

Working memory performance differentiated by physical functional capacity in late-adulthood

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KEYWORDS: Sternberg paradigm, Six-minute Walking Test, executive function

ABSTRACT: The aim of this study was to examine whether working memory performance is differentiated by higher and lower physical functional capacities in the elderly. Forty-six healthy, active older males aged 65-75 years were assigned into either a Higher-capacity group (HC group; $n = 23$) or Lower-capacity group (LC group; $n = 23$) based on the median split of their distance walked in the 6-min walking test, an assessment tool for physical functional capacity. The Sternberg working memory paradigm was employed to measure working memory performance, where data on reaction times (RT) and response accuracy were collected as performance indices. Results demonstrated that the HC group had faster RT compared with the LC group. No group difference in response accuracy was observed. Overall, the study indicated that working memory performance may be differentiated by physical functional capacity in healthy, active older males.

Working memory is one of the core subcomponents of executive functioning (Miyake, Friedman, Emerson, Witzki and Howerter, 2000). Features of working memory are that it is capacity-limited, and an operation that retains previously encoded information for a short period of time and relates/manipulates the encoded information with upcoming events (Baddeley, 2012). Studies suggest that working memory is crucial and strongly predictive for executive function as well as a wide range of higher-order cognition such as episodic memory (Beilock and Carr, 2005; Conway et al., 2005; McCabe, Roediger, McDaniel, Balota and Hambrick, 2010). Further, working memory is susceptible to aging, where it declines substantially after the age of sixty, and substantially accounts for cognitive degradation (Nyberg, Lövdén, Riklund, Lindenberger and Bäckman, 2012; Park et al., 2002) as well as impaired daily functioning and individual independence (Goble, Mousigian and Brown, 2012; Schmitter-Edgecombe and Parsey, 2014; Tucker-

Drob, 2011). Accordingly, any approach that can facilitate working memory in the elderly may be relevant.

Despite the substantial decline of working memory in old age, it is suggested by past studies that older adults with higher aerobic capacity may have superior working memory performance compared with those with lower aerobic capacity. Specifically, by using a cross-sectional or correlational design, previous studies revealed positive associations of direct-measured or predicted maximal aerobic capacity with performances on a digital or visuospatial working memory paradigm (Erickson et al., 2009, 2012; Newson and Kemps, 2008; Weinstein et al., 2012). Further, one longitudinal study also demonstrated that improved working memory was correlated with enhanced aerobic capacity after a one-year walking intervention in older adults (Voss et al., 2013). However, measurement of aerobic capacity may be sometimes challenging for the elderly. Aerobic

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capacity represents the amount of oxygen consumption as measured during maximal or submaximal graded exercise testing (GXT), mostly on a motorized treadmill (Clemente, Withers and Thompson, 2009; Dlugosz et al., 2013). Administration of GXT is usually time- and resource-consuming (i.e., equipment, trained staff, medical supervision), especially when a large sample size is needed. Further, for older adults, risks that are associated with the maximal or submaximal GXT (i.e., injury, heart attack, strokes) may be substantially increased (American College of Sports Medicine, 2012).

Instead of using aerobic capacity as the predictor of cognitive performance in the elderly, the measure of physical functional capacity, usually assessed by the six-min walking test (6MWT), may be an alternative. The 6MWT is a widely used tool for physical functional capacity assessment in clinical and healthy elderly (Du, Newton, Salamonson, Carrieri-Kohlman and Davidson, 2009). Strengths of the 6MWT include easy administration, measurement, quantification, and interpretation (Enright, 2003). According to the guidelines of American Thoracic Society (ATS), this test evaluates the global and integrated responses of various physiological systems to physical exercise, including pulmonary, cardiovascular, circulatory, neuromuscular, and metabolic systems, rather than specific information regarding the function of individual system (ATS, 2002). This test measures the distance that individuals can quickly walk on a flat and hard-surface field in a period of 6 min with self-paced speeds. Additionally, even though 6MWT is not a valid measurement for maximal physical functional capacity, it is worth noting that most daily physical activities are performed at submaximal levels of exertion and require the involvement of various physiological systems. Accordingly, performance on the 6MWT is representative of older adults' capability to perform daily physical activities (ATS, 2002; Solway, Brooks, Lacasse and Thomas, 2001).

Converging evidence has suggested that performance on the 6MWT is positively correlated with various health benefits in older adults, including facilitated cognitive function. For example, a recent study (Serra et al., 2015) indicated that distance walked in the 6MWT (6MWD) was positively associated with self-reported ratings of physical function, social function, and emotion in the elderly. Another study revealed that the 6MWD was positively correlated with lower limb muscle strength (Pradon, Roche, Enette and Zory, 2013). Further, two clinical

studies have demonstrated positive associations of the 6MWD with cognitive function (Baldasseroni et al., 2010; Makizako et al., 2013). Specifically, the Baldasseroni et al. (2010) study found a positive relationship between the 6MWD and global cognitive performance as assessed by the Mini-mental State Examination (MMSE) in older outpatients with chronic heart failure (CHF). Similarly, by applying neuroimaging technique and recruiting community-dwelling older adults with mild cognitive impairments (MCI), Makizako et al. (2013) firstly revealed that performance on logical and visual memory tests was positively correlated with 6MWD; and secondly, demonstrated that inferior performance on the 6MWT was correlated with lower cerebral gray matter volumes in the left middle temporal gyrus, middle occipital gyrus, and hippocampus, respectively.

Despite the positive association of the 6MWD with cognitive function in clinical populations that has been demonstrated by previous studies, the relationship has remained unclear in a non-clinical, healthy population. We considered this line of research relevant due to its practical implications for healthy elderly. Therefore, it is imperative to investigate the relationship of physical functional capacity as assessed by the 6MWT with cognitive performance, working memory in particular, in a population consisting of healthy, non-clinical older adults. We hypothesized that older adults with greater 6MWD would outperform those with lower 6MWD in a working memory task.

Method

Participants

Fifty healthy older males aged 65 to 75 years were initially recruited via posters and fliers distributed around Taipei City, Taiwan. Forty-six participants were assigned into either a Higher-capacity group (HC group; $n = 23$) or the Lower-capacity group (LC group; $n = 23$) out of the fifty originally recruited, after four participants were excluded because their 6MWD were close to the median split value (579.0 m; ranged from 256-733 m) of their 6MWD. The strategy of recruiting only male participants was based upon that sex is suggested to affect cognitive performance in the elderly due to the transient change of hormonal environment in older women (Hogervorst, 2013). This recruiting strategy helped us rule out the potential confounding effects of sex on the behavioral results. Inclusion criteria were as follows:

participants had to be non-smokers who were free of diagnostic cardiovascular-related disease, psychiatric disorders, and neurological abnormalities. The design, procedure, and the informed consent were approved by the Institutional Review Board of National Taiwan University. All participants signed informed consent forms before participating in the study.

Experimental procedures

Participants were asked to visit the laboratory in the morning. They were requested to refrain from caffeine or alcohol intake and strenuous exercise the day before testing. The participants signed the informed consent after having been instructed on the content and procedure of the experiment by a trained examiner. Next, participants underwent an initial screening to determine their readiness for physical activity, health history, and anthropometric data (i.e., age, body mass index, waist circumference, and amount of physical activity). Age was reported by participants, body mass index (BMI) was estimated based on height and weight assessed by the examiners in the laboratory, and waist circumference (WC) was also assessed by the examiners in the laboratory. Afterwards, participants completed a working memory task that took approximately 25-30 minutes. Lastly, participants performed a 6MWT 10 minutes after the cognitive task.

Determination of physical functional capacity

Participants' physical functional capacities were determined using the 6MWT, where the total distance walked was measured as performance index. The test procedure involved walking continuously around a 50-yard (45.7 meters) course. The participants were instructed to walk as long and fast as possible in self-paced speeds for six min. Participants' paces were monitored by the same two examiners blinded for working memory results to confirm that all participants tried their best during the entire six min session. At the end of the six min, participants were stopped immediately and asked to step aside, and their distance walked was measured by the examiners. The entire procedure was based on the operating guidelines of ATS (2002) and Rikli and Jones (2013).

Assessments of the amount of physical activity

Amount of physical activity was determined using the Taiwanese version of the *International Physical Activity Questionnaire* (IPAQ) (Liou, Jwo, Yao,

Chiang and Huang, 2008). The IPAQ records physical activity characteristics regarding to the modality (e.g., working, household, transportation, exercise, and entertainment), the intensity (i.e., vigorous, moderate, and walking), the duration (e.g., 10 or more minutes), and the frequency (i.e., number of days per week) of physical activity performed during the previous week. The amount of physical activity was calculated in terms of the total metabolic equivalents (METs) by using the MET intensity x minutes/day x days/week formula. The MET intensity was 8, 4 and 3.3 METs for vigorous physical activity, moderate physical activity and walking, respectively. Further, three physical activity levels can be identified based on the total MET if necessary: physical inactivity level (i.e., less than 600 METs per week), middle physical activity level (i.e., 600-1500 METs per week), and high physical activity levels (i.e., vigorous physical activity > 1500 METs or overall physical activity > 3000 METs per week).

Working memory paradigm and procedures

The current study applied a modified digital Sternberg working memory paradigm to assess working memory via the NeuroScan STIM software (ver. 2.0; Neuro Inc., El Paso, TX, USA). This test has been adapted in physical activity-cognition research (Chang, Huang, Chen and Hung, 2013) and its working memory testing paradigm is sensitive to older adults (Finnigan, O'Connell, Cummins, Broughton and Robertson, 2011; Tays, Dywan, Capuana and Segalowitz, 2011). Participants completed a total of 110 trials consecutively. Each trial consisted of five stimulus digits in the encoding phase and two probe digits in the retrieval phase. Each trial started by a fixation cross +, followed by the five stimulus digits presented for 200 ms each, with a 1400 ms interval between each. Stimulus digits were presented in white color on a black background and were generated randomly from 1-9. Following a 2000 ms pause after the fifth stimulus digit, a yellow probe digit was presented for a duration of 3500 ms or until the participants responded. Participants were instructed to press a green button with their right index finger if the probe digit matched one of the previous encoded stimuli (matched probes) or to press a red button with the same finger if the probe digit did not match previous encoded stimuli (non-matched probes). Following another 2000 ms pause, a second probe digit was presented, and the participants were also instructed to respond. The matched and non-

matched trials were randomly presented with equal probability.

Participants were given practice trials prior to testing. The tests began when participants verbally reported understanding the task, and were observed operating the task properly. Participants were instructed to respond as quickly and accurately as possible. Performance was indexed by the reaction times (RT) and response accuracy of participants' responses to both the matched and non-matched probes.

Statistical analysis

All data were presented as mean ± SD. Independent-samples t-tests were firstly utilized to test homogeneity between groups for the demographics data. Next, independent-samples t-tests were separately computed for RT and accuracy to examine differences

in working memory performance between the HC and LC groups. Cohen's d effect sizes were reported once significant group difference was revealed. All data were processed using SPSS software (version 19.0), and the level of significance was set at $\alpha = .05$.

Results

Demographics

As expected, significant group difference in 6MWD ($t(44) = 7.79; p < .001$; Cohen's $d = 2.30$) was observed. No significant group difference was observed in other demographics such as age ($t(44) = -0.99; p > .05$; Cohen's $d = -0.31$), BMI ($t(44) = -1.13; p > .05$; Cohen's $d = -0.33$), WC ($t(44) = -0.85; p > .05$; Cohen's $d = -0.25$), and IPAQ ($t(44) = -0.54; p > .05$; Cohen's $d = -0.16$). Table 1 presents the demographics of participants.

Table 1

Demographics of Participants

Measure	HC group	LC group	Overall
	<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>
Sample size (N)	23	23	46
Age (years)	68.4 (2.8)	69.4 (3.7)	68.9 (3.3)
BMI (kg/m ²)	24.2 (2.6)	25.3 (4.0)	24.8 (3.4)
WC (cm)	88.6 (8.1)	90.9 (10.1)	89.7 (9.1)
IPAQ (METs)	2889.5 (2170.0)	3224.2 (2070.3)	3056.8 (2103.8)
6MWD (m)*	628.4 (37.8)	495.4 (72.6)	561.9 (88.3)

BMI: body mass index; WC: waist circumference; 6MWD: distance walked in the 6-min walking test. * Significant difference between groups, $p \leq .05$.

Working memory performance

For RT, significant group difference was observed ($t(44) = -2.38; p < .05$; Cohen's $d = -0.70$), where RT was significantly shorter in the HC group (953.61 ± 234.54 ms) compared with that in the LC group (1106.64 ± 199.36 ms). For accuracy, results demonstrated no significant group difference ($t(44) = 1.73; p > .05$; Cohen's $d = 0.49$). We also computed correlational analysis to further address the relationship between 6MWD and RT or accuracy. The results revealed similar patterns as demonstrated by the t-tests; for instance, 6MWD was significantly correlated with RT ($r = -0.43; p = .003$) but not accuracy ($r = 0.15; p > .05$). Table 2 presents the RT and accuracy fluctuations as a function of group.

Table 2

Means and SD of RT and Accuracy in Working Memory Paradigm

Measure	HC group	LC group
RT (ms)*	953.6 ± 234.5	1106.6 ± 199.4
Accuracy (%)	96.1 ± 3.2	94.0 ± 5.1

RT: mean reaction times. ms: milliseconds. * Significant difference between groups, $p \leq .05$.

Discussion

The main finding of this study was that working memory performance in healthy, active older males may be differentiated by their physical functional capacity. Specifically, older males with higher 6MWD demonstrated faster processing speeds, as indexed by RT, in the Sternberg paradigm compared with those with lower 6MWD. The faster processing speed in the HC group did not result from a speed-accuracy strategy during task administration because no group difference on accuracy was observed.

Our findings have provided preliminary evidence supporting the role of 6MWD in differentiating working memory performance. Previous clinical studies (Baldasseroni et al., 2010; Makizako et al., 2013) have evidenced the positive associations of the 6MWD with global cognition as well as logical and visual memory performances in older outpatients with CHF or older adults with MCI. The current study, therefore, has extended previous findings. Regarding possible mechanisms, studies have evidenced that 6MWD could be positively correlated with muscular strength of lower extremities (i.e., quadriceps) (Pradon et al., 2013) whereas superior muscular strength could be associated with preserved vascular function and lower levels of inflammation, which otherwise may lead to cerebrovascular insults that impair cognitive functioning (Chen et al., 2015; Rantanen et al., 2003). Further, step length variability, a factor that accounts for performance in walking tests, has been evidenced to be negatively associated with gray matter integrities in brain regions that were presumed responsible for executive function and working memory (i.e., hippocampus, anterior cingulate cortex) (Rosso et al., 2014). These findings have suggested possible underlying mechanisms that account for the relationship between higher 6MWD and superior working memory performance, yet more studies should be warranted to clarify this issue.

The practical implications provided by the present study should be noted. As mentioned, previous studies have mainly focused on the association of aerobic capacity and working memory. These studies usually employed directly-measured or estimated maximal aerobic capacity and found that older adults who are able to achieve their maximal amount of oxygen consumption during testing in greater extent have better working memory performance (Erickson et al., 2009; Erickson et al., 2012; Newson and Kemps, 2008; Weinstein et al., 2012). However, for older adults most daily physical activities are performed at submaximal levels of exertion and require involvements of various physiological systems (i.e., pulmonary, cardiovascular, circular, neuromuscular, and metabolic). The measurement of maximal aerobic capacity may, therefore, be limited for practical utilization because older adults rarely perform daily physical activities at their maximal levels of exertion, and various physiological systems should be involved when performing daily physical activities. In contrast, our results that show working memory performance was differentiated by the 6MWD may have better practical implications. The 6MWT evaluates the global responses of various physiological systems to exercise rather than the specific function of individual systems (ATS, 2002). Further, the 6MWT aims to examine individuals' submaximal physical functional capacity, which is representative of the capability to perform daily physical activities (ATS, 2002; Solway et al., 2001). Collectively, as compared with the direct-measured or estimated maximal aerobic capacity employed by previous studies, measurement of physical functional capacity could provide more comprehensive view and practical implications for the understanding of working memory improvement for older adults.

It is worth noting that most participants recruited by the present study were relatively active and with moderate to high physical functional capacities.

Most participants recruited were with middle to high levels of self-reported physical activity based on the stratification of Liou et al. (2008); only two participants' data on the 6MWD were out of the 400- to 700-m normal range of healthy elderly (Enright, 2003). Despite these participants' characteristics, our results still manifested the positive effect of higher physical functional capacity on working memory, which may indicate the potential role of physical functional capacity to differentiate working memory performance in such populations (i.e., healthy, active, with moderate to high physical functional capacity). Further, the potential role of physical functional capacity was not likely biased by difference in levels of physical activity, another factor associated with working memory performance in healthy elderly (Chang et al., 2013; Wang et al., 2014) given that no difference in IPAQ was observed between the HC and LC groups.

Characteristics of physical exercises performed by participants contributed, in part, to group differences in physical functional capacity and working memory performance while the IPAQ showed no group differences. For example, studies have shown that exercise with characteristics of multicomponent (e.g., Tai Chi, tennis, table tennis), which emphasizes the stimulation of multiple perceptual-motor pathways (e.g., visuomotor coordination, sensory ability, attention control) (Nashner and Peters, 1990), were more beneficial to cognitive function than aerobic exercise alone (Chang, Nien, Chen and Yan, 2014; Dai, Chang, Huang and Hung, 2013; Fong, Chi, Li and Chang, 2014; Huang, Lin, Hung, Chang and Hung, 2014) Further, Smith et al. (2010) suggested that individuals who participate in combined aerobic and strength exercise, which stimulates vascular, motor, and neuromuscular fitness, acquire greater working memory benefits than those participate in aerobic exercise alone. Accordingly, individuals who regularly participate in multicomponent exercise or combined aerobic and strength exercise may acquire superior physical capacity and working memory ability compared to those participate in exercise with more consistent and repetitive patterns (e.g., jogging, swimming) without difference in the amount of

participation.

There are several limitations that should be acknowledged. First, given that our participants mainly consisted of those with moderate and high physical functional capacities and active lifestyle, generalization of these findings to apply to a population with more sedentary lifestyle and lower physical functional capacity/fitness levels would require further investigation. Further, the present study is preliminary in nature with a relatively small sample size and limited measures, which limits our interpretations toward results. Yet, the current study has provided a foundation for future studies concerning functional capacity-working memory relation. Last but not least, even though the usefulness of self-reported measurement of physical activity levels in this type of research has been demonstrated (Chang et al., 2013; Wang et al., 2014), objective measures such as accelerometers and motion sensors should be incorporated in future studies to provide a more accurate assessment of physical activity levels.

In summary, this study has added to the knowledge by demonstrating that working memory performance in a healthy, active population may be differentiated by their physical functional capacity. Our results may provide a practical implication to such group: individuals who are able to better performing a quick walking test representative of daily physical activities may have superior working memory performance. Future studies that intend to replicate our findings in a female population or more comprehensively examine the association of physical functional capacity with working memory by considering issues listed by current study are strongly recommended. Moreover, the potential biasing effect of individual variability in genotypes should be considered. Specifically, individuals with the apolipoprotein E type 4 allelic genotype or the methionine-specifying (Met) allele of brain-derived neurotrophic factor (BDNF) could be more susceptible to cognitive benefits associated with exercise compared to those without (Erickson et al., 2013; Etnier et al., 2007). Future research must take into account this critical issue for study design.

RENDIMIENTO DE LA MEMORIA DE TRABAJO DIFERENCIADO POR LA CAPACIDAD FUNCIONAL FÍSICA EN LA EDAD ADULTA TARDÍA

PALABRAS CLAVES: Paradigma de Sternberg, Prueba de caminata de seis minutos, función ejecutiva.

RESUMEN: El objetivo de este estudio fue examinar si el desempeño de la memoria de trabajo se diferenció por mayores y menores capacidades físicas funcionales en los ancianos. Cuarenta y seis hombres sanos y activos mayores de 65-75 años fueron asignados a un grupo de mayor capacidad (grupo HC, $n = 23$) o grupo de menor capacidad (grupo LC, $n = 23$) basado en la división media de su distancia recorrida en el test de 6 min de marcha, una herramienta de evaluación de la capacidad funcional física. El paradigma de memoria de trabajo de Sternberg se empleó para medir el rendimiento de la memoria de trabajo, donde los datos sobre los tiempos de reacción (RT) y la precisión de respuesta se recogieron como índices de rendimiento. Los resultados demostraron que el grupo HC tuvo una RT más rápida en comparación con el grupo LC. No se observó diferencia de grupo en la exactitud de la respuesta. En general, el estudio indicó que el rendimiento de la memoria de trabajo puede ser diferenciado por la capacidad funcional física en los hombres mayores sanos activos.

DESEMPENHO DA MEMÓRIA DE TRABALHO DIFERENCIADO PELA CAPACIDADE FÍSICA FUNCIONAL NO FINAL DA IDADE ADULTA

PALAVRAS-CHAVE: Paradigma de Sternberg, Teste de caminhada de seis minutos, função executiva

RESUMO: O objetivo deste estudo foi analisar se o desempenho da memória de trabalho é diferenciado pela maior e menores por capacidades físicas e físicas nos idosos. Quarenta e seis homens saudáveis, ativos e mais velhos, com idades entre 65 e 75 anos, foram divididos em um grupo de maior capacidade (grupo HC, $n = 23$) ou grupo com menor capacidade (grupo LC, $n = 23$), com base na divisão mediana de seus Distância percorrida no teste de caminhada de 6 minutos, uma ferramenta de avaliação da capacidade funcional física. O paradigma da memória de trabalho de Sternberg foi empregado para medir o desempenho da memória de trabalho, onde os dados sobre tempos de reação (RT) e precisão de resposta foram coletados como índices de desempenho. Os resultados demonstraram que o grupo HC apresentou RT mais rápida em comparação com o grupo LC. Nenhuma diferença de grupo na exatidão de resposta foi observada. Em geral, o estudo indicou que o desempenho da memória de trabalho pode ser diferenciado pela capacidade funcional física em homens ativos e saudáveis, mais velhos.

References

- American College of Sports Medicine. (2012). *ACSM's guidelines for exercise testing and prescription*. Philadelphia, PA: Lippincott Williams and Wilkins.
- American Thoracic Society (2002). ATS statement: Guidelines for the six-minute walk test. *American Journal of Respiratory and Critical Care Medicine*, 166(1), 111-117.
- Baddeley, A. (2012). Working memory: Theories, models, and controversies. *Annual Review of Psychology*, 63, 1-29.
- Baldasseroni, S., Mossello, E., Romboli, B., Orso, F., Colombi, C. and Fumagalli, S. (2010). Relationship between cognitive function and 6-minute walking test in older outpatients with chronic heart failure. *Aging Clinical Experimental Research*, 22(4), 308-313.
- Beilock, S. L. and Carr, T. H. (2005). When high-powered people fail: Working memory and “choking under pressure” in math. *Psychological Science*, 16(2), 101-105.
- Chang, Y. K., Huang, C. J., Chen, K. F. and Hung, T. M. (2013). Physical activity and working memory in healthy older adults: An ERP study. *Psychophysiology*, 50(11), 1174-1182.
- Chang, Y. K., Nien, Y. H., Chen, A. G. and Yan, J. (2014). Tai Ji Quan, the brain, and cognition in older adults. *Journal of Sport and Health Science*, 3(1), 36-42.
- Chen, W. L., Peng, T. C., Sun, Y. S., Yang, H. F., Liaw, F. Y., Wu, L. W., . . .Kao, T. W. (2015). Examining the association between quadriceps strength and cognitive performance in the elderly. *Medicine*, 94(32), e1335.
- Clemente, C. J., Withers, P. C. and Thompson, G. G. (2009). Metabolic rate and endurance capacity in

Australian varanid lizards. *Biological Journal of the Linnean Society*, 97, 664-676.

Conway, A. R. A., Kane, M. J., Bunting, M. F., Hambrick, D. Z., Wilhelm, O. and Engle, R. W. (2005). Working memory span tasks: A methodological review and user's guide. *Psychonomic Bulletin and Review*, 12(5), 769-786.

Dai, C. T., Chang, Y. K., Huang, C. J. and Hung, T. M. (2013). Exercise mode and executive function in older adults: An ERP study of task-switching. *Brain and Cognition*, 83(2), 153-162.

Dlugosz, E. M., Chappell, M. A., Meek, T. H., Szafranska, P. A., Zub, K., Konarzewski, M., ...Garland Jr., T. (2013). Phylogenetic analysis of mammalian maximal oxygen consumption during exercise. *The Journal of Experimental Biology*, 216(24), 4712-4721.

Du, H. Y., Newton, P. J., Salamonson, Y., Carierri-Kohlman, V. L. and Davidson, P. M. (2009). A review of the six-minute walk test: Its implication as a self-administered assessment tool. *European Journal of Cardiovascular Nursing*, 8(1), 2-8.

Enright, P. L. (2003). The six-minute walk test. *Respiratory Care*, 48(8), 783-785.

Erickson, K. I., Banducci, S. E., Weinstein, A. M., Macdonald, A. W., 3rd, Ferrell, R. E., Halder, L., . . .Manuck, S. B. (2013). The brain-derived neurotrophic factor Val66Met polymorphism moderates an effect of physical activity on working memory performance. *Psychological Science*, 24(9), 1770-1779.

Erickson, K. I., Prakash, R. S., Voss, M. W., Chaddock, L., Hu, L., Morris, K. S.,...Kramer, A. F. (2009). Aerobic fitness is associated with hippocampal volume in elderly humans. *Hippocampus*, 19(10), 1030-1039.

Erickson, K. I., Weinstein, A. M., Sutton, B. P., Prakash, R.S., Voss, M. W., Chaddock, L.,...Kramer, A. F. (2012). Beyond vascularization: Aerobic fitness is associated with N-acetylaspartate and working memory. *Brain and Behavior*, 2(1), 32-41

Etnier, J. L., Caselli, R. J., Reiman, E. M., Alexander, G. E., Sibley, B. A., Tessier, D. and McLemore, E. C. (2007). Cognitive performance in older women relative to ApoE-epsilon4 genotype and aerobic fitness. *Medicine and Science in Sports and Exercise*, 39(1), 199-207.

Finnigan, S., O'Connell, R. G., Cummins, T. D. R., Broughton, M. and Robertson, I. H. (2011). ERP measures indicate both attention and working memory encoding decrements in aging. *Psychophysiology*, 48(5), 601-611.

Fong, D. Y., Chi, L. K., Li, F. and Chang, Y. K. (2014). The benefits of endurance exercise and Tai Chi Chuan for the task-switching aspect of executive function in older adults: An ERP study. *Frontiers in Aging Neuroscience*, 6: 295.

Goble, D. J., Mousigian, M. A. and Brown, S. H. (2012). Compromised encoding of proprioceptively determined joint angles in older adults: The role of working memory and attentional load. *Experimental Brain Research*, 216(1), 35-40.

Hogervorst, E. (2013). Effects of gonadal hormones on cognitive behaviour in elderly men and women. *Journal of Neuroendocrinology*, 25(11), 1182-1195.

Huang, C. J., Lin, P. C., Hung, C. L., Chang, Y. K. and Hung, T. M. (2014). Type of physical exercise and inhibitory function in older adults: An event-related potential study. *Psychology of Sport and Exercise*, 15(2), 205-211.

Liou, Y. M., Jwo, C. J. C., Yao, K. G., Chiang, L. C. and Huang, L. H. (2008). Selection of appropriate Chinese terms to represent intensity and types of physical activity terms for use in the Taiwan version of IPAQ. *Journal of Nursing Research*, 16(4), 252-263.

Makizako, H., Shimada, H., Doi, T., Park, H., Yoshida, D. and Suzuki, T. (2013). Six-minute walking distance correlated with memory and brain volume in older adults with mild cognitive impairment: A voxel-based morphometry study. *Dementia and Geriatric Cognitive Disorders Extra*, 3(1), 223-232.

McCabe, D. P., Roediger, H. L., McDaniel, M. A., Balota, D. A. and Hambrick, D. Z. (2010). The relationship between working memory capacity and executive functioning: Evidence for a common executive attention construct. *Neuropsychology*, 24(2), 222-243.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H. and Howerter, A. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology*, 41(1), 49-100.

- Nashner, L. M. and Peters, J. F. (1990). Dynamic posturography in the diagnosis and management of dizziness and balance disorders. *Neurologic clinics*, 8(2), 331-349.
- Newson, R. S. and Kemp, E. B. (2008). Relationships between fitness and cognitive performance in younger and older adults. *Psychology and Health*, 23(3), 369-86.
- Nyberg, L., Lövdén, M., Riklund, K., Lindenberg, U. and Bäckman, L. (2012). Memory aging and brain maintenance. *Trends in Cognitive Sciences*, 16(5), 292-305.
- Park, D. C., Lautenschlager, G., Hedden, T., Davidson, N. S., Smith, A. D. and Smith, P. K. (2002). Models of visuospatial and verbal memory across the adult life span. *Psychology and Aging*, 17(2), 299-320.
- Pradon, D., Roche, N., Enette, L. and Zory, R. (2013). Relationship between lower limb muscle strength and 6-minute walk test performance in stroke patients. *Journal of Rehabilitation Medicine*, 45(1), 105-108.
- Rantanen, T., Volpato, S., Ferrucci, L., Heikkinen, E., Fried, L. P. and Guralnik, J. M. (2003). Handgrip strength and cause-specific and total mortality in older disabled women: Exploring the mechanism. *Journal of the American Geriatric Society*, 51(5), 636-641.
- Rikli, R. E. and Jones, J. (2013). *Senior Fitness Test Manual*. Champaign, IL: Human Kinetics.
- Rosso, A. L., Olson Hunt, M. J., Yang, M., Brach, J. S., Harris, T. B., Newman, A. B., . . .Rosano, C. (2014). Higher step length variability indicates lower gray matter integrity of selected regions in older adults. *Gait and Posture*, 40(1), 225-230.
- Schmitter-Edgecombe, M. and Parsey, C. M. (2014). Assessment of functional change and cognitive correlates in the progression from healthy cognitive aging to dementia. *Neuropsychology*, 28(6), 881-893.
- Serra, A. N., de Carvalho Pde, T., Lanza, F., de Amorim Flandes, C., Silva, S. C., Suzuki, F. S., . . .Silva Jr., J. A. (2015). Correlation of six-minute walking performance with quality of life is domain- and gender-specific in healthy older adults. *PLoS one*, 10(2), e0117359.
- Smith, P. J., Blumenthal, J. A., Hoffman, B. M., Cooper, H., Strauman, T. A., Welsh-Bohmer, K., . . .Sherwood, A. (2010). Aerobic exercise and neurocognitive performance: A meta-analytic review of randomized controlled trials. *Psychosomatic Medicine*, 72(3), 239-252.
- Solway, S., Brooks, D., Lacasse, Y. and Thomas, S. A. (2001). A qualitative systematic overview of the measurement properties of functional walk tests used in the cardiorespiratory domain. *Chest*, 119(1), 256-270.
- Tays, W. J., Dywan, J., Capuana, L. J. and Segalowitz, S. J. (2011). Age-related differences during simple working memory decisions: ERP indices of early recognition and compensation failure. *Brain Research*, 1393, 62-72.
- Tucker-Drob, E. M. (2011). Neurocognitive functions and everyday functions change together in old age. *Neuropsychology*, 25(3), 368-377.
- Voss, M. W., Heo, S., Prakash, R. S., Erickson, K. I., Alves, H., Chaddock, L., . . .Kramer, A. F. (2013). The influence of aerobic fitness on cerebral white matter integrity and cognitive function in older adults: Results of a one-year exercise intervention. *Human Brain Mapping*, 34(11), 2972-2985.
- Wang, C. H., Tsai, C. L., Tseng, P., Yang, A. C., Lo, M. T., Peng, C. K., . . .Liang, W. K. (2014). The association of physical activity to neural adaptability during visuo-spatial processing in healthy elderly adults: A multiscale entropy analysis. *Brain and Cognition*, 92, 73-83.
- Wienstein, A. M., Voss, M. W., Prakash, R.S., Chaddock, L., Szabo, A., White, S. M., . . .Erickson, K. I. (2012). The association between aerobic fitness and executive function is mediated by prefrontal cortex volume. *Brain, Behavior, and Immunity*, 26(5), 811-819.

