International Journal on Advanced Science Engineering Information Technology

Vol.10 (2020) No. 5
ISSN: 2088-5334

The Construction of Computer-based Application of Working Memory Test for Early Age Children in Indonesia

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***Abstract*— Working memory (WM), a central component of executive function (EF) which facilitates the capability to store and modulate information, develops rapidly during early childhood, and has proven to contribute to children's academic achievement. WM generally has two types of measures, each of which mainly involves the WM's verbal and visuospatial aspect. However, research on the standardized and developed assessment of WM aspects for early age children in Indonesia remains inadequate, especially embedded with information technology. This study aimed to develop a WM measurement tool using a computer-based application test to support the integration between the computer-based and behavioral measurements of WM aspects in early age children. Construct validity of the WM computerized test was determined by comparing the conventional and computerized EF tests on 36 children (15 boys and 21 girls) age 48-72 months old. Two computerized WM tasks that specified WM's verbal aspect, namely the Backward Animal Task and Shining Star respectively, were administered individually to each child by a trained tester. The Spearman correlation analysis resulted in Shining Star as the most suitable computer-based WM task for early age children. Both conventional and computer-based measures of the visuospatial aspect of WM had similar task mechanisms and rules. They equivalently required visual and kinesthetic modalities, which emphasized the common nonverbal aspects of WM. This result provides an initiative for the evidence-based development of the computer-based WM test in Indonesia for early age children, which is critically important to help individuals with psychological and behavioral problems during Covid-19.**

***Keywords*— computer-based test; early age children; executive function; working memory.**

I. INTRODUCTION

As the global pandemic of Coronavirus perseveres, applying the new normal regulation leads to inevitable changes that demand prevalent adjustment in many sectors. One of the significantly affected job sectors in human services due to this restriction is practitioner psychologists whose work scope involves direct face-to-face interaction with their clients during psychological assessment or intervention. However, they are currently forced to perform their practices remotely via online to prevent further Covid-19 transition. Unfortunately, the innovation of information technology-based tests for psychological assessment and interventions in Indonesia is relatively less developed than the conventional ones, hence the restricted practices in helping individuals and groups with mental and behavioral problems during the pandemic. This study aimed to develop a psychological test of working memory (WM), one of the core components of higher-order neurocognitive skills called executive function (EF).

EF is a set of neurocognitive skills consisting of planning, monitoring, modulating, and emotion and behavior regulation skills considered as determining factors that contribute to an individual's capacity to adapt to their surroundings [1]. Working memory (WM), which is one of EF's main components, enables storing and modification of required information to meet social demands [2]. Together with other EF components, namely inhibitory control and shifting, WM facilitates an individual to maintain a mental representation of memories and rules relevant to the ongoing context [1]. Thus, the individual can manifest a self-regulated behavior that is fully conscious, which is required to accomplish his or her goals.

Theoretically, WM involves multimodal encoding of several underlying systems. One type of system is known as the slave systems, consisted of the phonological loop and the visuospatial sketchpad. Whereas the other has a role as the central executive and episodic buffer [3], [4]. The phonological loop takes charge of provisional auditory-verbal information and stores it for a mere couple of seconds.

Thus, the act of rehearsing and articulating verbal information is necessary to activate the memories before they decline. For example, immediate recall of a sequential order after the objects are presented serves as memory maintenance as well as the recording of pieces of information of the named objects [4].

Meanwhile, the visuospatial sketchpad is responsible for processing nonverbal information, such as visual, spatial, and kinesthetic aspects. This aspect is central to maintaining close attention to integrate colors, locations, and shapes of an object required to activate and preserve the memories [3], [4]. Besides, although it is less associated with language, the visuospatial sketchpad is involved in maintaining mental representations of a page arrangement and proper eye movement while reading, as well as grammatical structure in general [4].

On the other hand, the central executive lacks a memory storage mechanism. Nonetheless, it plays a significant role in monitoring and coordinating the two underlying slave systems, i.e., the phonological loop and the visuospatial sketchpad. In addition, it also manages another system called the episodic buffer. The term "episodic buffer" [3] is temporary storage that combines information from the phonological loop, the visuospatial sketchpad, and the long-term memory (LTM) (e.g., Fig. 1). This system enables individuals to activate memories directly associated with the verbal and nonverbal stimuli and link this information with memories formerly stored in the LTM [3], [4].

Typically, WM experiences rapid growth during the early childhood period [5]. According to Piaget's object permanence theory, WM's development is manifested by the time the child can store online memory of a previously hidden object since as early as 7,5 months old [6].

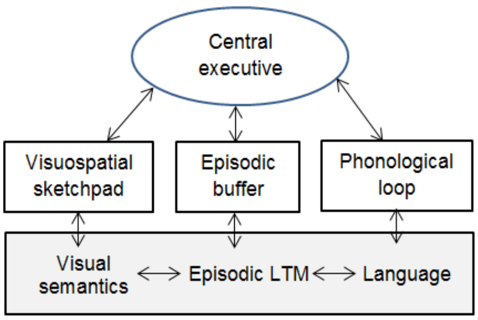

Fig. 1 WM Model [3]

Furthermore, 12 months old infants also showed the capability to memorize the new location of an object previously hidden in a different place through A-not-B-task. Physiologically, basic WM skill requires the activation of dispersed parts of the brain during the first year of life. However, the functional localization employed during the performance of a WM task is already formed in the frontal lobe at age 4, which indicates a rapid brain development in preschoolers.

In due course, the typical neural development facilitates the establishment of specialization and interconnection between WM brain areas. Different WM aspects activate different regions of the brain [3]. For instance, the Brodmann area number 40 and 44 in the brain are activated by encoding verbal related memory, which facilitates the phonological loop. On the other hand, the brain's right hemisphere, such as area 6, 9, 40, and 47, are activated by the visuospatial sketchpad stimuli. Although central executive and episodic buffer usually involve several parts of the brain concurrently, both are considered to rely heavily on the frontal lobe activation.

Concerning WM's role, previous studies reported a meaningful contribution of WM in facilitating language, arithmetic, and reading skills, which contribute to the child's academic achievement [7]. Specifically, a deficit in WM's verbal aspect is associated with subpar language skill, while lacking in the spatial aspect of WM led to low literacy, comprehension, and arithmetic skills [8]. Children with a neurodevelopmental disorder, such as dyslexia and dyscalculia, are associated with deficits in verbal-auditory modality related to WM's phonological loop aspect and the visuospatial sketchpad aspect of WM, respectively [9]. Meanwhile, the Attention Deficit and Hyperactivity Disorder (ADHD) is also associated with deficits in WM related to EF [9], which significantly influence the aspects of academic performance and social interaction. These findings highlight the importance of WM's contribution to a child's developmental milestone and future achievement.

Besides WM's crucial contribution to language and academic achievement, stress regulation is also known to directly impact WM performance. The letter fluency task, which measured verbal WM among healthy student participants, predicted acute stress responses due to reduced attentional control that caused a lack of mental representation and retrieval of the verbal memory [10]. Furthermore, a child's trait anxiety leads to deficits in central executive functioning, which negatively impacts WM performance [11]. Therefore, WM is predicted as one of the most important psychological assessment components at the time of the Covid-19 pandemic, which serves as an indicator of stress regulation ability. Additionally, an intervention based on enhanced WM performance may also be considered for further stress reduction treatment to overcome stressful situations due to the pandemic.

In general, WM tasks were developed [12] and employed [13], both auditory and visual modality, respectively. These tasks are administered using the conventional method with manual scoring. Initially, WM tasks were developed by conventionally measuring the performance through behavioral observations on tasks such as the Backward Digit Span task [12] and the Corsi Block task [14]. Consequently, a conventional battery of EF tasks was developed [15], some of which particularly measure the WM aspects, that is made compatible for children in Indonesia. Although these tasks were already adapted into Bahasa, several limitations were found due to technical shortfalls while collecting the data, especially in terms of time precision and storage efficiency.

To date, several studies have not only developed WM tasks using a conventional procedure but also with a computer-based testing program for preschool children and other range of ages with both typical [16]-[18] and atypical development [19]-[20]. This computer-based administration method is considered more efficient and accurate compared to the conventional one. The computer-based WM test allows for the time efficiency regarding the duration of test administration. Besides, unlike the traditional WM test that only provides for the single scores of total correct and false responses, the computer-based WM test also records other measures, such as the reaction time and test duration. Overall, data collection and calculation automation using a computer-based application for the test cuts back on human-induced error due to any probability of mistakes in manual scoring. Moreover, given the current Covid-19 pandemic situation, the WM test's conventional administration is not favorable because it requires face-to-face interaction between the child and the administrator or tester. Therefore, a standardized computer-based WM test likely serves as the solution to this issue.

However, research on the WM measurement in Indonesia remains limited due to the lack of methodological grounding and interdisciplinary collaboration regarding technological tools that can be used to measure human mental capacity. Meanwhile, there is a surging call for the online assessment of neuropsychological measures to help psychologists substitute the conventional administration procedure with a well-suited remote option for clients' treatment and evaluation, especially during the Covid-19 during the pandemic season. Therefore, this study aimed to develop WM tasks into a computer-based test in Bahasa Indonesia. This computer-based WM test is essential to improving the data quality and efficiency and answering the challenges of the increasing needs of online assessment throughout the pandemic season. With this WM task development, a parallel study of a computer-based measurement was also being developed for other EF components, such as Inhibitory Control (IC) [21]. Both computer-based tasks employed similar software engine to support prototype for test stimuli and attain data with high precision and accuracy.

The use of a systematical data collecting method with computer-based software was designed to enhance the quality, quantity, and time reliability of data. The administration procedure of the computer-based was highly standardized to avoid human error factor. This test application software was a manifestation of the artificial cognitive system [21], which refers to a set of software utilized to interact with the child's cognitive skill. Therefore, the systematical computer-based application improved the standardizations of the WM test and administration method.

In this study, two WM tasks were developed into computer-based measurement based on the conventional ones, which were designed and adjusted for Indonesian children [15]. These tasks were tested on typically developed children between age 4 to 6 years old in Jabodetabek. Correlation analysis between each conventional and computer-based task was conducted to examine whether both tasks measured the common construct.

II. Materials and Method

The Research Ethics Committee approved all of the study procedures at the Faculty of Psychology, University of Indonesia.

A. Participants

Thirty-six children age 48-72 months old (15 boys and 21 girls) participated in this study. All participants were subjected to a screening procedure by completing parental information about the child's medical records and developmental trajectories. Children who had symptoms of any psychiatric, neurological, genetic, sensory, or chronic medical conditions and any indications of any developmental disorders are excluded from our study. Finally, only children with typical development could participate in this study.

B. Procedure

Recruitment for the data collection was managed by cooperating with kindergartens and preschools, distributing flyers, and posting the recruitment information on social media. Parents interested in this study were asked to complete the screening test. Children who passed the participant criteria were invited to make an appointment schedule for the primary data collection session at the Faculty of Psychology, University of Indonesia.

Parents of each participant were explained about the procedure of the tests before filling in the informed consent. Afterward, only those whose child passed the screening procedure and consented to participate were invited to the Faculty of Psychology, University of Indonesia, to take the test. Each child had the WM test administered individually by a trained tester in an examination room. During the test, the child was given both conventional and computer-based WM tasks, with the duration ranged from 30-60 minutes. Rewards were presented to every child who completed the tests.

C. Measurements

This study employed WM tasks using both conventional (Backward Word Span and Backward Corsi Block Span) and computer-based tasks (Backward Animal and Shining Star). The computer-based tasks were developed using *Unity Engine 5.3*, easy-to-use game-making software, which enabled the developer to build prototypes of the tasks.

The Backward Word Span used in this study originated from a previous study [12], which was later adjusted [15] to be appropriately used for early age children in Indonesia. In this task, the child was required to memorize words mentioned by the tester in a specific order. Afterward, the child was asked to recall and mention the words in a reversed order. The first level consisted of two words. The number of words increased with every level, with the highest one comprised of five words. Failure to mention the words in the correct reversed order within the three given trials on each level failed to proceed to the next level. Another conventional task was Backward Corsi Block Span, which required a retrospective recall of spatial sequences [13].

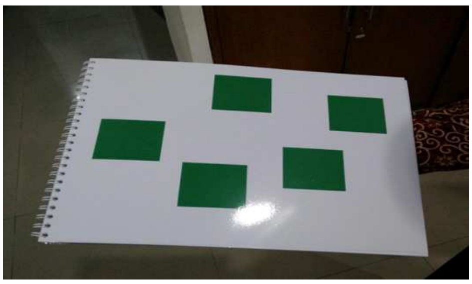

Fig 2. Backward Corsi Block Span stimuli

This task was adjusted for the early age of the children population in Indonesia [15]. This task used visual stimuli in the form of five green blocks arranged in a particular layout in a piece of paper (e.g., Fig. 2). The tester showed the child which blocks to point at in a specific order, before asking the child to point at the blocks one by one in a correct reversed order. On the first level consisted of two blocks, and the number of blocks increased each time the child succeeded in performing the instruction within three given trials on each level.

Both computer-based tasks used the same backward mechanism with different stimuli variants (e.g., Fig. 3). In the Backward Animal task, various species of animals appeared successively on the monitor. Each animal appeared with a simultaneous auditory stimulus pronouncing the name of the animal. Afterward, the monitor showed the previously presented animals in a horizontal row, and the child was asked to tap at the animals successively in reversed appearance order. On the first level, there were two animals presented. The number of animals increased with every level, with the highest one consisted of eleven animals. Only three trials can be given within each trial.

Fig 3. Example of Backward Animal task display

Shining Star task used the same backward mechanisms, number of stimuli on each level, and rules as the Backward Animal one. The stimuli employed in this task were pictures of stars with an audio effect of "sparkling" sound each time the star shined a brighter luminance and opened its eyes (e.g., Fig. 4). Failure to point at the stars in the required reversed order within three trials on each level automatically terminated the task.

Fig 4. Shining Star stimuli

C. Technical Details

Unity Engine 5.3 was used to provide android support and prototype for test stimuli, such as the auditory and visual output. It allowed rapid game development and supported Android for portable device use [23]. The WM tasks were presented through the game application to arouse the child's interest in the task. Both the Backward Animal task and Shining Star tasks used a similar mechanism.

The program generated scores from the number of stars that the child correctly tapped in backward order, while the reaction time between the appearance of the shining effect and the participant's tap was also recorded. The results were then exported into a .csv format for further analysis.

1) Backward Animal task: the workflow of this task is depicted in Fig. 5A. When the child was ready to start the task, a picture of a zoo appeared as a background on the screen. Afterward, animals were set to appear based on a predetermined sequence from the developer. The animal's names were pronounced as the picture showed up one by one within two seconds from each other. After the appearance sequence was completed, the formerly presented animals showed up on the screen all at once. The application then waited for the participant's input to be stored. The scores were derived from the number of animals the child managed to put in backward order correctly. If the child taps the animals one by one according to the correct backward order at the first attempt, the child would be automatically directed to the second level. However, if the child failed at the first chance, the same number yet different variants of animals would appear for the child's second and also third attempt. Reaction time for each trial was recorded together with the scores and automatically stored in a .csv format in the device.

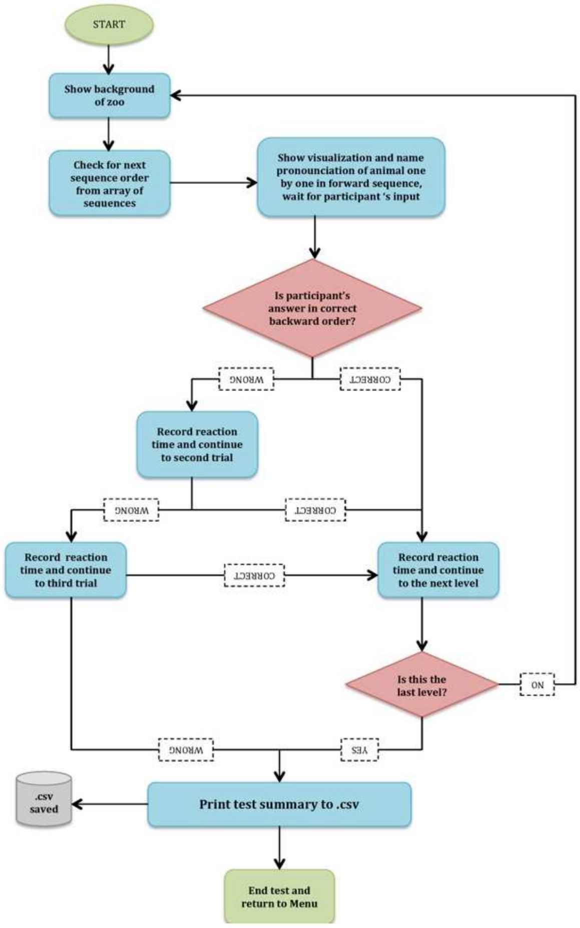

Fig 5A. Mechanism Flowchart of Backward Animal Task

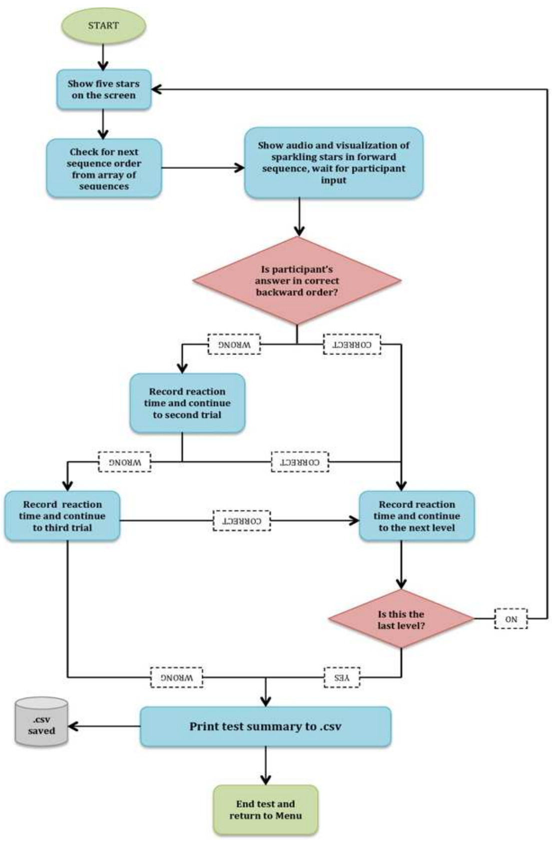

Fig 5B. Mechanism Flowchart of Shining Star Tasks

2) Shining Star task: the workflow of this task is depicted in Fig. 5B. After the child started the task, five cartoon-faced stars were displayed on the screen. At the beginning of each task, all five stars closed their eyes. Each star took a turn to shine one by one, which was displayed by the increased brightness and waking expression of the corresponding star with a sparkling sound effect. The sequence of the order was arranged beforehand in a predetermined manner. On each level, once the order is completed, a circle at the bottom left of the screen switched from red to green to give a sign for the participant to take a turn.

D. Statistical Analysis

All collected data were analyzed using SPSS. Descriptive analyses were conducted to generate detailed features of the dataset. Afterward, Spearman correlation analysis was employed to generate concurrent validity between conventional and computer-based tasks due to small sample size, hence the non-normal distribution of the data.

III. RESULT AND DISCUSSION

Before running the inferential analysis, descriptive statistics were conducted to gain an overview of the data.

A. Descriptive

The scores in conventional and computer-based WM tasks ranged from 2 to 5 and 11, respectively. Since the children were able to achieve the highest score on WM conventional tasks, the score range in the computer-based tasks was increased to capture the extent to which the child could achieve the highest score on WM tasks [11]. Based on 36 participants' results in the WM test with conventional methods, five children scored 4 in the Backward Word Span task, and five others scored 5 in the Backward Corsi Block Span task. Meanwhile, according to the computer-based test, the Backward Animal task and Shining Star task's maximum scores were 4 and 5, respectively.

TABLE I
TEST RESULT DESCRIPTION

No.	Working Memory Tasks	Mean
1	Backward Word Span	2,14
2	Backward Corsi Block Span	2,47
3	Backward Animal	1,80
4	Shining Star	2,16

Considering the difference in the upper and lower threshold, and between conventional and computer-based tests, all the scores were converted to Z-score before comparing the means (e.g., Table 1). Thus, all the converted Z-scores were transformed into a normal distribution. In the conventional test, the Backward Word Span task's mean was lower than that of the Backward Corsi Block Span task. Meanwhile, the computer-based Shining Star task's mean was higher than that of the Backward Animal task.

B. Spearman Correlation

Inferential statistical analysis was conducted to investigate the correlation between the computer-based application tasks and the conventional ones. According to Spearman correlation analysis, both the computer-based Backward Animal and Shining Star tasks correlated significantly (r = 0.396, p < 0,05). Both conventional Backward Word Span and Backward Corsi Block Span tasks also yielded significant correlation r = 0,565, p < 0,01).

TABLE II
SPEARMAN CORRELATION RESULT

	Backward Corsi Span task	**Backward Animal task**	**Shining Star Task**
Backward Word Span task	0,565**	-0,218	0,298
Backward Corsi Block Span task		0,150	0,539**
Backward Animal task			0,396*

Subsequently, based on the Spearman correlations between each conventional and computer-based task, only Backward Corsi Block Span task correlated significantly with the Shining Star task (r = 0,539, p < 0,01). This result might be due to the similarity of the WM aspect measured by the task stimuli. Both tasks employed visuospatial stimuli, which required the child to activate the nonverbal aspect of WM. Both tasks also required the same kinesthetic modality of response by tapping on the screen. Although the stimuli object was different, both equally emphasized visuospatial and kinesthetic modality with similar task mechanisms and rules. Therefore, both the computer-based Shining Star task and the conventional Backward Corsi Block Span task corroborated the same measurement aspect in WM tasks, namely the nonverbal memory, which was facilitated by the visuospatial sketchpad aspect of WM.

On the contrary, the computer-based Backward Animal task did not associate significantly with the conventional Backward Word Span task (r = -0,128, p > 0,05). This difference might be caused by the difference in the aspects of WM measured in each task. In the conventional Backward Word Span, the child was instructed to memorize the auditory stimuli before giving a verbal response. Thus, this task involved mere auditory modality, which activated the phonological loop [4]. On the other hand, the computer-based Backward Animal task involved both visual and auditory modalities, which activated the phonological loop and the visuospatial sketchpad and the kinesthetic response. These multiple modalities and rule mechanisms in a single task might lead to the decline of one's memory performance [20]. Thus, participants attained the lowest mean score in the Backward Animal task compared to the other three tasks.

Concerning the computer-based application test, the game elements in the test appealed to the child's interest and helped the child maintain his or her attention to the tasks. The computer-based procedure also supported the tester's role in promoting a child's understanding of the task's instructions and rules. However, according to an observational report, children were found to experience considerable difficulties in the Backward Animal task, which was demonstrated by a relatively higher number of trials needed before the child was ready to begin the actual main task. In contrast, children showed better performance in the Backward Word Span task, which emphasized mere auditory modality. On that account, the task's complexity contributed to the insignificant correlation between the Backward Word Span task and the Backward Animal task.

Consequently, we assumed a correlation between the task complexity in Backward Animal tasks and the participants' age. Previous studies reported that children's WM skills developed along with the complexity of the materials, which required more considerable task demand during the school period, especially in the first year of the elementary school [25]. Considering that our participants were still preschool children, we suggested that the Backward Animal Task was more suitable for older children or at least children who have passed the elementary school's first year.

This study aimed to enhance the measurement accuracy and standardization of WM tasks and provided the initiative to develop a computer-based application test for WM tasks in Indonesia. However, as pioneering research, several limitations were found in this study. First, the sample size used in this study was relatively small, that the normal distribution assumption was not adequately met. Second, this study's demographical data indicated a proportional imbalance of the participants' socioeconomic status (SES), where the number of participants from the high SES was particularly less than those from the middle and low SES. A previous study [15] found that SES as one of the contributing factors that complemented a child's EF performance, in which the participants from high SES most likely achieved better EF scores than those from the middle and low SES. Therefore, the small sample size and imbalance proportion of SES categorization in this study led to the data's non-normal distribution.

Regardless of the limitations, this study has developed the first computer-based application test, which accurately measures the WM aspects for early age children in Indonesia. Further studies on this topic should consider administering the tasks to the older age groups to see which task and difficulty level fit best with the older children or adolescent, especially the Backward Animal task that holds a wider range of difficulties than the other three WM tasks. A bigger sample size consisting of proportional SES categorization is also necessary for future studies to obtain a normal data distribution representing the WM skills of early age children in Indonesia. Additionally, an advanced computer-based test development for the WM tasks is further required to decipher auditory responses from the participants. This feature is also expected to provide a system that automatically and precisely analyses the phonological loop components in WM tasks for a more detailed measurement in the future.

IV. Conclusion

This preliminary study managed to develop a computer-based application test to measure WM aspects for Indonesia's early age children. Based on the findings, Shining Star task proved to measure the same construct as the Backward Corsi Block Span task. Therefore, further studies can employ Shining Star task as a measurement tool for developing standardized norms of WM in early age children in Indonesia, which is an essential step to obtain an overall representative data of WM skills for the early age children in Indonesia. In addition, this computer-based WM test is of practical use for optimizing the child's WM skills through an evidence-based intervention. Furthermore, this finding facilitates integrating the computer-based and physiological measurement of WM aspects to gain more comprehensive results.

Acknowledgment

This research is fully granted by Indonesia's Ministry of Research, Technology, and Higher Education through a research grant given to Donny Hendrawan. The technical team of the WM tasks consisted of Firas Atha Muhtadi and Jundi Ahmad Alwan. The authors wish to thank Farida Kurniawati for her support during the process of this study.

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