models used throughout the environment were imported via the Unity Asset store, and the Unity environment itself was developed using C#. A HTC Vive Pro headset fitted with a Looxid Link EEG mask attachment was used to enable participants to interact with the aforementioned virtual environment. The headset was connected to an Alienware M15 Ryzen Edition R7 laptop. For each participant, a questionnaire consisting of 6 questions that were rated on a Likert scale was prepared and then conducted at the end of each task (See Appendix A).

Procedure:

Participants were first tested for normal vision and hearing to ensure that they were suitable for the tasks involved in the study. Those that were suited were then counterbalanced via assignment into one of three groups to determine whether their starting task would be the SART or a Traditionally-Formatted Task (TFT). Two groups consisting of 10 and 13 participants first performed the TFT, while the remaining group of 10 participants first performed the SART. VR headsets were first placed over users before starting the tasks' Unity environment. User calibration and practice trials were then conducted after participants read instructions for each task. After these practice trials were the actual SART and TFT tasks then conducted. Both tasks involved 225 digits from 1 to 9 appearing on the book in front of the participant for 1.15 seconds after a delay of 1.15 seconds. Each digit is presented 25 times (225/9) in a random order. During SART, all numbers except the number 3 were to be attended to via a button press on the VR controller. During the TFT, only the number 3 should be attended to. The Unity environment was stopped at the end of both tasks and participants had their VR headsets removed. Participants also filled out questionnaires at the end of both tasks.

Measures:

Measures such as task accuracies, reaction times, the present digit displayed, and the timestamp of each button press were captured via the unity environment and recorded in a MySQL database. EEG measurements were recorded during each task using a Looxid Link EEG attachment for the HTC Vive Pro. The attachment includes sensor electrodes at the AF3, AF4, AF7, AF8, Fp1, Fp2 and a reference electrode at the FPz of the 10-10 system. Theta, alpha, and beta activity were obtained through built-in software and the provided Unity API. Measurements regarding the ecological validity of the experiment and participant sentiment during each task were recorded via post-task questionnaires.

DOI: 10.36838/v6i9.13

Data Analysis:

For each task, absolute accuracies were calculated (correct responses / total number of responses). These scores were used to measure task performances between groups, akin to Rosvold *et al.*[14] Due to several outliers in these accuracies, data that exceeded an absolute Z-Score of 2 were winsorized to either their 5th or 95th percentiles. Additionally, because of an observed ceiling effect in the resulting data, accuracies were compared between groups through a Mann-Whitney U test.

Inattention scores and impulsivity scores were calculated for each task. Inattention scores were defined as the number of omission errors / maximum possible omission errors. Impulsivity scores were defined as the number of commission errors / maximum possible commission errors. Because of an observed floor effect for the inattention scores in both tasks and the impulsivity scores in the TFT, scores were compared between groups through a Mann-Whitney U test. Impulsivity scores for the SART did, however, achieve a normal distribution. Hence, a t-test was conducted on the SART's impulsivity scores across both tasks. The SART's inattention scores were also compared across tasks with the Mann-Whitney U test.

For each user on both tasks, reaction times (RT) with an absolute Z-Score of more than 2 relative to a user's mean reaction time were removed due to their strong influence on a user's RT variability. Reaction time variability (RTV) and CV (RTV / Mean RT) were then calculated with this new data set. Because of a positive skew present in both tasks for RTV, a log10 transformation was conducted to achieve a normal distribution. Both CV and RTV were then analyzed via a 2-way ANOVA - Groups (Control, ADHD) x Task (TFT, SART).

EEG measures lost complete data for 2 control participants and suffered from minor data loss in other participants due to software fault. Hence, an XGboost regression model was trained and used for missing data predictions. Outliers identified by the 1.5 x IQR rule were removed from the resulting dataset. Theta, beta, and TBR values were then grouped according to an overall region (an average of all electrode readings), the Fp Region (an average of Fp1 and Fp2 electrode readings), and the AF region (an average of AF3, AF4, AF7, and AF8 electrode readings). Each region was then analyzed via a 2-way ANOVA - Groups (Control, ADHD) x Task (TFT, SART).

Questionnaires were summarised with the counts and relative proportions of each prompt. An agreed or disagreed sentiment would then be determined for each prompt based on whether each prompt had a mode of agreement ("Agree" + "Strongly Agree") or disagreement ("Disagree" + "Strongly Disagree"). Doing so enables the comparison of each group's sentiment towards a prompt for each task.

Results and Discussion

Task Performance Measures:

Table 1: Descriptive Statistics for Absolute Accuracies, Inattention Scores, Impulsivity Scores, RTV, & CV.

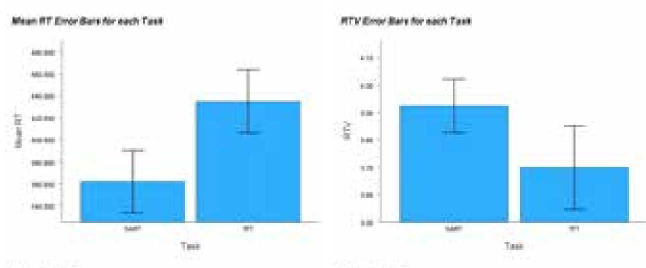
		TFT		SART	
		Control	ADHD	Control	ADHD
N		17	16	17	16
Absolute Accuracies	Mean	0.977	0.928	0.972	0.967
	SD	0.034	0.091	0.015	0.025
Inattention Scores	Mean	0.024	0.065	0.010	0.014
	SD	0.049	0.099	0.016	0.023
Impulsivity Scores	Mean	0.003	0.003	0.146	0.155
	SD	0.005	0.004	0.068	0.119
Mean RT	Mean	627.037	643.433	546.339	578.628
	SD	60.175	99.669	68.313	89.956
RTV*	Mean	3.619	3.784	3.893	3.956
	SD	0.372	0.478	0.287	0.266
CV	Mean	0.111	0.137	0.171	0.170
	SD	0.487	0.073	0.054	0.040

* RTV refers to the RTV values after a log10 transformation

Table 2: Hypothesis Testing Summary for Relevant Task Performance Measures.

Hypothesis	Hypothesis Outcome	Task	Test	Dependent Variable	Independent Variable	p
H1: The ADHD group exhibits poorer performances across both tasks	Rejected	TFT	Mann-Whitney U	Absolute Accuracy	Groups	0.168
		SART	Mann-Whitney U	Absolute Accuracy	Groups	0.736
H2: ADHD group exhibit attention deficits across both tasks	Rejected	TFT	Mann-Whitney U	Inattention Score	Groups	0.276
		SART	Mann-Whitney U	Inattention Score	Groups	0.790
H3: The ADHD group exhibits inhibition deficits across both tasks	Rejected	TFT	Mann-Whitney U	Impulsivity Score	Groups	0.763
		SART	Independent t-test	Impulsivity Score	Groups	0.804
H4: ADHD group exhibit heightened RTV	Rejected	NA	2-Way ANOVA	RTV	Groups	0.203
					Tasks	0.014*
					Group x Task	0.566
				CV	Groups	0.361
					Tasks	<.001*
					Group x Task	0.327

* Reaches significance but isn't relevant to hypothesis testing



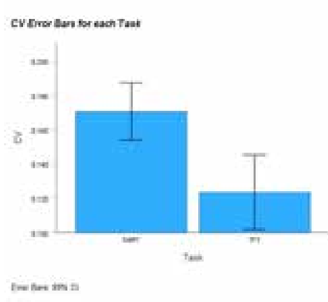


Figure 1: Error Bars for Mean RT, RTV, and CV.

* Reaches significance but isn't relevant to hypothesis testing

Results indicated that when compared to the control group for both tasks, the ADHD group had lower absolute accuracies (TFT [U= 175.00, p= .168], SART [U= 146.00, p= .736]), heightened inattention scores (TFT [(U= 105.50, p= .276], SART [U= 128.00, p= .790]), and heightened impulsivity scores (TFT [U= 127.00, p= .763], SART [t= 0.250, p= .804]), though such differences were not significant. These results suggest the rejection of H1, H2, and H3. It can also be noted that while the overall inattention scores were marginally lower in the SART than in the TFT (U= 518.00, p= .708), overall impulsivity scores were significantly higher in the SART than in the TFT (U= 66.00, p= <.001).

The mean RT of the ADHD group was higher than that of the control group across both tasks. Despite this, the results of a two-way ANOVA to evaluate the effects of groups and tasks on mean RT indicated no significant main effect for groups [F(1, 62) = 1.503, p= .225]. There was, however, a significant main effect for tasks [F(1, 62) = 13.424, p= <.001] and no significant interaction between groups and tasks [F(1, 62) = 0.160, p= .690]. A post hoc t-test conducted indicated that RTs were significantly higher for the TFT than for the SART [t(64)= 3.687, p= < .001].

Similarly, the RTV and CV of the ADHD group were marginally higher if not roughly equal to that of the control group. Results of the two-way ANOVAs conducted for RTV and CV indicate that there was no significant main effect for groups (RTV [F(1, 62) = 1.655, p= .203]; CV [F(1, 62) = 0.847, p= .361]), a significant main effect for tasks for both measures (RTV [F(1, 62) = 6.365, p= .014]; CV [F(1, 62) = 11.97, p= < .001]), and no significant interaction between groups and tasks for both measures (RTV [F(1, 62) = 0.333, p= .566]; CV [F(1, 62) = 0.977, p= .327]). *Post hoc* t-tests indicated that both RTVs and CVs were significantly higher for the SART than for the TFT (RTV [t(64)= -2.542, p= .013]; CV [t(64)= -3.496, p= <.001]). Hence, results for RTV and CV reject H4.

EEG Measurements:

Table 3: Descriptive Statistics for Theta Activity, Beta Activity & TBR for AF, Fp, and Overall Regions.

			TFT		SART	
			Control	ADHD	Control	ADHD
		N	14	13	12	12
Fp Region	Theta	Mean	0.831	0.835	0.838	0.844
		SD	0.042	0.037	0.041	0.031
	Beta	Mean	0.871	0.886	0.875	0.891
		SD	0.046	0.039	0.044	0.037
	TBR	Mean	0.955	0.943	0.958	0.948
		SD	0.026	0.032	0.030	0.032
AF Region	Theta	Mean	0.816	0.815	0.826	0.826
		SD	0.029	0.032	0.037	0.025
	Beta	Mean	0.864	0.880	0.868	0.885
		SD	0.039	0.040	0.039	0.039
	TBR	Mean	0.946	0.927	0.952	0.934
		SD	0.028	0.028	0.033	0.026
Overall	Theta	Mean	0.821	0.822	0.830	0.832
		SD	0.033	0.033	0.038	0.026
	Beta	Mean	0.866	0.881	0.871	0.887
		SD	0.043	0.038	0.041	0.038
	TBR	Mean	0.949	0.932	0.954	0.939

Table 4: Hypothesis Testing Summary for relevant EEG Measurements.

Hypothesis	Hypothesis Outcome	Region	Test	Dependent Variable	Independent Variable	p
H5: The ADHD group exhibits heightened theta activity in frontal regions	Rejected	Fp	2-Way ANOVA	Theta Activity	Groups	0.422
					Tasks	0.717
					Group x Task	0.788
			2-Way ANOVA	TBR	Groups	0.022*
					Tasks	0.942
					Group x Task	0.874
		AF	2-Way ANOVA	Theta Activity	Groups	0.308
					Tasks	0.038
					Group x Task	0.197
			2-Way ANOVA	TBR	Groups	0.002*
					Tasks	0.591
					Group x Task	0.981
		Overall	2-Way ANOVA	Theta Activity	Groups	0.677
					Tasks	0.258
					Group x Task	0.818
			2-Way ANOVA	TBR	Groups	0.005*
					Tasks	0.738
					Group x Task	0.964

* *Statistical significance was the opposite of the proposed hypothesis.

DOI: 10.36838/v6i9.13

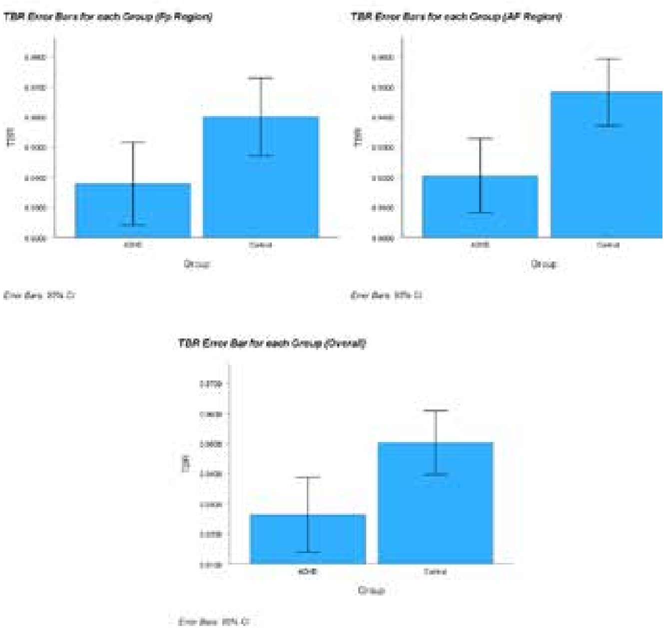


Figure 2: Error Bars for TBR in each Region.

Theta activity for the ADHD group in both the Fp and Overall regions was marginally higher, if not roughly equal to that of the control group for both tasks. Results showed that there was no significant main effect for groups (Fp Theta [F(1, 50) = 0.657, p= .422]; Overall Theta [F(1, 50) = 0.176, p= .677]), no significant main effect for tasks (Fp Theta [F(1, 50) = 0.717, p= .401]; Overall Theta [F(1, 50) = 1.311, p= .258]), and no significant interaction between groups and tasks (Fp Theta [F(1, 50) = 0.073, p= .788]; Overall Theta [F(1, 50) = 0.054, p= .818]).

Theta activity in the AF region was roughly equal between groups for both tasks. Though results indicated no significant main effect for groups [F(1, 53) = 1.058, p= .308], there was a significant main effect for tasks [F(1, 53) = 4.527, p= .038]. There was no significant interaction between groups and tasks, [F(1, 53) = 1.704, p= .197]. A *post hoc* t-test conducted on tasks indicated that theta activity in the AF region was significantly lower for the TFT task than for the SART task [t(55)= -2.146, p= 0.036].

The ADHD group displayed heightened beta activity across all regions compared to the control group for both tasks. However, results showed that there was no significant main effect for groups (Fp Beta [F(1, 58) = 0.184, p= .670]; AF Beta [F(1, 58) = 0.570, p= .453]; Overall Beta [F(1, 58) = 0.411, p= .524]), no significant main effect for tasks (Fp Beta [F(1, 58) = 0.071, p= .791]; AF Beta [F(1, 58) = 0.039, p= .844]; Overall Beta [F(1, 58) = 0.049, p= .825]), and no significant interaction between tasks (Fp Beta [F(1, 58) = 0.315, p= .577]; AF Beta [F(1, 58) = 0.342, p= .561]; Overall Beta [F(1, 58) = 0.334, p= .565]).

For TBR across all regions, results interestingly indicate a significant main effect for groups (Fp TBR [F(1, 57) = 5.523, p= .022]; AF TBR [F(1, 55) = 11.075, p= .002]; Overall TBR [F(1, 55) = 8.425, p= .005]), no significant main effect for tasks (Fp TBR [F(1, 57) = 0.005, p= .942]; AF TBR [F(1, 55) = 0.292, p= .591]; Overall TBR [F(1, 55)= 0.113, p= .738]), and no significant interaction between groups and tasks ((Fp TBR [F(1, 57) = 0.025, p= .874]; AF TBR [F(1, 55) = 0.001, p= .981]; Overall TBR [F(1, 55) = 0.002, p= .964]). Post hoc t-tests conducted on groups indicated that TBRs were significantly higher for the control group than for the ADHD group across all regions (Fp TBR [t(59)= 2.392, p= .020]; AF TBR [t(57)= 3.388, p= < .001]; Overall TBR [t(57)= 2.959, p= .004]).

Results regarding statistical tests for EEG measurements across all examined regions suggest non-significant differences in theta activity between both groups. Hence, these results suggest the rejection of H5.

Questionnaires:

For the TFT task, the control group generally disagreed with the prompts "Pressing the button for the wrong number affected my next responses", "The lecturer and other students were distracting me during this task", and "I think I didn't do very well in completing this task" and agreed with the prompts "I felt present and involved in VR", "The task was interesting and was similar to a scenario that can happen in our day-to-day life", and "I think I did very well in completing this task". It should be noted that though the prompt "The task was interesting and was similar to a scenario that can happen in our day-to-day life" was evaluated to have a general sentiment of agreed, its response distribution suggests a near-neutral sentiment. The ADHD group similarly disagreed with the prompts "Pressing the button for the wrong number affected my next responses" and "I think I didn't do very well in completing this task" while agreeing with the prompts "I felt present and involved in VR", "The task was interesting and was similar to a scenario that can happen in our day-to-day life", and "I think I did very well in completing this task". However, unlike that of the control group, the ADHD group generally agreed with the prompt "The lecturer and other students were distracting me during this task". A summary of each prompt for the TFT questionnaire may be seen in Table 5 below.

Table 5: TFT Questionnaire response summary.

Group	Prompt	Response				
		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Controls	Q1[a]	5 (33.33%)	6 (40%)	4 (26.67%)	0 (0%)	0 (0%)
	Q2[b]	4 (26.67%)	6 (40%)	2 (13.33%)	3 (20%)	0 (0%)
	Q3[c]	1 (6.67%)	1 (6.67%)	2 (13.33%)	8 (53.33%)	3 (20%)
	Q4[d]	0 (0%)	5 (33.33%)	5 (33.33%)	4 (26.67%)	1 (6.67%)
	Q5[e]	5 (33.33%)	6 (40%)	4 (26.67%)	0 (0%)	0 (0%)
	Q6[f]	0 (0%)	0 (0%)	3 (20%)	6 (40%)	6 (40%)
ADHD	Q1[a]	6 (37.5%)	4 (25%)	6 (37.5%)	0 (0%)	0 (0%)
	Q2[b]	2 (12.5%)	2 (12.5%)	2 (12.5%)	8 (50%)	2 (12.5%)
	Q3[c]	0 (0%)	1 (6.25%)	1 (6.25%)	9 (56.25%)	5 (31.25%)
	Q4[d]	0 (0%)	3 (18.75%)	3 (18.75%)	6 (37.5%)	4 (25%)
	Q5[e]	7 (43.75%)	7 (43.75%)	1 (6.25%)	1 (6.25%)	0 (0%)
	Q6[f]	0 (0%)	1 (6.25%)	2 (12.5%)	6 (37.5%)	7 (43.75%)

DOI: 10.36838/v6i9.13

a. Q1 refers to "Pressing the button for the wrong number affected my next responses".
b. Q2 refers to "The lecturer and other students were distracting me during this task".
c. Q3 refers to "I felt present and involved in VR".
d. Q4 refers to "The task was interesting and was similar to a scenario that can happen in our day-to-day life".
e. Q5 refers to "I think I didn't do very well in completing this task".
f. Q6 refers to "I think I did very well in completing this task".

For the SART task, the control group generally disagreed with the prompts "Pressing the button for the wrong number affected my next responses", "The lecturer and other students were distracting me during this task", and "I think I didn't do very well in completing this task" while agreeing with the prompts "I think I did very well in completing this task", "The task was interesting and was similar to a scenario that can happen in our day-to-day life", and "I felt present and involved in VR". It should be noted that though the prompts "I think I did very well in completing this task" and "The task was interesting and was similar to a scenario that can happen in our day-to-day life" were evaluated to have a general sentiment of agreed, their response distributions suggest a near neutral sentiment. The ADHD group similarly agreed with the prompts "The task was interesting and was similar to a scenario that can happen in our day-to-day life" and "I felt present and involved in VR". Unlike the control group however, the ADHD group generally agreed with the prompts "Pressing the button for the wrong number affected my next responses", "The lecturer and other students were distracting me during this task", and "I think I didn't do very well in completing this task" while disagreeing with the prompt "I think I did very well in completing this task". It should also be noted that though the prompts "I think I did very well in completing this task" and "I think I didn't do very well in completing this task" were evaluated to have a general sentiment of agreement, their distributions suggest a near neutral sentiment. A summary of each prompt for the SART questionnaire may be seen in Table 6 below.

Table 6: SART Questionnaire response summary.

Group	Prompt	Response				
		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Controls	Q1[a]	3 (20%)	5 (33.33%)	1 (6.67%)	6 (40%)	0 (0%)
	Q2[b]	2 (13.33%)	7 (46.67%)	1 (6.67%)	5 (33.33%)	0 (0%)
	Q3[c]	0 (0%)	3 (20%)	7 (46.67%)	5 (33.33%)	0 (0%)
	Q4[d]	2 (13.33%)	5 (33.33%)	6 (40%)	2 (13.33%)	0 (0%)
	Q5[e]	0 (0%)	5 (33.33%)	3 (20%)	7 (46.67%)	0 (0%)
	Q6[f]	1 (6.67%)	1 (6.67%)	3 (20%)	9 (60%)	1 (6.67%)
ADHD	Q1[a]	3 (18.75%)	2 (12.5%)	3 (18.75%)	8 (50%)	1 (6.25%)
	Q2[b]	2 (12.5%)	2 (12.5%)	0 (0%)	11 (68.75%)	1 (6.25%)
	Q3[c]	1 (6.25%)	5 (31.25%)	5 (31.25%)	3 (18.75%)	2 (12.5%)
	Q4[d]	1 (6.25%)	4 (25%)	5 (31.25%)	4 (25%)	2 (12.5%)
	Q5[e]	0 (0%)	4 (25%)	5 (31.25%)	4 (25%)	3 (18.75%)
	Q6[f]	0 (0%)	1 (6.25%)	1 (6.25%)	10 (62.5%)	4 (25%)

a. Q1 refers to "Pressing the button for the wrong number affected my next responses".
b. Q2 refers to "The lecturer and other students were distracting me during this task".
c. Q3 refers to ""I think I did very well in completing this task".
d. Q4 refers to "I think I didn't do very well in completing this task".
e. Q5 refers to "The task was interesting and was similar to a scenario that can happen in our day-to-day life".
f. Q6 refers to "I felt present and involved in VR".

The control group generally had consistent sentiment across both tasks for each equivalent prompt whereas the ADHD group differed in sentiment for the prompts "Pressing the button for the wrong number affected my next responses", "I think I didn't do very well in completing this task", and "I think I did very well in completing this task" across both tasks. Table 7 describes a summary of sentiments for both tasks between both groups.

Table 7: Sentiment Summaries for Task Questionnaires.

Group	Task	Sentiment					
		Q1[a]	Q2[b]	Q3[c]	Q4[d]	Q5[e]	Q6[f]
Controls	TFT	Disagree	Disagree	Agree	Agree*	Disagree	Agree
	SART	Disagree	Disagree	Agree	Agree*	Disagree	Agree*
ADHD	TFT	Disagree	Agree	Agree	Agree	Disagree	Agree
	SART	Agree	Agree	Agree	Agree	Agree*	Disagree*

Note. The SART Questionnaire's questions were relabelled for ease of reading.
a. Q1 refers to " Pressing the button for the wrong number affected my next responses ".
b. Q2 refers to " The lecturer and other students were distracting me during this task ".
c. Q3 refers to " I felt present and involved in VR ".
d. Q4 refers to " The task was interesting and was similar to a scenario that can happen in our day-to-day life ".
e. Q5 refers to " I think I didn't do very well in completing this task ".
f. Q6 refers to " I think I did very well in completing this task ".

Discussion of Measures Across Groups:

Results indicate statistically non-significant but expected differences in all but one measure between those with ADHD and healthy individuals across both tasks; the exception being brain activity. While this could imply these metrics lose sensitivity in detecting attentional or inhibitory symptoms in those with ADHD during a TFT or SART that includes elements that improve the ecological validity of the tasks, it is more likely that the tasks themselves become less demanding on such EFs. This is because insignificant differences in theta and beta brain activity across all regions imply that attentional or inhibitory differences aren't present to begin with.[25] TBRs were even the opposite of predicted directions.

A proposed explanation for the loss of the aforementioned sensitivities is the effect of the VR environment and its distractors. By introducing an environment that simulates one that's typically found in daily life into the SART and TFT, elements that alleviate the mundane setting of a TFT or SART, such as students, lecturers, and ambient noise, are introduced. Removing the mundane setting of these tasks might've not only alleviated the attentional demands of these tasks, but also raised participants' overall attentiveness. This would especially

DOI: 10.36838/v6i9.13

be the case for those with ADHD, since healthy participants aren't predicted to be as easily aroused by distractors and also reported little to no effect from the VR environment's distractors during both tasks.[1] Though questionnaire responses from the ADHD group imply hindrance to task performances in addition to their increased arousal via distractors, such hindrances were likely not reflected in investigated measures because these hindrances reflect increased load on divided attention, an EF that the present study's tasks and measures are ill-equipped to assess. Therefore, elements that increase the ecological validity of the TFT and SART in the same manner as the present study likely elevate the attention levels of those with ADHD. This thus prevents the observation of metrics typically expected of those with ADHD during a traditional TFT or SART and explains why control participants might have reflected higher TBRs, which imply heightened levels of "inattentiveness", as compared to the ADHD group.

Such a theory is further supported by participant sentiment that implies the ecological validity of these tasks in VR environments. Sentiment towards the prompts "I felt present and involved in VR" and "The task was interesting and was similar to a scenario that can happen in our day-to-day life" were both generally agreed on by both groups across both tasks. Since both prompts relate to the ecological validity of tasks within the VR environment, it is suggested that the VR tasks did, in fact, introduce ecological validity to the TFT and SART. Hence, if the tasks were ecologically valid but failed to reflect expected differences found in daily tasks via measures related to attention and inhibition, it is likely that the conducted tasks feature reduced sustained attention and inhibitory demand.

Measures of task accuracies, inattention scores, impulsivity scores, RTV, and CV have all been previously shown to assess symptoms of inattention and impulsivity in those with ADHD.[14,19,23,24,29,42] Because these measures all generally followed predicted differences (see Appendix B, Table B) but to a less-than-expected degree, the present study lends slight support to authors who suggest that these measures are useful in assessing inattention and impulsivity in those with ADHD.[14,19,23,24,29,42] The present study also highlights the possibility that introducing ecological validity to the TFT and SART in a similar manner to the present study's method decreases the tasks' demand for the EFs of sustained attention and inhibition, which hinders the tasks' abilities to assess these EFs.

Discussion of Measures Across Tasks:

Despite not being the primary aim of the present study, significant differences in results between tasks suggest that performance in the SART requires greater inhibitory demand than the TFT (see Appendix B). This lends support to research on the subject which proposes that the SART develops a feed-forward motor routine where participants respond in an automatic manner where regardless of being conscious of the type of presented stimuli (target / non-target), participants find an inability to withhold responses.[13,20-22]

This higher inhibitory demand may be observed through the present study's various metrics, such as inhibition scores. Errors of impulsivity have been shown to be reflected in task commission errors.[23] Hence, the significant differences found in inhibition scores across tasks, which are calculated based on such errors, suggest a higher inhibitory demand in the SART over the TFT. A significantly faster mean RT in the SART additionally supports the perspective of Helton *et al.*[20], who argue that the "high go / low no-go" leads to a feed-forward motor routine. This is because faster mean RTs imply that participants responded to the SART's targets in a fast-paced rhythmic manner, which isn't possible in the TFT. The presence of this feed-forward routine is also potentially supported by significantly heightened RTV and CV measures in the SART. Because participants were likely aware of commission errors,[20] they might have adjusted their response strategies mid-task to ones that involved responding to targets more slowly to improve overall task performances. When comparing AF theta activity across tasks, it was revealed that theta activity was heightened for the SART over the TFT. A likely explanation is that the SART exhibits little to no attentional demand and relies mostly on inhibition.[13,20-22] Hence, if participants entered a mostly automatic response routine that requires little to no attentional demand, finding a trend of heightened theta activity in the SART would be unsurprising.

Sentiment towards the prompts "I think I did very well in completing this task" and "I think I didn't do very well in completing this task" suggests better perceived performances in the TFT than the SART for both groups. This difference in perceived task performances was more extreme for the ADHD group. The more extreme difference in perceived task performances for the ADHD group is likely related to their response to the prompt "Pressing the button for the wrong number affected my next responses", where the group expressed agreement for the SART but not the TFT. Given the ADHD group's response to this prompt and their potential inhibitory deficits relative to the control group,[1,3] it is likely that the ADHD group experienced greater irritation from commission errors during the task and hence expressed poorer perceived performances in the SART than in the TFT. This probable experience of greater irritation due to errors of inhibition is in line with other studies involving the SART that describe participants being well aware of the errors of their actions before committing the action, but are nevertheless unable to inhibit their motor responses.[20,21] Hence, observed differences in performance sentiments in the SART over the TFT for both groups also suggest the SART's heightened demand for inhibition compared to the TFT because participants were likely conscious of task errors and because the study's ADHD participants likely experience inhibitory deficits.[1,3,20,21]

Limitations:

Conclusions drawn in the present study are, however, limited by several factors that are potentially confounded by the introduction of ecological validity to the TFT and SART. One factor is the sole use of the ASRS-5 for ADHD diagnosis and thereafter grouping. Though shown to have high sensitivity (91.4%) and specificity rates (96.0%),[5] the self-assessed and subjective nature of the scale is still subject to personal bias. This might have led to false classifications in grouping. Next, because the ASRS-5 only consisted of 6 questions, unlike that of the ASRS v1.1, it was not possible to accurately identify whether participants' ADHD symptoms were in significant deficits of attention, inhibition, or hyperactivity.[5,6] Since the TFT and SART are known to assess inattention and impulsivity, it is entirely possible that ADHD participants who suffer primarily from symptoms of hyperactivity would then show little difference in various measures for both tasks.[9,13]

Another factor to consider was the general abilities of the study's participants, which are implied via reported education levels. Since all participants have completed an education of a bachelor's degree or above, it is evident that they have been able to perform tasks of relatively higher levels of difficulty than the TFT/SART in spite of symptoms. Such achievement might've partially been achieved with effective coping mechanisms that compensate for their symptoms.[43,44] If this heavily influenced the results of the study, the ceiling effect observed for task accuracies and the floor effect for inattention scores and impulsivity scores might have resulted from the selected participants' abilities and not elements found within the VR environment. Observation of such effects could also be compounded by the present study's use of adults and not children, unlike that of other similar studies, because adults are likely to display relatively heightened general abilities and less severe ADHD traits.[1,3,4,23,24,42]

The utility of VR itself might be a confounding factor. Currently, regular use of VR is still fairly uncommon amongst populations. In the UK, only 6% of the population is estimated to own a VR headset.[45] It has also been shown that ADHD individuals suffering from symptoms of inattention aren't necessarily unable to sustain attention to tasks, especially when engaging in tasks of interest.[46] Hence, the novelty of engaging with VR technology itself could arouse participants. This might consequently affect measures such as EEG recordings by lowering theta activity and heightening the beta activity of those with ADHD to normalcy.

Other minor limitations might have affected the results of the present study. For instance, the present study did not employ a task similar to the CPT-AX. Since inattention and impulsivity scores rely on additional definitions that made use of an 'A' or equivalent element that preceded an 'X' or target (which is absent in the TFT and SART), the present study's scores potentially lack the appropriate sensitivity necessary to detect significant differences.[23] Additionally, because the TFT is designed for participants to specifically respond to 25 targets as opposed to 200 in the SART, there might've not been adequate samples to accurately represent participants' reaction time metrics for the TFT.[14,19] Finally, software limitations may have affected the study, because it resulted in the minor loss of some data. With less-than-ideal sample sizes in some data, potentially biased results may have emerged through the use of ML predictions.

Recommendations for Future Studies:

Future studies that wish to pursue similar interests should consider the following recommendations. Firstly, multiple alternative scales such as Conners' Adult ADHD Rating Scales and Brown Attention-Deficit Disorder Rating Scale for Adults could be used in tandem with the ASRS-5 or the 18-question version of the ASRS v1.1.[5,6,47] If possible, results from scales would then be followed up with a clinical diagnosis. This almost exhaustively lowers the risk of misclassifying participants into blocks and enables separate analysis of inattention, impulsivity, and hyperactive symptoms.

To investigate the possibility of education level playing a factor in the study of adults with ADHD, it is recommended that future studies make use of adults with a diverse range of academic or general abilities, such as IQ.[48,49] Doing so would help to clarify the ambiguity of confounding non-significance with someone's general ability to compensate for frontal lobe dysfunction.

A greater sample size is also recommended for future studies. Besides easing statistical analysis through increased resistance towards outliers, increasing the sample size helps alleviate faults in software or hardware. Hence, results obtained from data analysis would be more representative of the population being studied.

To better identify if failure to meet hypotheses was the result of the TFT/SART's ecological validity, the novelty of VR use, or other potential faults in experimental design, a future study that recreates real-life equivalents of the tasks described in the present study that follows the above recommendations would prove useful. Including a numerical "CPT-AX" task or a fixed SART could further bolster this study's usefulness.

Because of the many interrelated limitations identified with the present study, it is recommended that all of these limitations be addressed simultaneously in future studies. If results observed in the present study weren't the product of introducing elements that improved ecological validity to the TFT and SART, it is expected that most of the present study's hypotheses would be met and that greater support for reviewed literature would be found.

Conclusion

The present study generally produced results with non-significant differences in expected directions between groups for various measures of interest. This observation is typically unexpected in traditionally conducted TFTs and SARTs. However, the present study primarily differs from past studies in its method of utilizing VR to modify the TFT and SART for improved ecological validity. Hence, observed results suggest that doing so possibly reduces the tasks' demand for the EFs of sustained attention and inhibition due to the introduction of several factors to the tasks and thus, participants (e.g. novelties found within the VR environment). Therefore, by accounting for these factors and the fact that investigated measures were in expected directions, the present study lends limited support to literature that proposes the usefulness of such measures. Despite not being the primary aim of the study, the study also provides evidence that substantiates the claim that the SART demands greater inhibitory demand. To conclude, because of the number of markers investigated through the sole use of two similar tasks, overall participant sentiment that cites immersion and the real-life reflection of the tasks in VR environments, and the many rectifiable limitations identified throughout the present study, the introduction of ecological validity into the TFT and SART via VR in the

DOI: 10.36838/v6i9.13

study of ADHD should be further explored to substantiate existing research. Such future studies may look to identify if the present study's results are due to an improvement in ecological validity, the novelty of VR use, or other identified limitations. Doing so may not only substantiate or challenge existing research, but also prove VR to be an appropriate environment for the conduct of other CPTs and other future ADHD studies.

Acknowledgment

I would like to thank Dr. Fjorda Kazazi for being my mentor throughout the research project. She not only assisted with the conduct of the present study's experiments and data collection, but also enabled me to conduct research in psychology, a field in which I had little experience yet much interest in.

References

1. American Psychiatric Association. *Diagnostic and statistical manual of mental disorders* **2013**. DOI:10.1176/appi.books.9780890425596
2. Gentile, J. P.; Atiq, R.; Gillig, P. M. Adult ADHD: Diagnosis, Differential Diagnosis, and Medication Management. *Psychiatry (Edgmont (Pa. : Township))* **2006**, *3*(8), 25–30.
3. Felt, B. T.; Biermann, B.; Christner, J. G.; Kochhar, P.; Harrison, R. V. Diagnosis and management of ADHD in children. *American family physician* **2014**, *90*(7), 456–464. https://www.aafp.org/pubs/afp/issues/2014/1001/p456.html?utm_medium=email&utm_source=transaction#afp20141001p456-b4 (accessed 2022-12-28)
4. Wolraich, M. L.; Chan, E.; Froehlich, T.; Lynch, R. L.; Bax, A.; Redwine, S. T.; Ihyembe, D.; Hagan, J. F. ADHD Diagnosis and Treatment Guidelines: A Historical Perspective. *Pediatrics* **2019**, *144* (4). DOI:10.1542/peds.2019-1682
5. Ustun, B.; Adler, L. A.; Rudin, C.; Faraone, S. V.; Spencer, T. J.; Berglund, P.; Gruber, M. J.; Kessler, R. C. The World Health Organization Adult Attention-Deficit/Hyperactivity Disorder Self-Report Screening Scale forDsm-5. *JAMA Psychiatry* **2017**, *74* (5), 520. DOI:10.1001/jamapsychiatry.2017.0298
6. Kessler, R.C., Adler, L., Ames, M., Demler, O., Faraone, S., Hiripi, E., Howes, M.J., Jin, R., Secnik, K., Spencer, T., Ustun, T.B., Walters, E.E. The World Health Organization ADULT ADHD Self-Report Scale (ASRS): A Short Screening Scale for Use in the General Population. *Psychological Medicine* **2005**, *35* (2), 245–256. DOI:10.1017/s0033291704002892
7. Silverstein, M. J.; Faraone, S. V.; Alperin, S.; Leon, T. L.; Biederman, J.; Spencer, T. J.; Adler, L. A. Validation of the Expanded Versions of the Adult ADHD Self-Report Scale V1.1 Symptom Checklist and the Adult ADHD Investigator Symptom Rating Scale. *Journal of Attention Disorders* **2018**, *23* (10), 1101–1110. DOI:10.1177/1087054718756198
8. Gilbert, S. J.; Burgess, P. W. Executive Function. *Current Biology* **2008**, *18* (3). DOI:10.1016/j.cub.2007.12.014
9. Diamond, A. Executive Functions. *Annual Review of Psychology* **2013**, *64* (1), 135–168. DOI:10.1146/annurev-psych-113011-143750
10. Lezak, M. D. The Problem of Assessing Executive Functions. *International Journal of Psychology* **1982**, *17* (1–4), 281–297. DOI:10.1080/00207598208247445
11. Gopher, D.; Armony, L.; Greenshpan, Y. Switching Tasks and Attention Policies. *Journal of Experimental Psychology: General* **2000**, *129* (3), 308–339. DOI:10.1037/0096-3445.129.3.308
12. Cepeda, N. J.; Cepeda, M. L.; Kramer, A. F. *Journal of Abnormal Child Psychology* **2000**, *28* (3), 213–226. DOI:10.1023/a:1005143419092
13. Stevenson, H.; Russell, P. N.; Helton, W. S. Search Asymmetry, Sustained Attention, and Response Inhibition. *Brain and Cognition* **2011**, *77* (2), 215–222. DOI:10.1016/j.bandc.2011.08.007
14. Rosvold, H. E.; Mirsky, A. F.; Sarason, I.; Bransome, E. D.; Beck, L. H. A Continuous Performance Test of Brain Damage. *Journal of Consulting Psychology* **1956**, *20* (5), 343–350. DOI:10.1037/h0043220
15. Shalev, L.; Ben-Simon, A.; Mevorach, C.; Cohen, Y.; Tsal, Y. Conjunctive Continuous Performance Task (Ccpt)—a Pure Measure of Sustained Attention. *Neuropsychologia* **2011**, *49* (9), 2584–2591. DOI:10.1016/j.neuropsychologia.2011.05.006
16. Rosenberg, M.; Noonan, S.; DeGutis, J.; Esterman, M. Sustaining Visual Attention in the Face of Distraction: A Novel Gradual-Onset Continuous Performance Task. *Attention, Perception, & Psychophysics* **2013**, *75* (3), 426–439. DOI:10.3758/s13414-012-0413-x
17. Klee, S. H.; Garfinkel, B. D. The Computerized Continuous Performance Task: A New Measure of Inattention. *Journal of Abnormal Child Psychology* **1983**, *11* (4), 487–495. DOI:10.1007/bf00917077
18. Smid, H. G. O. M.; de Witte, M. R.; Homminga, I.; van den Bosch, R. J. Sustained and Transient Attention in the Continuous Performance Task. *Journal of Clinical and Experimental Neuropsychology* **2006**, *28* (6), 859–883. DOI:10.1080/13803390591001025
19. Robertson, I. H.; Manly, T.; Andrade, J.; Baddeley, B. T.; Yiend, J. `oops!': Performance Correlates of Everyday Attentional Failures in Traumatic Brain Injured and Normal Subjects. *Neuropsychologia* **1997**, *35* (6), 747–758. DOI:10.1016/s0028-3932(97)00015-8
20. Helton, W. S.; Hollander, T. D.; Warm, J. S.; Matthews, G.; Dember, W. N.; Wallaart, M.; Beauchamp, G.; Parasuraman, R.; Hancock, P. A. Signal Regularity and the Mindlessness Model of Vigilance. *British Journal of Psychology* **2005**, *96* (2), 249–261. DOI:10.1348/000712605x38369
21. Carter, L.; Russell, P. N.; Helton, W. S. Target Predictability, Sustained Attention, and Response Inhibition. *Brain and Cognition* **2013**, *82* (1), 35–42. DOI:10.1016/j.bandc.2013.02.002
22. Staub, B.; Doignon-Camus, N.; Bacon, E.; Bonnefond, A. Investigating Sustained Attention Ability in the Elderly by Using Two Different Approaches: Inhibiting Ongoing Behavior versus Responding on Rare Occasions. *Acta Psychologica* **2014**, *146*, 51–57. DOI:10.1016/j.actpsy.2013.12.003
23. Overtoom, C.C.E.; Verbaten, M.N.; Kemner, C.; Kenemans, J.; Engeland, H.; Buitelaar, J.K.; Camffereman, G.; & Koelega, H.S. Associations between Event-Related Potentials and Measures of Attention and Inhibition in the Continuous Performance Task in Children with ADHD and Normal Controls. *Journal of the American Academy of Child & Adolescent Psychiatry* **1998**, *37* (9),977–985. DOI:10.1097/00004583-199809000-00018
24. Levy, F.; Pipingas, A.; Harris, E. V.; Farrow, M.; Silberstein, R. B. Continuous Performance Task in ADHD: Is Reaction Time Variability a Key Measure? *Neuropsychiatric Disease and Treatment* **2018**, *Volume 14*, 781–786. DOI:10.2147/ndt.s158308
25. Loo, S. K.; Makeig, S. Clinical Utility of EEG in Attention-Deficit/Hyperactivity Disorder: A Research Update. *Neurotherapeutics* **2012**, *9* (3), 569–587. DOI:10.1007/s13311-012-0131-z
26. Eman, E.; Larsson, J.; Persson, H. E.; Rydelius, P. Altered Cortical Activity in Children with Attention-Deficit/Hyperactivity Disorder during Attentional Load Task. *Journal of the American Academy of Child & Adolescent Psychiatry* **2002**, *41* (7), 811–819. DOI:10.1097/00004583-200207000-00013
27. Lazzaro, I.; Gordon, E.; Whitmont, S.; Plahn, M.; Li, W.; Clarke, S.; Dosen, A.; Meares, R. Quantified EEG Activity in Adolescent Attention Deficit Hyperactivity Disorder. *Clinical Electroencephalography* **1998**, *29* (1), 37–42. DOI:10.1177/155005949802900111
28. Bresnahan, S. M.; Barry, R. J. Specificity of Quantitative EEG A

nalysis in Adults with Attention Deficit Hyperactivity Disorder. *Psychiatry Research* **2002**, *112* (2), 133–144. DOI:10.1016/ s0165-1781(02)00190-7
29. Tucha, L.; Fuermaier, A. B.; Koerts, J.; Buggenthin, R.; Aschenbrenner, S.; Weisbrod, M.; Thome, J.; Lange, K. W.; Tucha, O. Sustained Attention in Adult ADHD: Time-on-Task Effects of Various Measures of Attention. *Journal of Neural Transmission* **2015**, *124* (S1), 39–53. DOI:10.1007/s00702-015-1426-0
30. Musso, M. W.; Gouvier, W. D.; Barker, A. A. ecological validity. Encyclopaedia Britannica October 28, 2014. https://www.britannica.com/science/ecological-validity (accessed 2023-2-06)
31. Andrade, C. Internal, External, and Ecological Validity in Research Design, Conduct, and Evaluation. *Indian Journal of Psychological Medicine* **2018**, *40* (5), 498–499. DOI:10.4103/ijpsym.ijpsym_334_18
32. Schmuckler, M. A. What Is Ecological Validity? A Dimensional Analysis. *Infancy* **2001**, *2* (4), 419–436. DOI:10.1207/s1532778in0204_02
33. Kihlstrom, J. F. Ecological Validity and "Ecological Validity." *Perspectives on Psychological Science* **2021**, *16* (2), 466–471. DOI:10.1177/1745691620966791
34. Vince, J. *Introduction to virtual reality* **2004**. DOI:10.1007/978-0-85729-386-2
35. Lowood, H. E. virtual reality. Encyclopedia Britannica Septembeer 8, 2022. https://www.britannica.com/technology/virtual-reality (accessed 2023-02-07)
36. Sherman, W. R.; Craig, A. B. *Understanding Virtual Reality: Interface, Application, and Design*; Morgan Kaufmann Publishers, **2003**.
37. Kozlov, M. D.; Johansen, M. K. Real Behavior in Virtual Environments: Psychology Experiments in a Simple Virtual-Reality Paradigm Using Video Games. *Cyberpsychology, Behavior, and Social Networking* **2010**, *13* (6), 711–714. DOI:10.1089/cyber.2009.0310
38. Bohil, C. J.; Alicea, B.; Biocca, F. A. Virtual Reality in Neuroscience Research and Therapy. *Nature Reviews Neuroscience* **2011**, *12* (12), 752–762. DOI:10.1038/nrn3122
39. Foreman, N.; Pantelidis, V. S.; Chen, C. J. Virtual Reality in Psychology. *Themes in Science and Technology Education* **2019**, *2*, 225-252.
40. Wilson, C. J.; Soranzo, A. The Use of Virtual Reality in Psychology: A Case Study in Visual Perception. *Computational and Mathematical Methods in Medicine* **2015**, *2015*, 1–7. DOI:10.1155/2015/151702
41. Danis, A.; Pêcheux, M.-G.; Lefèvre, C.; Bourdais, C.; Serres-Ruel, J. A Continuous Performance Task in Preschool Children: Relations between Attention and Performance. *European Journal of* Developmental *Psychology* **2008**, *5* (4), 401–418. DOI:10.1080/17405620600866800
42. Johnson, K. A.; Robertson, I. H.; Kelly, S. P.; Silk, T. J.; Barry, E.; Dáibhis, A.; Watchorn, A.; Keavey, M.; Fitzgerald, M.; Gallagher, L.; Gill, M.; Bellgrove, M. A. Dissociation in Performance of Children with ADHD and High-Functioning Autism on a Task of Sustained Attention. *Neuropsychologia* **2007**, *45* (10), 2234–2245. DOI:10.1016/j.neuropsychologia.2007.02.019
43. Young, S. Coping Strategies Used by Adults with ADHD. *Personality and Individual Differences* **2005**, *38* (4), 809–816. DOI:10.1016/j.paid.2004.06.005
44. Canela, C.; Buadze, A.; Dube, A.; Eich, D.; Liebrenz, M. Skills and Compensation Strategies in Adult ADHD – A Qualitative Study. *PLOS ONE* **2017**, *12* (9). DOI:10.1371/journal.pone.0184964
45. Laricchia, F. Ownership of VR headsets in the UK 2023 by age. Statista **2023**. https://www.statista.com/statistics/1362661/share-of-vr-headset-owners-by-age-uk/#:~:text=During%20a%2023%20survey%20conducted,respondents%20owned%20a%20VR%20headset (accessed 2023-10-28)
46. DeWitt, R. ADHD, Willpower, and Interest: A Positive Approach. Master Thesis, University of Pennsylvania, Philadelphia, PA, **2020**. https://repository.upenn.edu/handle/20.500.14332/38828 (accessed 2023-12-03)
47. Murphy, K. R.; Adler, L. A. Assessing attention-deficit/hyperactivity disorder in adults: focus on rating scales. *Journal of Clinical Psychiatry* **2004**, *65*, 12-17.
48. Gottfredson, L. S. (1998). The general intelligence factor. *Scientific American* **1998**, *4*, 24-29.
49. Jalili, A.; Hejazi, M.; Entesar Fomani, G.; Morovvati, Z. The Correlation between IQ with Educational Performance and Problem Solving Mediation. *Journal of Health Promotion Managment* **2018**, *7* (1), 1–8. DOI:10.21859/jhpm-08011

■ Authors

Russell Hariman Kwok is a graduate from Ngee Ann Polytechnic. His interests lie in interdisciplinary ventures between computer science and other disciplines such as psychology, philosophy, and linguistics. Hence, he will be pursuing a degree in computer science and philosophy at the University of Illinois, Urbana-Champaign in the near-future.

DOI: 10.36838/v6i9.13