Developing Psychophysical Measurement of Working Memory

Isman Rahmani Yusron[1], Anggi Anggraeni[2], Zulmi Ramdani[3]
[1] *Universitas Muhammadiyah Bandung, Jl. Soekarno-Hatta No.752, Kota Bandung, Indonesia*
[2] *Universitas Muhammadiyah Bandung, Jl. Soekarno-Hatta No.752, Kota Bandung, Indonesia*
[3] *Universitas Islam Negeri Sunan Gunung Djati, Jl. A.H. Nasution No.105, Bandung, Indonesia*
E-mail: isman.rahmani@umbandung.ac.id

Keywords: Measurement, Psychophysical, Test Construction, Working Memory.

Abstract: This experimental research aims to develop a valid and reliable working memory measurement instrument based on psychophysical and computerized characteristics. The authors developed a measuring instrument for working memory capacity, including speed, space or capacity, and energy measurements. We used the Opensesame application from Cogsci.nl to develop a measurement instrument with a paradigm based on the conceptual definition of working memory capacity, such as: speed, space or capacity, and energy. The samples in this study are determined by using the Disproportionate Stratified Random Sampling technique, to obtain a representative sample based on different strata of academic qualification levels. This research involved 93 undergraduate students as the respondents. The Rasch analysis shows the reliability coefficient of the test items is 0.9066 and 0.9295 for the person reliability coefficient, this indicates that the items in the test are reliable. The number of strata as an index of item variation in this measuring instrument also shows a coefficient of 4.4870 at the item level and 5.1743 at the person level, which meets the criteria for a good variation index. On the other hand, Item Response Theory analysis shows the mean value of parameter-a or item discrimination level about 0.210, while the average value of parameter-b or item difficulty level is -1.32 with medium difficulty category.

1 INTRODUCTION

Working memory is a cognitive process of a small amount of memory retention or information in human brain, it facilitates planning processes, reasoning and problem solving (Cowan, 2014). Working memory refers to individual ability to collect and provide existing information used in activity, decision making, guide action, or navigate and support both creative thinking and problem solving (Logie et al., 2021). In daily activities, working memory plays a vital role in making our behavior and decisions consistent and effective. Without working memory or when the working memory on deficit state, it can lead a problem that associated with such dysfunction as major depression (Nikolin et al., 2021), dyscalculia and dyslexic (Schuchardt et al., 2008), ADHD, and specific learning difficulties such as difficulties in math and reading (Chai et al., 2018).

Working memory capacity on individuals is associated with various cognitive performance, such as liquid intelligence (Li et al., 2022; Meiran & Shahar, 2018; Ren et al., 2017), cognitive control (Boag et al., 2021; Gazzaniga et al., 2019), mathematical achievement (Friso-van den Bos et al., 2013; Szczygieł, 2021) and potential of problem-solving on mathematic (Lee Swanson et al., 2021), characteristic of intellectually children (Aubry et al., 2021), as well as individual competence and academic performance (Bergman Nutley & Söderqvist, 2017; Blankenship et al., 2015; Freeman et al., 2017; Maehler & Schuchardt, 2016). The findings of this study provide many indications about the importance of the individual's working memory in predicting various cognitive competencies, especially in academic aspects. At the same time, this study underlies the importance of detection and assessment that can measure the capacity of working memory as a variable that can explain cognitive performance that contributes to academic success.

In the previous study, measuring working memory capacity has been done in various ways. However, there is no general agreement about a robust and parsimony approach that can determine the working memory capacity accurately. Some studies suggest using the n-back task paradigm as a psychometric instrument for measuring working memory capacity (Frost et al., 2021; Gkalitsiou & Byrd, 2021; Nikolin et al., 2021; Yaple et al., 2019), however, the use of n-back paradigm has many limitations, such as only specifically measuring

Yusron, I. R., Anggraeni A., & Ramdani Z.
Developing Psychophysical Measurement of Working Memory
In *Proceeding of the International Conference on Current Advancement in Psychology (ICCAP) 2022 - Psychology for Sustainable Recovery in the Life after the Pandemic,* page 476-483

updating ability from working memory and for clinical setting (Rac-Lubashevsky & Kessler, 2016), while the ability updating while measuring working memory within the sub-sphere of executive function, still accounts for only 15% and without correlating with (reasoning ability) and working memory capacity in general (Frischkorn et al., 2022). In addition, there is no standard procedure as well as a normative measure on the use of n-back task paradigms to measure working memory (Pelegrina et al., 2015), furthermore, it also proven that n-back task is not effective to be used to measure the working memory capacity of different individuals (Jaeggi et al., 2010).

In addition to that, a sub component of measuring psychological test tools can be used as complementary properties that can be used to measure working memory. For example, Digit Span Task (Conklin, 2000; Wells et al., 2018) that is sub test component of Weschler Adult Intelligence Scale (WAIS) which is popular to measure working memory. Despite its popularity, it is still unclear whether the use of this sub-test has sufficient reliability and can measure specific domains of working memory. Other properties also have been used and investigated for working memory measuring, for instance: Wisconsin Card Sorting Test (WCST) (Stratta et al., 1997), Automated Working Memory Assessment (AWMA) that specifically used for children with impaired working memory (Alloway et al., 2008), or The Jack and Jill Visuospatial Working Memory task (Tsigeman et al., 2022).

To measure working memory, we need to involve three aspects to describe the capacity of the working memory: analogy of the space area or capacity; time response or time processing; and lastly, the energy referred to only what the range of information can be manipulated at one time in a working memory (Cowan, 2014). These three aspects are holistic enough to describe the working memory, as Allan Baddeley definition (in Logie et al., 2021) " A limited capacity system for the temporary maintenance and processing of information in the support of cognition and action". A temporary maintenance process refers to the space and time aspects of working memory, as well as the processing of information that supports cognition and action aligned with energy aspects.

Theoretically, a lot of literature that supports detailed definitions of working memory. But nothing was agreed-not to say nothing at all, a holistic measure measured the capacity of working memory. Measurement on working memory is almost absent as a property of measurement of cognitive ability, as most measurement abilities only focus on fluid intelligence measurement which specifically measure general domain not specific domain. On the other hand, to predict actual ability, such as academic achievement or study performance, psychometric measurement that can measure not only the potential domain, but also on specific and actual domain.

Almost all measurements that are related to cognitive are done with paper and pen. Measurements with this method are categorized as subjective measurement. Subjective measurement has some drawbacks due to the risk that does not match with the actual condition (Lohani et al., 2019). Moreover, the subjects can not always accurately assess their cognitive situation (Schmidt et al., 2009). Therefore, psychometric measurement is more precise and can avoid the subjective risk, although the cognitive situation can be measured through subjective, behavioral and psychophysics measurement (Lohani et al., 2019; Mauss & Robinson, 2009; Strayer et al., 2015).

Based on these studies, the authors are interested in investigating comprehensively to get psychometric properties based on psychophysics that can measure working memory accurately and robustly in predicting actual performance of individuals or concurrent with their achievement in an academic setting. The development of this working memory measuring tool has been developed with the help of computerization in order to produce a measuring tool that is easy to use and accurately measures aspects of working memory.

2 METHOD

Researchers developed a working memory capacity measurement tool that includes measurements of aspects of capacity space, reaction time, and energy (Cowan et al., 2008). The researcher developed a measurement tool constructed with the help of the Opensesame© application from Cogsci.nl (Mathôt et al., 2012) with a paradigm that follows the conceptual definition of working memory capacity used in this study, and we named it the Psychophysical Working Memory Task of the University of Muhammadiyah Bandung. The paradigm task for each working memory measurement subtest is described in Figure 1.

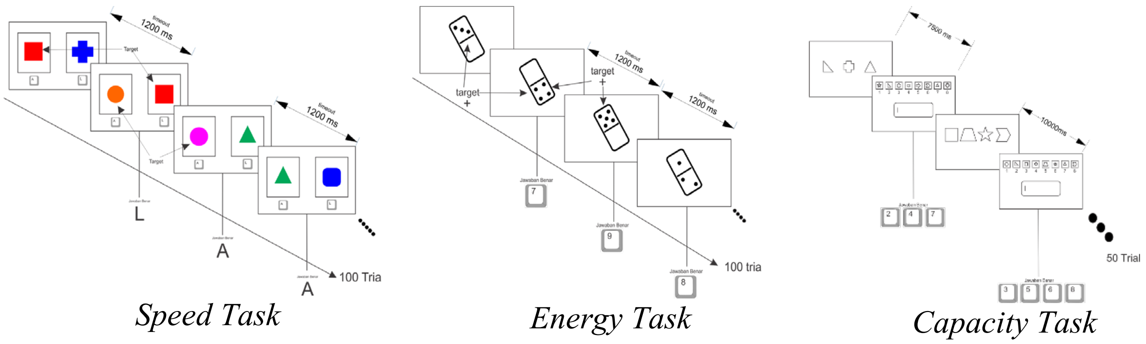

Figure 1: Working Memory Measurement Task Paradigm

The author analyzed the content of the response results using the Rasch approach (Andrich, 1988) and Item Response Theory (IRT), which examined three logistic parameters to obtain reliable psychometric properties and predict latent attributes of individuals (DeMars, 2010). The IRT analysis of the measuring instrument developed in this study is assisted by a psychometric application, jMetrik© (Meyer, 2014). Through the R-Studio application, the author also uses it to obtain logit graphs from IRT which include IRT Plot graphs, Test Information Functions, and Item Characteristic Curves using the LTM, mirt, and shiny package libraries (Chalmers, 2012; Rizopoulos, 2006; Sievert, 2020).

In total 93 participants participated in data collection by completing all University of Muhammadiyah Bandung Psychophysical Working Memory Tasks. Research subjects are willing to participate in the research by first filling out the informed consent form. The instrument used is the measurement of working memory which consists of three dimensions and is manifested in 3 balanced test parts, as described in Figure 1.

3 RESULT AND DISCUSSION

The authors used two techniques to test the validity and reliability of the instrument using the Rasch method (Andrich, 1988) and Item Response Theory or IRT with three logistic parameters (Baker, 2004). Based on the results of testing the Rasch method, the statistical quality of the measurement scale shows a reliability coefficient of 0.90 for the item parameter and 0.93 for the respondent parameter. Thus, the qualifications of the reliability of the measuring instrument that the researchers developed are in the very good category (see table 1). These results are supported by the separation index, which shows a coefficient of 3.1 at the item level and 3.6 at the individual level. The number of strata or item variations shows an index of 4.48 for the test level, and the level of variation in the abilities of the respondents also varies with an index of 5.17.

Table 1: Scale Quality Statistics

Statistic	Items	Persons
Observed Variance	0.7039	0.8594
Observed Std. Dev.	0.8390	0.9271
Mean Square Error	0.0658	0.0606
Root MSE	0.2564	0.2462
Adjusted Variance	0.6381	0.7988
Adjusted Std. Dev.	0.7988	0.8938
Separation Index	3.1153	3.6307
Number of Strata	4.4870	5.1743
Reliability	0.9066	0.9295

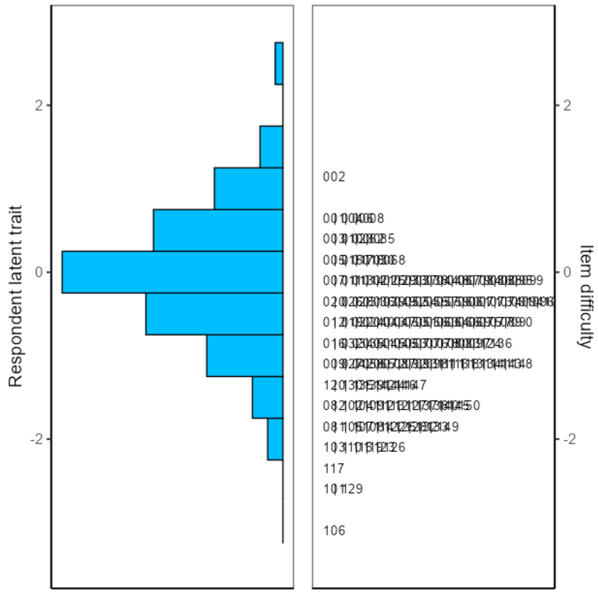

Figure 2: Wright Map of Working Memory Task Items

Figure 2 above shows the Wright map, which shows the difficulty level of the items and the ability of each respondent to answer the given test items. We interpret the Wright map in this measurement to explain each level of the respondent's ability to answer the items in the working memory task in this study. The higher the ability of the respondent, the more linear the ability to answer items with a high degree of difficulty and vice versa.

Table 2: Summary of Item Statistics and Item Fit Parameters

	Measure	S.E Measure	Infit	Outfit
Mean	-0.91	0.25	0.99	0.99
S.D	0.83	0.04	0.09	0.17
Min	-3.06	0.22	0.78	0.55
Max	1.285	0.43	1.21	1.54

The results of item statistics and item suitability can also be seen in table 2 presented above. The Infit and Outfit columns show a score of 0.99. The infit and outfit scores interpret how the variation data is made by the Rasch Model. This value of 0.99 means that 1% of the observed data has less variation than predicted by the Rasch Model. Meanwhile, the scores of outfits that move from 0.5 to 1.5 indicate that the items used are good for the measurement.

Through Item Response Theory analysis, the results of the Test Information Function graph show that the test performance is quite good, where the test provides quite a lot of information at the average ability level or theta value close to 0 (Figure 3). The energy and capacity sub-tests showed satisfactory results with a slope of discriminant power and a difficulty level close to 0.5 confidence. In the speed task, the data were analyzed by associating the speed level with the accuracy of the answers, which showed a significant negative correlation. This result means that the faster the subject responds to the stimulus, the higher the working memory score generated through this test.

The graph in Figure 3 below shows the Information Function Curve and the Error Distribution of the test, which in this case is the Energy and Capacity subtest. The two sub-tests measure the level of difficulty and item differentiation as well as the guessing level of the test takers' responses. Both of them show graphs with good differential power parameters and item discrimination levels. The average value of parameter-a or item discrimination level is 0.210, a good value because it is below 0.5 (De Beer, 2004), and the average value of parameter-b or the item difficulty level is -1.32 with the category of medium difficulty level.

In the speed sub-test, because what is measured is reaction time and accuracy in responding to the presented stimulus, the authors use Pearson's correlation technique to see the association between IRT score and response speed, as presented in Table 3. The correlation results show a significant negative association at the 99% significance level. % ($r=-0.441$; $p<.01$), which means the less time it takes to respond to the stimulus accurately, the higher the ability score estimated by the IRT.

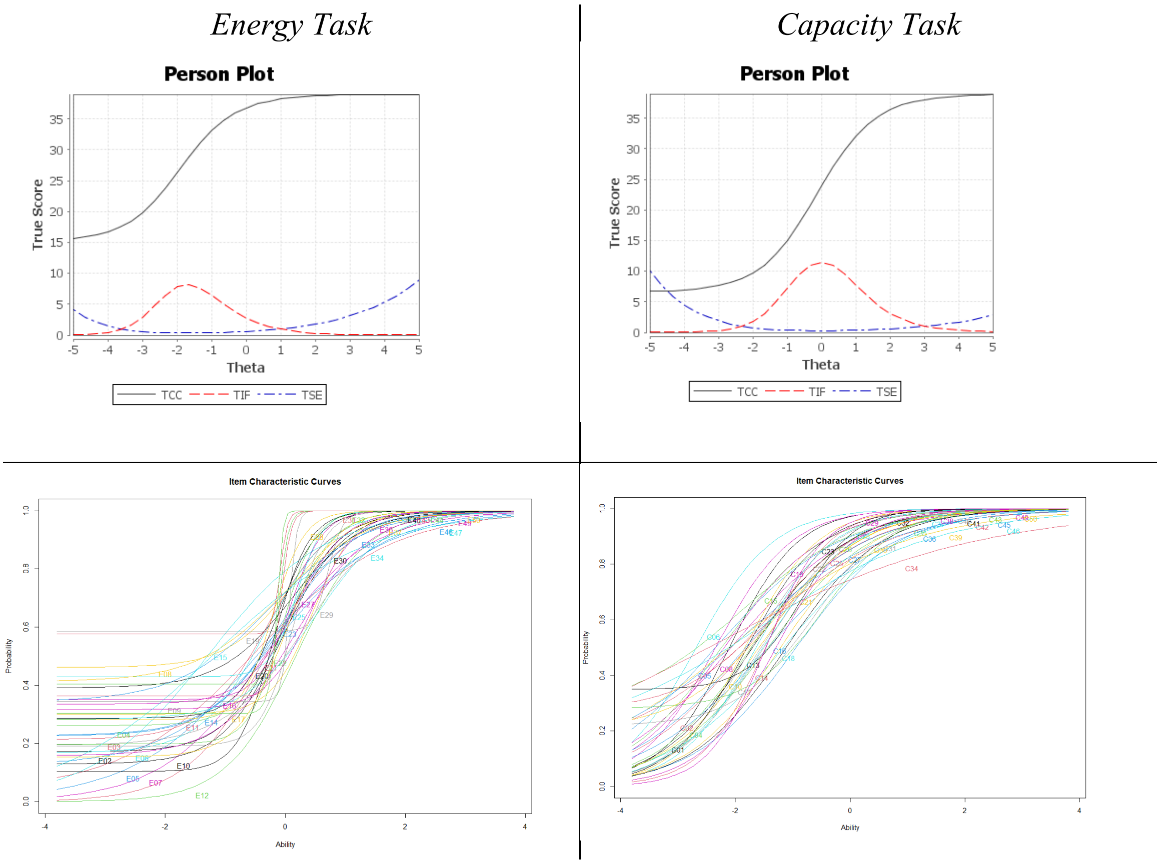

Figure 3: Information Function Curve and Error Distribution

Table 3: *Results of Pearson's Product Correlation Analysis Between Reaction Speed and IRT Score*

Correlation Matrix

		IRT-Skor	Kecepatan
IRT-Skor	Pearson's r	—	
	p-value	—	
Kecepatan	Pearson's r	-0.441**	—
	p-value	0.004	—

To test the construct validity, the researcher used exploratory factor analysis techniques to look at the factor loading of each item on the working memory factors or dimensions, which include speed, energy, and capacity. Based on the test results, most of the items are assembled and have a loading factor above 0.3 for each of their respective factors. These results indicate that these items are valid in revealing the dimensions measured on this measuring instrument. The eigenvalues presented through the scatterplot show the three dimensions contained in the items in this task. These results indicate a concordance between the dimensions defined in this test and those extracted through the EFA. The results of this EFA plot are presented in Figure 4.

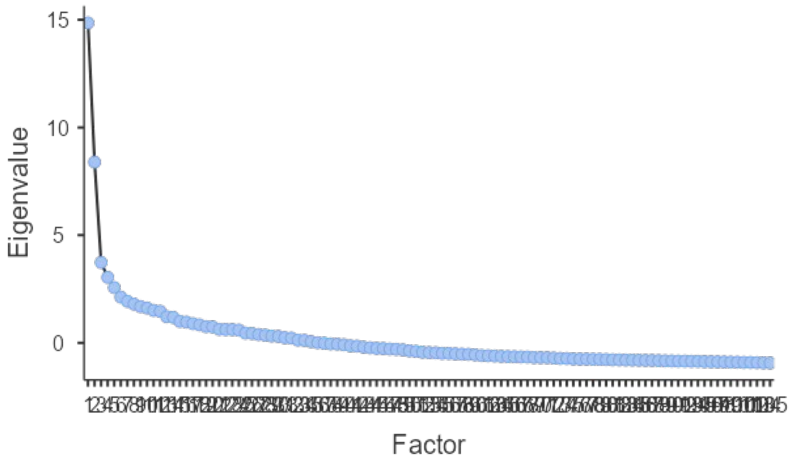

Figure 4: Instrument Factor Analysis Test Results

Table 4: Model Fit Measures of Working Memory Task

Model Fit Measures

	RMSEA 90% CI				Model Test		
RMSEA	**Lower**	**Upper**	**TLI**	**BIC**	**χ^2**	**Df**	**p**
0.171	0.170	0.175	0.0145	-4143	19191	5148	< .001

To see the suitability of the existing model can be seen in table 4. Table 4 shows the elements that are important to see whether the model is fit or not. If seen from the RMSEA value alone, the model from the existing measurements is 0.171, which means it is greater than 0.08; this indicates that the model is not yet fit. This means that the structure of the working memory model must be modified to get a more fit model.

4 CONCLUSION

The results of the development of working memory tests show a high value of reliability through the Rasch testing method. So this indicates that the test developed is reliable for measuring working memory in terms of speed, energy, and capacity. The three-parameter IRT analysis shows that the parameters a, b, and c indicate good results and have sufficient information to estimate the respondents' test results.

The validity of the measuring instrument was tested through the exploratory factor analysis method and showed the results of the items in the test having a high factor loading and converging on the factors referred to in the operational definition. Through various test results conducted, the working memory measurement tool that the researchers developed has sufficient psychometric quality to be used in estimating speed, energy, and working memory capacity.

REFERENCES

Alloway, T. P., Gathercole, S. E., Kirkwood, H., & Elliott, J. (2008). Evaluating the validity of the Automated Working Memory Assessment. *Educational Psychology*, *28*(7), 725–734. https://doi.org/10.1080/01443410802243828

Andrich, D. (1988). *Rasch models for measurement*. Sage Publications. http://search.ebscohost.com/login.aspx?direct=true&scope=site&db=nlebk&db=nlabk&AN=24774

Aubry, A., Gonthier, C., & Bourdin, B. (2021). Explaining the high working memory capacity of gifted children: Contributions of processing skills and executive control. *Acta Psychologica*, *218*, 103358. https://doi.org/10.1016/j.actpsy.2021.103358

Baker, F. B. (2004). *Item response theory: Parameter estimation techniques* (2nd ed., rev.expanded). Marcel Dekker.

Bergman Nutley, S., & Söderqvist, S. (2017). How Is Working Memory Training Likely to Influence Academic Performance? Current Evidence and Methodological Considerations. *Frontiers in Psychology*, *8*. https://doi.org/10.3389/fpsyg.2017.00069

Blankenship, T. L., O'Neill, M., Ross, A., & Bell, M. A. (2015). Working memory and recollection contribute to academic achievement. *Learning and Individual Differences*, *43*, 164–169. https://doi.org/10.1016/j.lindif.2015.08.020

Boag, R. J., Stevenson, N., van Dooren, R., Trutti, A. C., Sjoerds, Z., & Forstmann, B. U. (2021). Cognitive Control of Working Memory: A Model-Based Approach. *Brain Sciences*, *11*(6), 721. https://doi.org/10.3390/brainsci11060721

Chai, W. J., Abd Hamid, A. I., & Abdullah, J. M. (2018). Working Memory From the Psychological and Neurosciences Perspectives: A Review. *Frontiers in Psychology*, *9*, 401. https://doi.org/10.3389/fpsyg.2018.00401

Chalmers, R. P. (2012). Mirt: A Multidimensional Item Response Theory Package for the *R* Environment. *Journal of Statistical Software*, *48*(6). https://doi.org/10.18637/jss.v048.i06

Conklin, H. M. (2000). Verbal Working Memory Impairment in Schizophrenia Patients and Their First-Degree Relatives: Evidence From the Digit Span Task. *American Journal of Psychiatry*, *157*(2), 275–277. https://doi.org/10.1176/appi.ajp.157.2.275

Cowan, N. (2014). Working Memory Underpins Cognitive Development, Learning, and Education. *Educational Psychology Review*, *26*(2), 197–223. https://doi.org/10.1007/s10648-013-9246-y

Cowan, N., Morey, C. C., Chen, Z., Gilchrist, A. L., & Saults, J. S. (2008). Theory and Measurement of Working Memory Capacity Limits. In *Psychology of Learning and Motivation* (Vol. 49, pp. 49–104). Elsevier. https://doi.org/10.1016/S0079-7421(08)00002-9

De Beer, M. (2004). Use of differential item functioning (DIF) analysis for bias analysis in test construction. *SA Journal of Industrial Psychology*, *30*(4). https://doi.org/10.4102/sajip.v30i4.175

DeMars, C. (2010). *Item response theory*. Oxford University Press.

Freeman, E. E., Karayanidis, F., & Chalmers, K. A. (2017). Metacognitive monitoring of working memory performance and its relationship to academic achievement in Grade 4 children. *Learning and Individual Differences*, *57*, 58–64. https://doi.org/10.1016/j.lindif.2017.06.003

Frischkorn, G., von Bastian, C., Souza, A., & Oberauer, K. (2022). Individual Differences in Updating are not related to Reasoning Ability and Working Memory Capacity. *Journal of Experimental Psychology General*. https://doi.org/10.1037/xge0001141

Friso-van den Bos, I., van der Ven, S. H. G., Kroesbergen, E. H., & van Luit, J. E. H. (2013). Working memory and mathematics in primary school children: A meta-analysis. *Educational Research Review*, *10*, 29–44. https://doi.org/10.1016/j.edurev.2013.05.003

Frost, A., Moussaoui, S., Kaur, J., Aziz, S., Fukuda, K., & Niemeier, M. (2021). Is the n-back task a measure of unstructured working memory capacity? Towards understanding its connection to other working memory tasks. *Acta Psychologica*, *219*, 103398. https://doi.org/10.1016/j.actpsy.2021.103398

Gazzaniga, M. S., Ivry, R. B., & Mangun, G. R. (2019). *Cognitive neuroscience: The biology of the mind (Fifth edition)*. W.W. Norton & Company.

Gkalitsiou, Z., & Byrd, C. T. (2021). Working memory in adults who stutter using a visual N-back task. *Journal of Fluency Disorders*, *70*, 105846. https://doi.org/10.1016/j.jfludis.2021.105846

Jaeggi, S. M., Buschkuehl, M., Perrig, W. J., & Meier, B. (2010). The concurrent validity of the *N* -back task as a working memory measure. *Memory*, *18*(4), 394–412. https://doi.org/10.1080/09658211003702171

Lee Swanson, H., Arizmendi, G. D., & Li, J.-T. (2021). Working memory growth predicts mathematical problem-solving growth among emergent bilingual children. *Journal of Experimental Child Psychology*, *201*, 104988. https://doi.org/10.1016/j.jecp.2020.104988

Li, C., Ren, X., Schweizer, K., & Wang, T. (2022). Strategy use moderates the relation between working memory capacity and fluid intelligence: A combined approach. *Intelligence*, *91*, 101627. https://doi.org/10.1016/j.intell.2022.101627

Logie, R., Camos, V., & Cowan, N. (Eds.). (2021). *Working memory: The state of the science*. Oxford University Press.

Lohani, M., Payne, B. R., & Strayer, D. L. (2019). A Review of Psychophysiological Measures to Assess Cognitive States in Real-World Driving. *Frontiers in Human Neuroscience*, *13*. https://www.frontiersin.org/article/10.3389/fnhum.2019.00057

Maehler, C., & Schuchardt, K. (2016). The importance of working memory for school achievement in primary school children with intellectual or learning disabilities. *Research in Developmental Disabilities*, *58*, 1–8. https://doi.org/10.1016/j.ridd.2016.08.007

Mathôt, S., Schreij, D., & Theeuwes, J. (2012). OpenSesame: An open-source, graphical experiment builder for the social sciences. *Behavior Research Methods*, *44*(2), 314–324. https://doi.org/10.3758/s13428-011-0168-7

Mauss, I. B., & Robinson, M. D. (2009). Measures of emotion: A review. *Cognition & Emotion*, *23*(2), 209–237. https://doi.org/10.1080/02699930802204677

Meiran, N., & Shahar, N. (2018). Working memory involvement in reaction time and its contribution to fluid intelligence: An examination of individual differences in reaction-time distributions. *Intelligence*, *69*,176–185. https://doi.org/10.1016/j.intell.2018.06.004

Meyer, J. P. (2014). *Applied Measurement with jMetrik* (0 ed.). Routledge. https://doi.org/10.4324/9780203115190

Nikolin, S., Tan, Y. Y., Schwaab, A., Moffa, A., Loo, C. K., & Martin, D. (2021). An investigation of working memory deficits in depression using the n-back task: A systematic review and meta-analysis. *Journal of Affective Disorders*, *284*, 1–8. https://doi.org/10.1016/j.jad.2021.01.084

Pelegrina, S., Lechuga, M. T., García-Madruga, J. A., Elosúa, M. R., Macizo, P., Carreiras, M., Fuentes, L. J., & Bajo, M. T. (2015). Normative data on the n-back task for children and young adolescents. *Frontiers in Psychology*, *6*. https://doi.org/10.3389/fpsyg.2015.01544

Rac-Lubashevsky, R., & Kessler, Y. (2016). Decomposing the n-back task: An individual differences study using the reference-back paradigm. *Neuropsychologia*, *90*, 190–199. https://doi.org/10.1016/j.neuropsychologia.2016.07.013

Ren, X., Schweizer, K., Wang, T., Chu, P., & Gong, Q. (2017). On the relationship between executive functions of working memory and components derived from fluid intelligence measures. *Acta Psychologica*, *180*, 79–87. https://doi.org/10.1016/j.actpsy.2017.09.002

Rizopoulos, D. (2006). **ltm**: An *R* Package for Latent Variable Modeling and Item Response Theory Analyses. *Journal of Statistical Software*, *17*(5). https://doi.org/10.18637/jss.v017.i05

Schmidt, E. A., Schrauf, M., Simon, M., Fritzsche, M., Buchner, A., & Kincses, W. E. (2009). Drivers' misjudgement of vigilance state during prolonged monotonous daytime driving. *Accident Analysis & Prevention*, *41*(5), 1087–1093. https://doi.org/10.1016/j.aap.2009.06.007

Schuchardt, K., Maehler, C., & Hasselhorn, M. (2008). Working Memory Deficits in Children With Specific Learning Disorders. *Journal of Learning Disabilities*, *41*(6), 514–523. https://doi.org/10.1177/0022219408317856

Sievert, C. (2020). *Interactive Web-Based Data Visualization with R, plotly, and shiny* (1st ed.). Chapman and Hall/CRC. https://doi.org/10.1201/9780429447273

Stratta, P., Daneluzzo, E., Prosperini, P., Bustini, M., Mattei, P., & Rossi, A. (1997). Is wisconsin card sorting test performance related to 'working memory' capacity? *Schizophrenia Research*, *27*(1), 11–19. https://doi.org/10.1016/S0920-9964(97)00090-X

Strayer, D. L., Turrill, J., Cooper, J. M., Coleman, J. R., Medeiros-Ward, N., & Biondi, F. (2015). Assessing Cognitive Distraction in the Automobile. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *57*(8), 1300–1324. https://doi.org/10.1177/0018720815575149

Szczygieł, M. (2021). The relationship between math anxiety and math achievement in young children is mediated through working memory, not by number sense, and it is not direct. *Contemporary Educational Psychology*, *65*, 101949. https://doi.org/10.1016/j.cedpsych.2021.101949

Tsigeman, E., Silas, S., Frieler, K., Likhanov, M., Gelding, R., Kovas, Y., & Müllensiefen, D. (2022). The Jack and Jill Adaptive Working Memory Task: Construction, Calibration and Validation. *PLOS ONE*, *17*(1), e0262200. https://doi.org/10.1371/journal.pone.0262200

Wells, E. L., Kofler, M. J., Soto, E. F., Schaefer, H. S., & Sarver, D. E. (2018). Assessing working memory in children with ADHD: Minor administration and scoring changes may improve digit span backward's construct validity. *Research in Developmental Disabilities*, *72*, 166–178. https://doi.org/10.1016/j.ridd.2017.10.024

Yaple, Z. A., Stevens, W. D., & Arsalidou, M. (2019). Meta-analyses of the n-back working memory task: FMRI evidence of age-related changes in prefrontal cortex involvement across the adult lifespan. *NeuroImage*, *196*, 16–31.