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Relationship between Fluid Intelligence and Executive Function among University Students in Indonesia

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ABSTRACT

Fluid intelligence is the ability to think logically and abstractly. Executive function is the behavioural ability to coordinate, control and adapt to new situations. Fluid intelligence and executive function are important in problem-solving, adapting, and carrying out daily behaviour. Previous studies in several countries showed that individuals with high fluid intelligence tend to have high executive function components. However, those studies focus on participants within specific age brackets, are sometimes confined to a single scientific field and do not profoundly consider the associated socio-demographic factors. Therefore, this study aimed to examine the relationship and socio-demographic factors between fluid intelligence and executive function among university students in Indonesia. A total of 306 university students in Indonesia participated in this study. The respondents were asked to do the Baddeley Reasoning Test (BRT) to assess fluid intelligence and the Tower of Hanoi to assess executive function. This study found that high fluid intelligence is significantly associated with fewer movements and shorter total time in the Towers of Hanoi, indicating that fluid intelligence may contribute to speeding up problem-solving. The socio-demographic component related to fluid intelligence is age, with a decline in performance occurring with age. For executive function, females have significantly longer planning time and higher total time than males, and students in the social humanities field have a much higher movement than students in the science and technology field. Furthermore, undergraduate students have significantly lower total time than graduate students. These findings highlight the role of socio-demographic factors in cognitive performance.

1. Introduction

Intelligence, essential for problem-solving, involves cognitive functions such as planning, language, and the ability to memorise (Colom *et al*. 2010; Shin and Lowry 2020). It is crucial in human adaptation and survival (Mobbs *et al*. 2015). Intelligence is commonly categorised into crystallised and fluid intelligence (Cattell 1963). Crystallised intelligence develops through accumulated knowledge and life experiences, such as vocabulary, historical knowledge, and mathematical skills, making it highly influenced by learning and environmental factors (Cattell 1963). Meanwhile, fluid intelligence can be defined as the ability to solve problems logically and abstractly, correlating with skills and comprehension. Activities related to fluid intelligence include pattern recognition (facial, auditory, written) and analysing occurring problems (Huepe *et al*. 2011; Unsworth *et*

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al. 2014). While fluid intelligence is often considered more genetically influenced, research suggests it is not entirely fixed and can be enhanced through cognitive training, education, and life experiences (Jaeggi *et al*. 2008).

In daily life, fluid intelligence refers to an individual's ability to think and solve new problems logically. This problem-solving process relies on executive function, which includes the ability to organise, control impulses, and adapt to changing situations effectively (Spinella 2005; Benedek *et al*. 2014; Drigas *et al*. 2018). Executive function consists of three components: updating, shifting, and inhibition. Updating refers to an individual ability to update information (such as updating schedules, adding new information to a plan, etc.). Shifting refers to the cognitive and physical flexibility and ability to make transitions and movements smoothly and efficiently. Inhibition was the ability to increase efficiency in solving problems by controlling impulses and acting more directed in accordance with goals (Miyake *et al*. 2012). Executive functions include verbal fluency, navigating, planning, target setting, and achieving goals (Alvarez and Emory 2006).

High fluid intelligence correlates with increased executive function (Benedek *et al*. 2014; Ren *et al*. 2017; Friedman *et al*. 2022). Higher fluid intelligence is associated with increased updating and inhibition but not with shifting among Chinese students. The findings indicate that updating information in working memory and inhibiting irrelevant responses is crucial for problem solving and reasoning. (Ren *et al*. 2017). In Austria and United States students, higher fluid intelligence correlated with higher updating (Benedek *et al*. 2014; Friedman *et al*. 2022). These results imply that some socio-demographic factors may correlated with fluid intelligence and executive function.

Furthermore, fluid intelligence and executive function are associated with several socio-demographic factors, including age, sex, and scientific discipline (Leon-Carrion *et al*. 1991; Fry and Hale 1996; Kim 2013). With age, our ability to think logically and solve new problems (called fluid intelligence) tends to decline. This is similar to how our ability to control our thoughts and actions, which is called executive function, also declines (Fry and Hale 1996; Rabbitt *et al*. 2001). There are differences in the fluid intelligence and executive function of males and females in cognitive strategies. These differences affected how each individual completes tasks, with males tending to complete tasks more quickly, while females may take a more systematic and meticulous approach (McGlone 1980; Leon-Carrion *et al*. 1991). Additionally, there are differences in thinking patterns among university students in the science and technology and social and humanities groups, affecting fluid intelligence and executive function levels among those two study disciplines (Leon-Carrion *et al*. 1991; Kim 2013).

However, information about socio-demographic factors such as age, sex, and study diciplines that may be associated with fluid intelligence and executive function levels is still limited. Previous studies have often focused on respondents within specific age brackets and are sometimes confined to a single scientific field (Rabbitt *et al*. 2001; Krumm *et al*. 2018). Exploring the relationships between fluid intelligence, executive function, and socio-demographic factors is important to enrich the understanding of cognition and behaviour. It helps to optimise cognitive abilities and the formation of soft skills, including adaptability to face future challenges. Therefore, this study investigates the relationship between fluid intelligence and executive function among university students and associated socio-demographic factors.

2. Materials and Methods

2.1. Respondents

The study's initial phase involved the collection of data from 431 students. However, following a screening process that included the inability to contact some respondents, the final number of respondents who contributed to the study was 306 students (100 males and 206 females).

2.2. Ethics Clearance

This research has been approved by The Ethical Commission of Health Research (ECHR) Indonesia Public Health Association (IPHA) Southeast Sulawesi (Ref:01/ECGH-IPHA/I/2023). Methods were carried out in accordance with approved ethics. All respondents were informed about the study and provided informed consent before participating.

2.3. Adaptation of the Instruments into Bahasa Indonesia

Two bilingual individuals proficient in both English and Bahasa Indonesia were selected to translate all questionnaires assessing fluid intelligence into Bahasa Indonesia. To ensure the accuracy of the translations,

two other experts in English-Bahasa Indonesia and vice versa translation conducted a back-translation into English. Any discrepancies in meaning were identified and resolved through a consensus process, ensuring that the translated version remained faithful to the original content. The Indonesian version of the questionnaire was then subjected to validation through expert evaluation. A pilot study was conducted, involving 100 respondents, to assess the clarity and usability of the questionnaire. While no issues were raised regarding the content of the questions, some respondents provided feedback on the presentation format. These concerns were addressed and refined promptly. To ensure internal consistency, a reliability analysis using Cronbach's alpha was performed. The BRT demonstrated Cronbach's $\alpha > 0.92$, thereby confirming its very high internal reliability.

2.4. Procedures

This research was conducted through an online questionnaire using Google Forms and distributed through several social media platforms, such as WhatsApp, Instagram, Line and Twitter. Firstly, the researchers mentioned the research background research objectives, provided their contact information, requested informed consent, and informed respondents that the data would be anonymous and only used for this research. If respondents agree, they would choose "Agree to participate" and start the survey. If they disagree, the respondent can resign at any time, and the respondent's data will not be used. The study consisted of three stages. In the first stage, respondent would answer questions about their socio-demographic information. The respondents were asked about their age, sex, region of residence (islands), education level, study discipline, and monthly income (i.e., salary, scholarship, pocket money, etc.). Then, respondents would be contacted again for two and three stages. In the second stage, we used the Baddeley Reasoning Test (BRT) to measure fluid intelligence. In the third stage, each respondent played Tower of Hanoi to measure executive function. The Baddeley Reasoning Test (BRT) and Tower of Hanoi were conducted online using the Zoom platform, and respondents individually took the test while being supervised by the researchers throughout the process.

2.5. Baddeley Reasoning Test

The scale of fluid intelligence is measured using the 3-Minute Grammatical Reasoning Test (Baddeley 1968; Baghaei *et al*. 2017). The test consists of 30 items, preceded by two practice items. Each respondent is asked to determine whether a sentence, for example, "A follows B", matches the arrangement of letters A and B (either "AB" or "BA"). Respondents are given 3 minutes to complete the task. The scores for each item are summed, and a higher BRT score indicates higher fluid intelligence. Respondents with a higher score than the average score of all respondents are considered to have higher fluid intelligence.

2.6. Tower of Hanoi

The executive function scale of an individual can be measured using the Tower of Hanoi (Simon 1975). Before playing, respondents are given 3 minutes to read the rules of the Tower of Hanoi. After that, the respondents cannot ask questions about Tower of Hanoi's rules. The game consists of 3 disks and 3 pegs, with the intention of moving all disks from the left peg to the rightmost peg. The movement of disks is constrained so that a smaller disk cannot be placed under a larger disk. Only one disk is allowed to move in each step. The game is played five times: twice with three disks, twice with four disks, and once more with three disks. The minimum number of moves for the game with three disks is 7, while for four disks, it is 15 moves. The data collected includes Planning Time, Movements, and Total Time. Planning Time is the time spent planning movements recorded from the beginning of the game until the first movement. Effective planning is typified by a minimal number of moves and a brief total time. Movements are the number of disk movements the subject requires to solve the puzzle, with a minimum average of 10.2 disk moves in a game session. In addition, total time is the time taken to complete a game session, where a faster completion time indicates greater efficiency in executive function; that is, the high or low data indicator is observed from the overall average data used.

2.7. Statistical Analysis

Spearman's rank correlation test (rho) analysed the correlation between fluid intelligence and executive function, where values close to ±1 indicate a strong correlation, while values near 0 indicate a weak or no correlation. The strength and direction of the correlation were interpreted based on the rho value, while statistical significance was determined using a p-value (p) threshold of 0.05. The Generalized Linear Model (GLM) was used to determine which socio-demographic factors may associated with fluid

intelligence and executive function, where model fit and significance of predictors were evaluated based on p-values and confidence intervals ($p<0.05$). In selecting the model, the Variance Inflation Factor (VIF) was applied to test for multicollinearity between independent variables, with a threshold of 10 indicating severe multicollinearity and values below five considered acceptable. A stepwise method was employed to obtain a simplified model of relevant predictors. Statistical analyses were conducted using R (R Core Team 2023).

3. Results

3.1. Socio-Demographic of Respondents

The respondents were 306 (100 males, 206 females) undergraduate and graduate students in Indonesia. The age range of the respondents varied from 19 to 47 years (Mean = 23.98±4.31 years; Meanmales = 23.5±3.69 years; Meanfemales = 24.22±4.56 years). Further demographic information about the respondents can be found in Table 1.

3.2. Fluid Intelligence Score using The Baddeley Test (BRT)

BRT covers a score range from 0 (no correct answers) to 30 (all answers correct), with a mean score of 22.05±7.18. Respondents with scores above the mean are considered to have high fluid intelligence.

Table 1. Socio-demographic profiles of the respondents

Variable	Category	Number of respondents	Percentage (%)
Sex	Male	100	32.68
	Female	206	67.32
Islands	Java	209	68.30
	Sumatra	61	19.95
	Kalimantan	11	3.59
	Sulawesi	12	3.92
	Others	13	4.24
Education level	Undergraduate	230	75.16
	Graduate	76	24.87
Study discipline	Science and Technology	262	85.62
	Social and Humanities	44	14.38
Income (IDR)	<500.000	62	20.26
	500.001-1.000.000	82	26.80
	1.000.001-3.000.000	112	36.60
	3.000.001-5.000.000	32	10.46
	5.000.001-7.000.000	11	3.59
	7.000.001-10.000.000	3	0.98
	>10.000.000	4	1.31

3.3. Socio-demographic Variables Associated with Fluid Intelligence

According to stepwise by GLM, the higher age is associated with lower fluid intelligence ($p<0.05$), as shown in Table 2.

3.4. Executive Function using Tower of Hanoi

The Tower of Hanoi planning time ranges from 1 to 18.6 sec, with an average of 3.68±1.79 seconds in this study. The Tower of Hanoi movement ranged from 10 to 47 moves. The total time range was from 14.2 to 171.4 seconds. Indonesian students have an average movement score of 20.26±6.4 moves and an average total time score of 55.01±25.47 seconds, as shown in Table 3.

3.5. Socio-demographic Variables Associated with Component of Tower of Hanoi

3.5.1. Planning Time

This study found that females have significantly longer planning time than males ($p<0.05$), as shown in Table 4.

3.5.2. Movement

The variables of education level and study discipline show a relationship with movement. This shows undergraduate students have lower movement than

Table 2. Variables associated with fluid intelligence (Generalised linear model, $p<0.05$ = Significant)

Variable	Estimate	Std error	t-value	Pr(>|t|)
Intercept	28.01	2.32	12.10	p<0.05
Age	-0.20	0.09	-2.14	0.03

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1'' 1

Table 3. Tower of Hanoi average score of respondents

Category	Tower of Hanoi	
	Mean	SD
Planning time	3.68	1.79
Movement	20.26	6.40
Total time	55.01	25.47

Table 4. Variables associated with planning time (Generalised linear model, $p<0.05$ = Significant)

Variable	Estimate	Std error	t-value	Pr(>|t|)
Intercept	3.25	0.18	18.32	p<0.05
Female (ref: male)	0.56	0.22	2.56	0.01

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1''

master's students ($p<0.05$). In addition, students in the social humanities field have a much higher movement than students in the science and technology field ($p<0.05$).

3.5.3. Total Time

This result showed that females have significantly higher total time than males ($p<0.05$). Furthermore, undergraduate students have significantly lower total time than graduate students ($p<0.05$).

3.6. Correlation between Fluid Intelligence and Each Variable of Tower of Hanoi

The result showed that higher fluid intelligence significantly correlated with lower movement ($R = -0.24$, $p<0.05$) and lower total time ($R = -0.27$, $p<0.05$). However, there is no significant correlation between higher fluid intelligence correlation and higher planning time ($R = 0.035$, $p>0.05$).

4. Discussion

This study found that all respondents average fluid intelligence score was 22.05. Additionally, 54% of respondents scored above this average, indicating a high fluid intelligence. A high fluid intelligence score with an average score above 22 has also been found among students in Iran, England, and Cyprus (Furnham and Petrides 2003; Sanchez-Ruiz *et al*. 2013; Baghaei *et al*. 2017). A high fluid intelligence score indicates that university students can think rationally and abstractly to solve new challenges (Cattell 1963; Horn and Cattell 1967). This implies that most Indonesian university students in this research have strong critical thinking and problem-solving abilities. This research found that older age was associated with lower fluid intelligence. As people age, their physiological performance of the body, brain, and memory may decrease, resulting in decreased fluid intelligence (Fry and Hale 1996; Leeson *et al*. 2008; Clay *et al*. 2009; Kievit *et al*. 2014).

Executive function can be measured by the Tower of Hanoi game, which measures the accuracy of decision-making assisted by planning to solve puzzles (Simon 1975; Welsh 1991; Mitani *et al*. 2022). Executive abilities consist of several parts, including planning, goal-directed implementation of plans (movement), and effective performance (total time) (Lezak *et al*. 1982).

Planning time can be used to test subjects' responses to problem-solving (Wright and Hardie 2015). This research showed that males needed less planning time than females. This indicated that males tended to have more systematic cognitive control strategies so that males planning time was faster (McGlone 1980; Leon-Carrion *et al*. 1991).

In the Tower of Hanoi game, decision-making greatly influences the movements that occur when moving the disc. The average number of movements by Indonesian students in this study was 20.26 steps, higher than the average movement of 17.57 (Hardy and Wright 2018). The movements formed can be reflected in a person's planning process and self-control in acting, where the better a person is at planning and self-control, the fewer movements are formed (Byrnes 1979; Kim 2013). However, males and females exhibited many movements when analysing the relationship between planning time and movement efficiency. This indicates that despite differences in planning time, cognitive control in task execution remained relatively low across both groups (McGlone 1980; Leon-Carrion *et al*. 1991). This study also found that study disciplines were related to the number of moves, with science and technology students requiring fewer moves than their social sciences and humanities peers. Science and technology students tended to have a mechanistic mindset, which could train them to think strategically in forming more efficient steps, leading to fewer movements (Leon-Carrion *et al*. 1991; Kim 2013).

The Tower of Hanoi game's planning length and amount of disc moves can impact the overall time required. This study found that Indonesian students required an average total time of 55.01 seconds, similar to the 55-second average reported for American students in previous studies (Humes 1997; Hardy and Wright 2018). The reduced total time indicated strong executive function, so it is assumed that someone successfully planned and minimised movements carefully (Mitani *et al*. 2022). It implied that most of the Indonesian students showed quite good executive function.

The results of this study showed that the total time is associated with several variables, including sex and education level. Regarding the sex variable, the total time for males was significantly lower compared to females. This was also observed in Spanish students, where males tended to complete tasks more quickly due to their cognitive strategies or abilities to build strategies. Cognitive strategies, such as planning, assist individuals in coordinating the steps to be taken, thus shortening the time needed to complete a task (Leon-Carrion *et al*. 1991). This planning ability is an important

component of executive function. This research showed that undergraduate students have a shorter total time and movement than graduate students. Undergraduate students are often exposed to a broader range of tasks and assignments, which may foster cognitive flexibility by encouraging them to think creatively and adaptively to meet diverse challenges. This ability to think flexibly can help minimise movements and reduce total time when completing tasks (Diamond 2013).

This research showed that individuals with high fluid intelligence scores tend to move less in the Tower of Hanoi games. They are assumed to have more potent reasoning abilities, allowing them to formulate more effective strategies and execute moves more accurately. (Gray *et al*. 2003; Zook *et al*. 2004). With careful planning and precise execution, individuals were considered to have effective strategies. This study showed that higher fluid intelligence resulted in a shorter total time to complete the Tower of Hanoi game. This was consistent with the findings of Kasneci *et al*. (2022), where individuals with higher fluid intelligence scores were assumed to be more capable of identifying patterns, resulting in faster and more accurate performance. Conversely, individuals with lower fluid intelligence scores required more time to recognise patterns in the game, thus requiring more time to solve the puzzle (Stankov 2000).

In conclusion, reported fluid intelligence is not significantly associated with planning time. However, high fluid intelligence is significantly associated with fewer movements and shorter total time. The only socio-demographic factor found to be associated with fluid intelligence is age. The analysis showed associations between several socio-demographic factors and components of executive function. Planning was found to be associated with sex, movement with educational level and discipline, and total time with sex and educational level.

Future research should conduct longitudinal research to investigate how fluid intelligence and executive function change over time within the same group.

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