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Research article

Developing and feasibility testing of the Indonesian computer-based game prototype for children with attention deficit/hyperactivity disorder

Tjhin Wiguna [a,*], Raden Irawati Ismail [a], Fransiska Kaligis [a], Kusuma Minayati [a], Belinda Julivia Murtani [a], Ngurah Agung Wigantara [a], Kent Pradana [a], Raymond Bahana [b], Bayu Prakoso Dirgantoro [b], Eko Nugroho [c]

[a] *Department of Psychiatry, Faculty of Medicine Universitas Indonesia, Dr. Cipto Mangunkusumo General Hospital, Jakarta, Indonesia*
[b] *Department of Computer Science, Bina Nusantara University, Jakarta, Indonesia*
[c] *Kummara Game Design Studio, Bandung, West Java, Indonesia*

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ABSTRACT

The aim of this study was to develop an Indonesian computer-based game prototype, including feasibility testing, targeted on attention deficit/hypersensitivity disorder (ADHD) clinical symptoms and executive function. The study comprised five steps. The first to third steps used an exploratory qualitative research design. The Delphi technique with FGD was applied to collect qualitative data. During the study, seven experts participated in ten FGDs. Feasibility testing was conducted as a one group pre- and post-test design that included ten children with drug-naïve ADHD without other mental or physical disorders. Feasibility data were collected before and after 20 training sessions with the Indonesian computer-based game prototype. The framework analysis was performed for qualitative data. Quantitative data were analyzed using the paired t-test, Pearson's correlation and Spearman's rank-order correlation. Outputs of the exploratory qualitative study were the Indonesian computer-based game prototype constructs and general agreements of the prototype,. The Indonesian computer-based game prototype construct comprised six components: reward-related processing, control inhibition, improved sustained attention, specific timing, increased arousal, and improved emotional regulation. After 20 sessions of training, several indicators decreased significantly, such as CATPRS-teacher rating (18.5 [5.31] vs. 12.9 [5.51], $p = 0.047$), BRIEF-GEC (64.80 [10.21] vs. 57.50 [7.51], $p = 0.02$), BRIEF-MI (66.1 [7.61] vs. 58.4 [7.56], $p = 0.014$), BRIEF-Initiate (66.6 [10.15] vs. 54.1 [6.49], $p = 0.008$), BRIEF-Working Memory (68.0 [6.89] vs. 60.9 [10.05], $p = 0.02$), and BRIEF-Organization of Material (60.7 [12.88] vs. 49.3 [11.79], $p = 0.04$). There was a low to moderate correlation between CATPRS-teacher and -parent rating and several BRIEF domains. Feasibility testing output also included the training procedure guideline. The present study indicated that the Indonesian computer-based game prototype could be used as a framework to develop a fixed computer-based game intervention for children with ADHD. However, further randomized controlled studies need to be conducted to show its effectiveness.

1. Introduction

Attention deficit/hyperactivity disorder (ADHD) is a neurodevelopmental disorder commonly found in elementary school-age children [1]. The worldwide prevalence of ADHD is 3%–15% [2, 3]; however, exact numbers have not been reported in Indonesia. A study conducted by Suryani et al. (2011) in Jakarta, the capital of Indonesia, found that the proportion of children with ADHD in grades 1–6 was approximately 26% [4, 5]. Some studies reported that executive function played an important role for all individuals, including children with ADHD [3, 6]. It is a higher-order cognitive process with multidimensional functions, such as working memory, planning, organizing, response inhibition, cognitive and mental flexibilities, initiation, problem solving, and analytical skills [3, 6, 7]. Furthermore, executive function influences individuals to optimally perceive stimuli from the environment, respond appropriately, transform in flexible ways, anticipate future plans, consider consequences, and react in a significantly more cohesive way [8, 9]. For example, Martino et al. (2017) suggested that children with ADHD experienced an executive dysfunction because they had deficits in controlled processing task, such as during Visual Information Processing

* Corresponding author.
E-mail address: twiga00@yahoo.com (T. Wiguna).

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Task and Clock Test. Moreover, the study also showed that deficit in executive function among children with ADHD can be partially associated to difficulties in the automatic processing of their basic learning skills such as in reading and mathematic abilities [10] Consequently, it is directly related to the entire learning process and reflects the individual's capability to assimilate and accommodate every stimulus.

More than 50% of children with ADHD demonstrate significant impairment in executive function, affecting their academic achievement and ability to develop optimal decision-making skills [4, 10]. Individuals with ADHD experience brain dysfunction in several regions, such as the fronto-cingulo-striato-thalamic and fronto-parieto-cerebellar networks, that mediate multisystem impairments of cognitive control, attention, timing, and working memory [5, 11, 12, 13]. Changes in dopamine transporter activity in the dorsolateral prefrontal cortex (DLPFC) are also associated with decreased dopaminergic and noradrenergic activities in those regions, leading to the occurrence of ADHD symptoms and executive dysfunction [14, 15, 16].

Psychostimulant medication is the primary choice for ADHD. It augments synaptic levels of dopamine and catecholamines by blocking their reuptake, thereby resulting in decreased ADHD symptoms, which eventually increases the quality of daily functioning, including learning capability [17]. A meta-regression analysis showed that psychostimulants had a small-to-moderate effect in several domains of executive function, such as response inhibition, working memory, and sustained attention, independent of age in children and adults with ADHD [18]. Another study found that psychostimulants improved performance in mental flexibility (71.4%) and inhibitory control tasks (69.7%) of individuals with ADHD. In addition, it only showed a 50% improvement in the working memory task [17]. Thus, all problems in executive function associated with ADHD are not remitted or have long-term benefits of medications. Consequently, children with ADHD may continue to show learning difficulties, having trouble following instruction and remaining reckless and distracted.

In the last decade, numerous studies have reported the use of computer-based game training as an alternative approach to target ADHD clinical symptoms and executive function. However, the results have been inconsistent [16, 19, 20]. Nouchi et al. (2012) reported that healthy young adults trained 5 times/week for 4 weeks with computer-based game interventions, such as with Tetris and Brain Age, showed improved executive function [21]. Another study on computerized cognitive remediation training that focused to enhance cortical activation and strengthen cortical connections is assumed to have a direct effect on ADHD symptoms and other goal-directed behaviors [19]. Cortese et al. (2015) reported that computer-based game training improved the working memory of children with ADHD but had less effect on ADHD clinical symptoms. Therefore, the study recommended that training should be paired with medication for better results [22]. Furthermore, several studies also mention the usefulness of computer-based instructional tools such as, hypermedia learning tools, Pedagogical Agents in computer-assisted instruction (CAI), and interactive virtual agents (interactive avatars) for children with ADHD particularly to enhance their selective and focus attention in their daily activities i.e. studying, understanding basic instructions at school, and performing a better problems solving skills [23, 24, 25]. In addition, a computer-based intervention may consistently provide an enjoyable experience for children. Thus, instead of a pleasurable time, it may also trigger the child's brain activity and neuroplasticity [26].

The National Institute of Mental Health in 2014 launched the ADHD Research Domain Construct (RDoC), which was developed based on several theoretical reviews that explained specific functions of brain circuitry could be stimulated in a particular way to improve ADHD clinical symptoms and executive function. ADHD RDoC comprised complex theoretical reviews that explained the association among several domains of ADHD behavior functioning, neuroscience components, and basic engineering principles to build a robust software architecture into computer-based game platforms [27, 28]. Baroni and Castellanos (2015) and Benyakorn et al. (2016) suggested that ADHD RDoC should have three components for consideration when designing intervention technology for ADHD. The three components were based on the ADHD symptomatology, comprising schedule setting (included specific goals, task completion, and time management), difficulty matching (included the current level of child adaptation style and what should be changed to modified their behavior), and immediate feedback, which may be salient and occurred in time when the behavior was modified. The three components were divided into six subcomponents: reward-related processing, inhibition, sustained attention, timing, arousal, and emotional lability [29, 30]. Moreover, computer-based game training may be better if it can create a cognitive rehabilitation atmosphere that affects the organization and reorganization of synapses (neuroplasticity) in response to input stimuli maintained to improve the new learning skills [25].

Therefore, this study was aimed at developing the Indonesian computer-based game prototype for children with ADHD that targeted to improve ADHD clinical symptoms and executive function (inhibition, working memory, planning/organization, material organization, emotional control, shifting, and initiation) following the theoretical framework of ADHD RDoC. It was also aimed at conducting a feasibility study of the Indonesian computer-based game prototype among children with drug-naïve ADHD.

2. Material and methods

This study was performed in five steps (Figure 1). The first to third steps were designed as an exploratory qualitative study [28]. The main purpose of this part was developing the Indonesian computer-based game prototype construct. The Delphi technique was applied through a focus-group discussion (FGD) to gather information from experts. The FGD involved three experts from the Indonesian Game Laboratory Group in the Faculty of Computer Science of the Bina Nusantara International University, three child psychiatrists, and one neuropsychiatrist from the Department of Psychiatry of the Faculty of Medicine Universitas Indonesia-dr. Cipto Mangunkusumo General Hospital. Moreover, FGDs included three children under the age of 12 years to collect information on their perception according to the design of computer-based game training for children. Furthermore, FGDs addressed several frameworks that translated ADHD clinical symptoms (based on CATPRS) and executive function (BRIEF) into computer-based game coding, including transforming the input and output data into a single computer-based game platform that could stimulate the brain and reduce ADHD clinical symptoms and executive function. Furthermore, FGDs referred to studies by Cortese et al. (2015), Orban et al. (2014), and Ballesteros et al. (2018) [22, 31, 32]. During the study, ten FGDs discussed; (1) the first step: FGD of idea and concept; the discussion included the game concept, strategy, visual appearance, character and interactivity of players, playing hours that could improve ADHD clinical symptoms and executive function; (2) the second step: FGD of the game design, included genre, game mechanics (game data and game engine), play mechanics, and play experience. In this step, the game designer presented the visual theme, character, environment, story board, distractor, and leveling of the computer-based game prototype; (3) the third step: FGD of the technical game analysis; the discussion included the programming technique of the Indonesian computer-based game prototype framework and software and selected the exact game engine, data management, computer-based game performance, and optimization. Each FGD was recorded and transcribed into text.

The fourth step outcome was the programming/development of the computer-based game prototype by starting to input data that were required to build a prototype, such as handling visuals, animations, sounds, dynamic objects, etc. The Unity game engine was used in this prototype. This part was done by the game designer specialists from the Faculty of Computer Science of the Bina Nusantara International University.

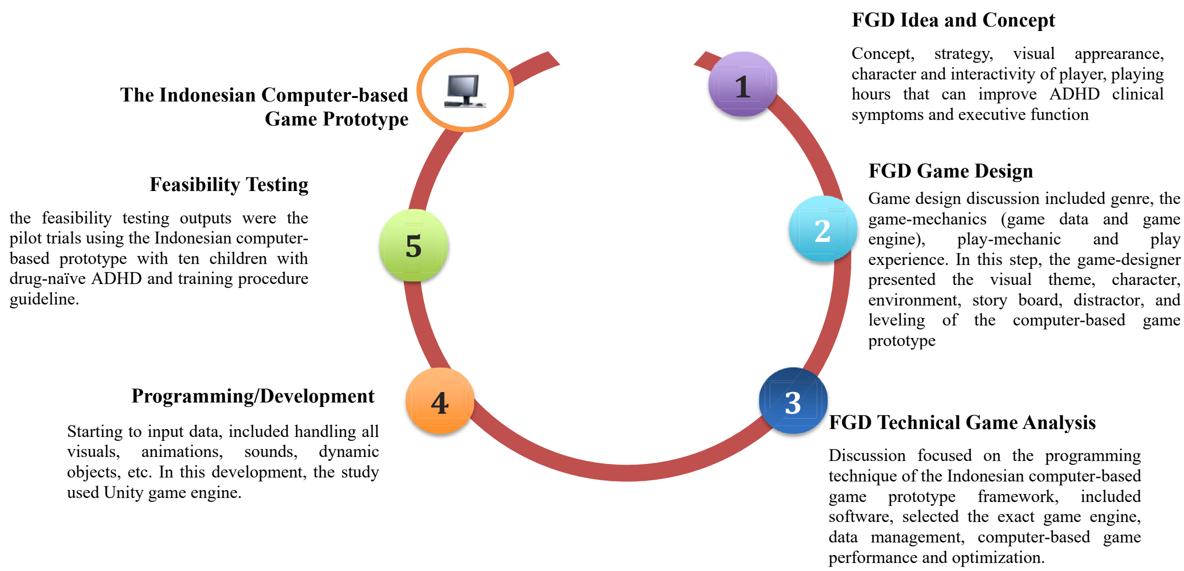


Figure 1. The Five-steps model of the Indonesian computer-based game prototype development.

The fifth step: Feasibility testing of the Indonesian computer-based game prototype was arranged as a one-group pre- and post-test design. It included 10 children with drug-naïve ADHD aged 7–12 years without chronic physical or mental illnesses [21]; they were interviewed and selected by two child psychiatrists in one public elementary school in Central Jakarta, Indonesia. They were trained with the prototype for 20 sessions (each session of 30 min) in 4 weeks. Each session of the training consisted of four parts: visual instruction without any distractors, auditory instruction without any distractors, visual instruction with distractors, and auditory instruction with distractors. Every part was designed for approximately 7 min of playing. Prior to the training session, all subjects joined in one tutorial session that aimed to explain goals of training, rules of the procedure, tasks to be accomplished, and to practice the game controller. After completing training, they were asked to report their experiences individually as feedback. Furthermore, the feasibility study was aimed at answering the question of whether or not the prototype training affected ADHD clinical symptoms (measured using the Connors' Abbreviated Teacher Parent Rating Scale [CATPRS]) and executive function (measured using the Behavioral Rating Inventory for Executive Function [BRIEF]) rated by parents. In the fifth step, output also included the training procedure guideline of the Indonesian computer-based game prototype intervention. The Ethics Committee of the Faculty of Medicine University of Indonesia, Jakarta, Indonesia, approved the research protocol (reference number: 187/UN2.F1/ETIK/2017).

2.1. Instruments

2.1.1. Behavior Rating Inventory of Executive Function (BRIEF)

The BRIEF is a parent-rating questionnaire developed by Gioia et al. to evaluate executive function in children aged 5–18 years [33]. In this study, parents completed the questionnaire before and after children completed their training by observing their children's daily behavior at home and at school. An Indonesian version of the BRIEF has been validated by the Department of Psychiatry of the Faculty of Medicine Universitas Indonesia-dr. Cipto Mangunkusumo General Hospital. The questionnaire consists of 86 statements rated on a 3-point Likert scale (1 = never happened, 2 = sometimes happened, 3 = always happened) and is categorized into 8 clinical domains: inhibition, shift, emotional control, initiation, working memory, planning/organization, organization of material, and monitor scales. In addition to sub-scores in each of the domains, the BRIEF also yields summary index scores, including the Global Executive Composite (GEC), an addition of the whole items from eight clinical domains; the metacognition index (MI), an addition of initiation, working memory, planning/organization, monitoring, and organization of material items; and the Behavioral Regulation Index (BRI), an addition of inhibition, shift, and emotional control items. BRIEF raw data were converted into *T*-scores, with higher *T*-scores reflecting a disturbance in each domain of executive function. The BRIEF data in this study appeared to be valid, as the inconsistency level was less than 9 and the negativity level was less than 7 [14].

2.1.2. Connors' Abbreviated Parent Teacher Rating Scale

The CATPRS is a 10-item scale used to quantify the symptoms of ADHD among children. This questionnaire has been validated in the Indonesian language by the Department of Psychiatry of the Faculty of Medicine Universitas Indonesia-dr. Cipto Mangunkusumo General Hospital in 1992 with good reliability (Cronbach's $\alpha = 0.973$). In this study, parents and teachers completed the questionnaire twice: before and after children completed their training. The CATPRS score ranged from 0 to 60.

2.2. Data analyses

Qualitative data were analyzed using a framework analysis. The analysis consisted of several stages: familiarization of qualitative data, identifying a thematic framework, mapping and interpreting the results, and formulation and presentation in text. The feasibility study data analysis was performed to find the mean differences between BRIEF and CATPRS before and after 20 sessions of training by using the paired t-test (Data were normally distributed by using the Shapiro–Wilk normality test and the parametric data analysis was applied). However, the mean differences of CATPRS-Teacher Rating, BRIEF-Emotional Control, and BRIEF-Behavior Regulation Index before and after 20 sessions of training were not distributed normally. Thus, the correlation analysis was applied in two different ways (Spearman's-rank-order correlation test and Pearson's correlation analysis). All statistical analyses were performed using SPSS version 21 for Mac (IBM, Armonk, NY). Statistical significance in all analyses was set at $p < 0.05$.

3. Results

The main goal of the study was to develop the Indonesian computer-based game prototype, and it was generated into five steps, including a feasibility testing. The framework analysis results were the Indonesian computer-based game prototype construct and general agreement towards the Indonesian computer-based game prototype. Meanwhile, the feasibility testing outputs were the pilot trials using the Indonesian computer-based prototype with ten children with drug-naïve ADHD and training procedure guideline.

3.1. Indonesian computer-based game prototype construct

The Indonesian computer-based game prototype was designed as a serious cognitive game intervention. The construct was generated from ADHD clinical symptoms (CATPRS) and executive function (BRIEF). The computer-based game prototype was described as a role-playing game intervention. Children with ADHD acted as a fruit car driver (a green car). They were provided with specific goals to be accomplished. The instructions were delivering fruits of a specific color (orange, red, purple, yellow, etc.) to houses of the specific color (blue, red, orange, green, etc.) repeatedly in order using auditory and visual instructions. There were two types of stimulation, i.e., with and without-distractors, which were defined by cars appearing simultaneously on the screen to be avoided by the subjects during the delivery process. The expert agreement of the Indonesian computer-based game prototype construct comprised the following six components:

a. Reward-related processing to reduce inattentive and hyperactivity-impulsivity symptoms. This processing is assumed to be related to alteration of dopamine systems. Therefore, activities or computer-based games need to be designed to stimulate dopamine release, such as role-playing (acted as a fruit car driver) and giving challenging tasks (deliver fruits of a specific color to houses of the specific color and distractors that needed to be overcome, including time limitation). Every time subjects delivered a specific color of fruit to a specific color of house correctly, the computer makes a nice sound. It is the only reward they got, and there were no other rewards during training to avoid the tendency to focus on immediate rewards, which may become a training bias.
b. Inhibitory control, reduced inattentive, hyperactivity-impulsivity symptoms, and improved working memory. One gamification technique that can be used to improve inattentive, hyperactivity-impulsivity symptoms, and working memory was to train self-monitoring skills that made children with ADHD become aware of their own goal-directed behaviors (as a fruit car driver to deliver fruits into the house of the specific color correctly) (Figure 2b). The computer-based game prototype had core mechanical qualities and followed the "Go/No-go" tasks combined with and without distractors, and it was done using the point-to-point game concept and matching technique that could improve focus and self-monitoring.
c. Improved sustained attention, organization skills, and working memory. The game construct using technology that tracked children sustained attention by recording the ability to correctly memorize the fruit color that needed to be delivered to a specific-color house, when it was coupled with distractors (cars) that came on the computer screen simultaneously in real-time. During the delivery process when the subjects stopped in front of the correct house, the computer screen showed three different colors of fruit but not if they picked the wrong house. Thus, subjects chose one correct fruit from those three different colors of fruit to be delivered (Figure 2c). The software provided continuous monitoring of instructions and distractor appearances along with tasks that needed to be accomplished.
d. Specific timing of training to improve organization skills. The computer-based game prototype was designed to improve time-management skills associated with inattention, hyperactivity-impulsivity, organization, and inhibition. Therefore, the total duration of the Indonesian computer-based training was designed for approximately 30 min of playing time. The faster they correctly finished the instructions meant they gained better motor timing, perceptual timing, and temporal foresight skills.
e. Regulating arousal and improving initiation skills. The computer-based game prototype was designed to regulate arousal. The Indonesian computer-based game prototype had the qualities to control distractors in order to accomplish the tasks (delivering a fruit of a specific color to a house of the specific color correctly and overcome the distractors) (Figure 2d). Once subjects delivered a specific color of fruit to a specific color of house correctly, the computer makes a nice sound that kept them aroused during the training and it may trigger the initiation skill respectively.
f. Improved emotional regulation and reduced hyperactivity-impulsivity symptoms. The computer-based game prototype was designed to improve emotional regulation. The computer-based game prototype did not mention any points on whether they correctly or incorrectly delivered fruits, did not interact via chatting or personal data exchange, and did not show writings or images related to cigarettes, liquor, narcotics, psychotropic substances, or other addictive substances. In addition, no data showed the points that were collected during training, playing time, etc.

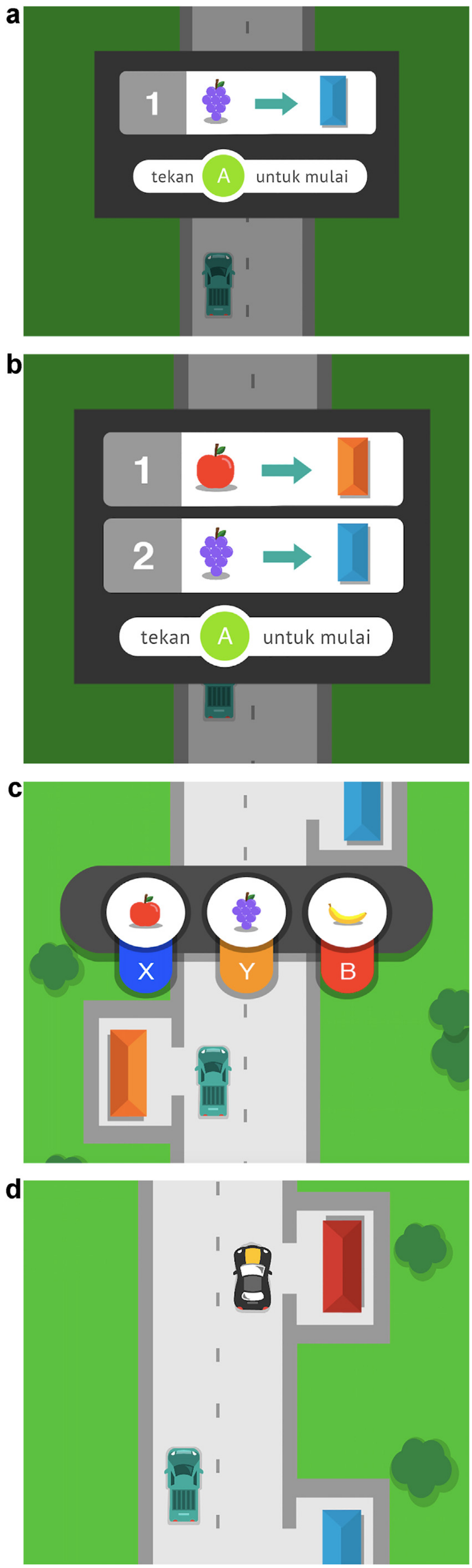
3.2. General agreement towards the Indonesian computer-based game prototype

a. The Indonesian computer-based game prototype was a serious game with training intended for health intervention, resulting in the game being used under supervision, thus differing from usual daily game application.
b. The Indonesian computer-based game prototype consisted of Indonesian local content and culture.
c. The Indonesian computer-based game could be played with a personal computer (PC) or laptop with a browser that can run HTML5 and Java script. The game can also be played in the form of execution (.exe) directly without a browser.
d. The Indonesian computer-based game prototype was described as a performance computer-based game prototype utilizing a central processing unit (CPU), an average of 60 frames per second. Image memory usage was tested in several browsers. The testing processes were performed using a desktop (Windows XPSP3, Dual-Core E5400 @ 2.70 GHz, 2GB RAM; Microsoft, Redmond, WA) and laptop (Windows 8.1 64-bit Edition, Core i3-2357M @ 1.30 GHz, 2GB RAM; Microsoft) computer. The browsers tested included Google Chrome (ver.60.0.3112.90; Google, Mountain View, CA), Firefox (ver.54.0.1; Mozilla Foundation, Mountain View, CA), and Opera (ver.46.0.2597.32; Opera, Oslo, Norway). The total size of the file was approximately 450 kB for a browser or approximately 1.4 MB for the execution file.

3.3. Results of feasibility testing of the Indonesian computer-based game prototype

The mean age of research subjects was 8.6 $\pm$ 1.35 years, and most of them were male (9 males, 1 female). Six children were diagnosed with combined-type ADHD, and the rest had inattentive-type ADHD. All research subjects' parents had at least a senior high school degree and above and a low-to-middle socioeconomic status. All subjects were right-handed, and none suffered from intellectual disabilities. During the 20 training sessions, there was no difference in the daily activities or nutrition of the research subjects. In addition, all subjects completed the training, and there were no adverse events or complaints during the training. The feedback from the subjects was that the game was easy to play; however, the repeated task completion throughout the sessions was tedious.

The CATPRS-teacher rating decreased significantly after 20 sessions of training (18.5 [5.31] vs. 12.9 [5.51], $p = 0.047$). The CATPRS-parent



rating was also improved after the training, but the difference was not statistically significant (Table 1). This study also revealed that the BRIEF-parent rating *T*-score decreased in all domains after 20 sessions of training. However, several domains significantly changed, such as BRIEF-GEC (64.80 [10.21] vs. 57.50 [7.51], p = 0.02), BRIEF-MI (66.1 [7.61] vs. 58.4 [7.56], p = 0.014), BRIEF-Initiate (66.6 [10.15] vs. 54.1 [6.49], p = 0.008), BRIEF-Working Memory (68.0 [6.89] vs. 60.9 [10.05], p = 0.02), and BRIEF-Organization of Material (60.7 [12.88] vs. 49.3 [11.79], p = 0.04; Table 1).

The feasibility testing revealed that both Connors' teacher and parent rating correlated with BRIEF-parent rating. Several statistically significant correlations were CATPRS-parent rating was significantly correlated with BRIEF-BRI (r = 0.596, 95% CI = 0.112–0.892, $p < 0.05$) and BRIEF-Emotional Control (r = 0.630, 95% CI = 0.260–0.891, $p < 0.05$) (Table 2).

3.4. Training procedure guideline of the Indonesian computer-based game prototype

a. Training was done in 20 sessions (each session was around 30 min).
b. Subjects were suggested to use a headphone during the training to reduce outside noises and to receive auditory instructions.
c. During the training, subjects were accompanied by one supervisor.
d. Prior the training session, subjects were informed that they acted as a fruit-car driver. Furthermore, they were explained about the content and how to play the computer-based game prototype (included goals, rules of the procedure, and game controller function) and tasks to be accomplished. They were asked to fill out their name in the provided column respectively. In addition, subjects were asked to join one tutorial with the prototype. During the tutorial, they practiced using game controller. In this tutorial, they were asked to accomplish tasks in visual instruction (appearing on the computer screen showing a picture of one fruit of a specific color to be delivered to the house of the specific color) (Figure 2a). The tutorial was designed to last approximately 5 min with around 5–7 tasks in order. An indicator was set to assess that subjects had understood and were familiar with the computer-based game procedure, i.e., the number of fruits that was correctly delivered to the house of the specific color. They needed to an achieve 80% correct score from the whole task completion before continuing to the training session. If task completion was less than 80%, they needed to repeat the task, as it was assumed that they have not familiarized or oriented with the computer-based game procedure yet. Once the subjects were already familiar with the procedure, they did not need to re-do the tutorial for the next training. Thus, they can directly start the training session without any tutorial.
e. The training session comprised four parts: visual instruction without any distractors, auditory instruction without any distractors, visual instruction with distractors, and auditory instruction with distractors. Visual instructions appeared on a computer screen and showed fruits of two colors that should be sent to houses of the two colors in order (Figure 2). Auditory instructions came directly through headphones used by subjects and informed subjects to deliver fruits of two colors to houses of two colors in order (i.e., "Please deliver purple fruit to the red house and orange fruit to the blue house."). The distractors were

(*caption on next* **Figure 2.** The computer-screen appearance of the Indonesian computer-based game prototype. (a) The visual instruction that appeared on the computer-screen during the tutorial.Whenever subjects were ready to start the delivery, they need to push the "A" symbol on the game controller. (b) The visual instruction that appeared on the computer-screen during the training session.Whenever subjects were ready to start the delivery, they need to push the "A" symbol on the game controller. (c) The visual appearance on computer-screen if subjects picked a house with specific color correctly. They need to choose a correct fruit by push the "X", "Y" or "B" sign on the game controller. (d) The visual appearance on computer-screen when there was any distractor (a black car) that should be avoided by subjects during the delivery process.

Table 1. CATPRS and BRIEF before and after 20 training sessions with the Indonesian computer-based game intervention (n = 10).

Characteristics	Mean (SD)		Mean difference (SD) before and after 20- sessions training	95% confidence interval of the mean difference	p-value
	Before the Indonesian computer-based game prototype training	After 20-sessions training with the Indonesian computer-based game prototype			
CATPRS teacher rating	18.5 (5.31)	12.9 (5.51)	5.6 (7.69)	0.098–1.10	0.047[a]
CATPRS parent rating	15.5 (4.35)	12 (5.7)	3.5 (6.2)	-0.94–7.94	0.108
BRIEF GEC[b] *T*-score	64.80 (10.21)	57.50 (7.51)	7.1 (7.94)	1.42–12.78	0.020[a]
BRIEF BRI[b] *T*- score	60.1 (13.10)	53.3 (12.29)	6.8 (15.73)	-4.45–18.05	0.205
BRIEF MI *T*-score	66.1 (7.61)	58.4 (7.56)	7.7 (8.06)	1.94–13.41	0.014[a]
BRIEF-Inhibition *T*-score	59.6 (11.34)	53 (12.64)	6.6 (10.62)	-0.99–14.19	0.081
BRIEF-Shift *T*-score	56.8 (9.07)	53.6 (10.32)	3.2 (12.05)	-5.42–11.82	0.423
BRIEF-Emotional control *T*-score	57.3 (14.51)	55.1 (12.65)	2.2 (16.82)	-9.84–14.24	0.689
BRIEF-Initiate *T*-score	66.6 (10.15)	54.1 (6.49)	12.5 (11.58)	4.22–20.78	0.008[a]
BRIEF-Working Memory *T*-score	68.0 (6.89)	60.9 (10.05)	7.1 (7.94)	1.42–12.78	0.02[a]
BRIEF-Plan/Organize *T*-score	63.8 (5.87)	61.5 (8.09)	2.3 (7.99)	-3.41–8.01	0.386
BRIEF- Organization of Material *T*-score	60.7 (12.88)	49.3 (11.79)	11.33 (10.39)	0.43–22.23	0.04[a]
BRIEF-Monitor *T*-score	60.3 (9.71)	52.7 (8.27)	7.6 (12.32)	-1.21–16.41	0.083

[a] Statistically significant ($p < 0.05$).
[b] GEC = Global Executive Composite, a summation of the 8 clinical domains; MI = metacognition index, a summation of initiation, working memory, plan/organize, monitor, and organization of material domains; BRI = Behavioral Regulation Index, a summation of inhibition, shift, and emotional control domains.

Table 2. Correlations between the mean differences of CATPRS, and BRIEF before and after 20 sessions of training with the Indonesian computer-based game (n = 10).

Mean difference of BRIEF	Correlation coefficient (95% confidence interval)	
	Mean difference of CATPRS-Teacher Rating before and after 20 sessions of training	Mean difference of CATPRS-Parent Rating before and after 20 sessions of training
Mean difference of BRIEF-GEC[c] before and after 20 sessions of training	0.368 (-0.428 – 0.965)[a]	0.558 (-0.146 – 0.923)[b]
Mean difference of BRIEF-BRI[e] before and after 20 sessions of training	0.238 (-0.711 – 0.747)[a]	0.596 (0.112–0.892)*,[a]
Mean difference of BRIEF-MI[d] before and after 20 sessions of training	0.511 (-0.327 – 0.997)[a]	0.397 (-0.311 – 0.868)[b]
Mean difference of BRIEF-Inhibition before and after 20 sessions of training	0.276 (-0.438 – 0.816)[a]	0.464 (-0.421 – 0.881)[b]
Mean difference of BRIEF-Shift before and after 20 sessions of training	0.277 (-0.545 – 0.955)[a]	0.100 (-0.502 – 0.683)[b]
Mean difference of BRIEF-Emotional Control before and after 20 sessions of training	-0.130 (-0.711 – 0.747)[a]	0.630 (0.260–0.891)*,[a]
Mean difference of BRIEF-Initiate before and after 20 sessions of training	0.254 (-0.549 – 0.905)[a]	0.545 (-0.345 – 0.981)[b]
Mean difference of BRIEF-Working Memory before and after 20 sessions of training	0.466 (-0.384 – 0.980)[a]	0.159 (-0.590 – 0.780)[b]
Mean difference of BRIEF-Plan/Organize before and after 20 sessions of training	0.214 (-0.633 – 0.874)[a]	0.118 (-0.518 – 0.734)[b]
Mean difference of BRIEF-Organization of Material before and after 20 sessions of training	0.398 (-0.411 – 0.835)[a]	0.135 (-0.728 – 0.919)[b]
Mean difference of BRIEF-Monitor before and after 20 sessions of training	0.370 (-0.430 – 0.988)[a]	0.477 (0.045–0.880)[b]

[a] Spearman's rank-order correlation.
[b] Pearson's correlation.
[c] GEC = Global Executive Composite, a summation of the 8 clinical domains.
[d] MI = metacognition index, a summation of initiation, working memory, plan/organize, monitor, and organization of material domains.
[e] BRI = Behavioral Regulation Index, a summation of inhibit, shift, and emotional control domains.
[*] $p < 0.05$.

several moving cars appearing simultaneously on the computer screen. Subjects should organize, plan, and find ways to overcome the distractors and simultaneously remember instructions to avoid the wrong delivery. The instructions were delivered randomly to avoid memorization.

f. When the session was over, the software would resume the total number of fruits delivered correctly, total number of houses picked correctly, total number of fruits delivered incorrectly, total number of houses picked incorrectly, and time needed to remember each instruction (both visual and auditory instructions). The whole data did not disclosed to the subjects.

4. Discussion

ADHD is a complex and heterogeneous disorder with cross-situational impairment [32]. Therefore, the National institute of Mental Health Research Domain Criteria (RDoC) suggested a framework that can be referred to design advanced intervention equipment, particularly when using recent technologies, such as computer-based gaming, machine learning, or other technologies [24]. The principle of the ADHD RDoC framework considered implementing the developmental psychopathology framework because ADHD is classified as a neurodevelopmental disorder in DSM 5, and symptoms of ADHD are associated with many other common mental disorders, such as depression or anxiety, and ADHD is highly comorbid with others mental illnesses. Finally, ADHD symptoms remit gradually throughout child development [32]. Based on the aforementioned explanation, the ADHD RDoC framework mostly focused on clinical symptom development and cognitive or executive function, which included Barkley's Self-Regulation Theory, Nigg's Multiple Pathway Model, and other related theories explaining the association between ADHD clinical symptoms and executive function [32, 33].

This study described the Indonesian computer-based game prototype development that comprised five steps. The first to third steps particularly focused on the Indonesian computer-based game prototype construct development. The construct described the prototype as a fruit-delivery game; subjects were asked to deliver fruits of certain color to houses of certain color. During training, there were two types of stimulation, i.e., without and with distractors, that needed to be avoided to deliver the fruit to the house correctly. The visual or auditory instructions forced the subjects to read or listen to the instructions patiently and carefully, control the impulsive urges to obey the instructions, sit still during the training, memorize the tasks, and follow the game rules precisely or risk failing. Moreover, the prototype tasks did not only ask the child to remember the colors of the fruit to be sent to the house of the specific color but also cover multiple aspects of executive function, such as planning (to overcome distractors that came in order), organizing (delivery of the fruit in order, as instructed), inhibiting impulses, emotional regulation, and shifting attention between one instruction and another, time managing to fulfill the maximum efforts during training. Therefore, the construct is designed to reduce ADHD symptoms (such as inattentive symptoms and hyperactivity-impulsivity symptoms) and improve executive function, such as initiation, working memory, organization skill, inhibition skills, planning, and emotional regulation to avoid boredom and disappointment.

The feasibility study results showed that persistent, consistent, and continuous stimulation with the Indonesian computer-based game prototype 20 times in 4 weeks improved ADHD clinical symptoms and executive function. It possibly improved the DLPFC functional connectedness. The hypothesis that arose from the feasibility results was that the Indonesian computer-based game prototype stimulated the DLPFC that was an important part of the brain for central executive function and responsible for many other mental processes, such as selectively adding and removing certain information, organization skills, planning and emotional regulation, and working memory so that children could accomplish tasks given to them, operating on certain tasks or information while concurrently organizing similar or other information, mentally influencing the time-order of held information from short-term memory into long-term memory, and minimizing non-relevant information to access relevant stored information [34]. Several studies showed that DLPFC impairment might trigger central executive dysfunction related to inattentive, hyperactivity, and impulsivity symptoms of ADHD [35, 36, 37, 38]. Although not all findings of this study were statistically significant, from a clinical perspective, they provide some insight into the benefits of training to alleviate ADHD clinical symptoms and improve executive function by improving DLPFC functional connectivity. However, further studies with better design should be performed to gain more understanding and provide stronger evidence of these processes.

Dominguez et al. (2015) explained that the circuit of the DLPFC is an important part of the brain that regulates sustained attention and problem solving. Activation of the DLPFC circuit could lead to task completion, material organization, behavior regulation, and general enhancement of executive function and optimization of brain functioning. A previous study that used an n-back test and functional near-infrared spectroscopy revealed that activating DLPFC could improve executive functioning [39]. Directly stimulating the DLPFC with transcranial stimulation also showed a faster and more accurate outcome of executive function tasks [40]. Moreover, Mohammadhasani et al. (2018) and Fabio et al. (2019) designed a Pedagogical Agent in CAI in virtual environment to increase learning motivation, interest, problem solving, and focus attention on educational stimuli for children with ADHD. The studies revealed that Pedagogical Agent CAI in virtual environment might improve student cognitive load especially in learning process of children with ADHD, because it help them to be more focus and attentive by giving them feedback on their behavior; thus enhance their dynamic intelligence test [23, 24]. It is apparent that using computer-based intervention may improve executive function, and possibly it is affected by better cognitive load, brain functional connectivity, and DLPFC plasticity. Hence, further study need to be done particularly using the functional imaging experiment design.

This feasibility testing showed that the Indonesian computer-based game prototype might be a promising intervention for children with ADHD in the near future. It is also beneficial for Indonesian children because it uses the Indonesian language; however, it can be reproduced in other languages, if necessary. In addition, the results of this study suggested that a good ADHD cognitive training program should be more stimulating to the DLPFC. Moreover, the study revealed a mild to high correlation between mean differences of ADHD clinical symptoms and executive function after 20 sessions of training. Therefore, this finding demonstrated a much stronger evidence of the association between executive dysfunction and ADHD clinical symptoms. Davidson et al. (2016) suggested that executive function should be assessed as a separate diagnostic test in children with ADHD to predict the overall level of behavioral impairment [11]. Thus, a specific intervention approach to enhance executive function in children with ADHD is necessary.

The strength of this study was presenting the steps of Indonesian computer-based game prototype development, including the feasibility testing. In addition, 20 sessions of training using this prototype is assumed to stimulate DLPFC functional connectedness. Therefore, further studies should be performed, particularly using functional magnetic imaging to test this hypothesis. However, there are two important limitations. First, feasibility testing was performed in a limited number of subjects, without any control, and the computer-based game prototype could not be utilized by color-blindness subjects. As further recommendation, the effectiveness study of the Indonesian computer-based game prototype needs to be conducted with a proper research design and an appropriate number of research subjects, particularly regarding long-term effectiveness and sustained improvement of ADHD symptoms and executive function. In conclusion, this research is in an early stage, but our findings could be referred to as pilot data to fabricate a significantly more sophisticated computer-based game intervention for children with ADHD in the near future.

Declaration

Author contribution statement

Tjhin Wiguna: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Raden Irawati Ismail: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Fransiska Kaligis: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Kusuma Minayati: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Belinda Julivia Murtani: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Ngurah Agung Wigantara, Kent Pradana: Contributed reagents, materials, analysis tools or data; Wrote the paper.

Raymond Bahana, Bayu Prakoso Dirgantoro: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data.

Eko Nugroho: Conceived and designed the experiments; Performed the experiments.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

The clinical trial described in this paper was registered at ClinicalTrials.gov under the registration number (NCT04329663).

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