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# Executive Function and Measures of Fall Risk Among People With Obesity

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## Abstract

This study investigated the relationship between obesity and executive function, and between executive function and fall risk (as estimated from select gait parameters). Of the 39 young adults (age = 21.3 ± 2.6 years) recruited from the local university population via email announcement, 19 were in the obese group (based upon BMI and body fat percentage) and 20 were in the nonobese comparison group. Executive function was assessed using standardized tests including the Stroop test for selective attention; Trail Making test for divided attention, visuomotor tracking, and cognitive flexibility; the Verbal Fluency test for semantic memory; and the Digit-span test for working memory. Participants performed single- and dual-task walking (walking while talking) to evaluate fall risk during gait as measured by minimum toe clearance, required coefficient of friction, stance time, and stance-time variability. The obese group had lower scores for selective attention, semantic memory, and working memory. All participants had gait changes suggestive of a higher fall risk, for example, lower minimum toe clearance, longer stance time, and increased stance variability, during dual-task walking compared with single-task walking, and executive function scores (selective attention) were associated with gait (stance-time variability) during dual-task walking. Results indicate obesity was negatively associated with executive function among young adults and could increase fall risk.

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obesity performed significantly worse on tests for executive function compared with healthy weight controls (Reinert, Poe, & Barkin, 2013). No studies to our knowledge have investigated a similar association among adults. The mechanism by which obesity adversely affects executive function remains unclear. However, the cerebellum and cerebral cortex play key roles in executive function (Golfman-Rakic, 1998; Mesulam, 1998), and alterations in these structures have been associated with obesity (Miller et al., 2007; Gustafson, Lissener, Bengtsson, Bjorkelund, & Skoog, 2004; Raji, Ho, Parikshak, Beck, & Lopez, 2010).

The higher fall rate among people with obesity may be due, in part, to the adverse effects of obesity on executive function and subsequent changes to gait. Obesity elicits several changes in gait including slower walking velocity (Hills & Parker, 1991; Lai, Leung, Li, & Zhang, 2008; Spyropoulos, Pisciotta, Pavlou, Carins, & Simon 1991; Wearing, Henning, Byrne, Steele & Hills, 2006), longer stance time (Hills & Parker, 1991; Lai et al., 2008; Wearing et al., 2006), and longer double stance time (Hills & Parker, 1991; Lai et al., 2008; McGraw, McClenaghan, Williams, Dickerson, & Ward, 2000). Obesity also elicits changes in gait that are associated with an increased risk of losing balance or falling, including higher required coefficient of friction (RCOF) that suggests a higher likelihood for slipping (Wu, Lockhart, & Yeoh, 2012), lower minimum toe clearance (MTC) that suggests a higher likelihood for tripping (Garman, Franck, Nussbaum, & Madigan, 2015), and longer stance time that suggests compromised balance stability (DeVita & Hortobagyi, 2003). Additional changes in gait would seem possible during dual-task conditions when attentional demands are higher (Forhan & Gill, 2013; Gill, 2011; Hung, Gill & Meredith, 2013), particularly because people with obesity appear to exhibit altered executive function. These additional changes in gait could further increase risk of falling.

The purpose of this study was twofold: to investigate whether there is a negative association of obesity and executive function among young adults, and to determine whether there is a relationship between executive function and fall risk.

*Hypothesis 1.* Executive function will be adversely affected by obesity.

*Hypothesis 2.* Adding a dual task to walking will increase fall risk among both obese and nonobese participants.

*Hypothesis 3.* The increase in fall risk associated with adding a dual task to walking will be more substantial among participants with obesity than those with normal weight.

*Hypothesis 4.* Executive function will be inversely associated with fall risk.

task, so they were excluded from all further analyses involving the Trail Making test). The Verbal Fluency test involves two subtests, with participants asked to name as many words as possible that start with a given letter (i.e., words starts with letter "p") and in a given category domain (i.e., fruit), each for 60 seconds (Rosen, 1980). A higher number of correct words indicated better performance. The Digit-span test has two subtests, the forward and backward tests (Foster, Lidder, & Sunram, 1998). For both subtests, participants were presented with a series of digits, and they were required to immediately repeat them back. The series of digits were presented verbally to participants at a rate of one per second. For the forward subtest, the participant's task was to repeat each sequence exactly as it was given. For the backward subtest, the participant was asked to repeat each sequence in reverse order. Both subtests began with three digits and increased by one at a time up to nine. Each subtest was performed twice using different series of digits. The number of successful sequences was considered the score and ranged from 0 to 14. The difference between the forward and backward subtest scores was used as an indicator of working memory function, with smaller differences indicated better working memory (Foster et al., 1998). All executive function tests were conducted by the same investigator, who was not blind to the study hypotheses.

Single-task and dual-task walking were then performed with the order counterbalanced across participants within each group. All participants wore a T-shirt, tight-fitting shorts, and identical dress shoes (hard polyvinyl chloride soles) to minimize shoe–sole differences. For single-task walking, participants were instructed to walk at a self-selected speed along a 9-m walkway. For dual-task walking, participants were instructed to walk at a self-selected speed along the walkway, but while also reciting every other letter of the alphabet (Verghese et al., 2007). Participants were instructed to "pay equal attention to both walking and talking" and "if the first 13 letters are finished, continue with the second 13 letters, starting with a letter 'B' if starting with letter 'A' the first time and vice versa, and continue this process until instructed to stop." The initial letter on the reciting task was randomly varied between "A" (A-C-E) and "B" (B-D-F) between participants. To reduce learning effects, participants were given three minutes to practice reciting alternate letters of alphabet, and 10 trials to practice the dual-task walking, prior to data collection. Practice walking trials also allowed participants to acclimate to the experimental setup, and allowed for determining the appropriate starting point along the walkway, so that participants naturally and consistently stepped on a force platform embedded within the walkway. Five walking trials were performed during each task.

During walking trials, ground reaction forces were sampled at 1,000 Hz using a six-degree-of-freedom force platform (Advanced Mechanical Technology Inc., Watertown, MA, USA) in the center of the walkway. The position of reflective markers on the left and right calcanei, top of the feet, and one on the right upper back were sampled at 100 Hz using a six-camera motion analysis system

**Table 1.** One-way ANCOVAs: Group differences on tests of executive function.

| | Obese | Comparison | *F* | *p* | Cohen's *d* |
|---|---|---|---|---|---|
| Stroop-test time (seconds) | 93.2 (17.0) | 82.7 (13.8) | 1.92 | .06 | 0.65 |
| Trail Making test time (seconds) | 48.8 (12.5) | 44.2 (11.6) | 1.12 | .27 | 0.38 |
| Verbal Fluency (letter) | 16.7 (5.0) | 20.0 (4.2) | 4.35 | .05* | 0.66 |
| Verbal Fluency (category) | 16.6 (4.2) | 15.8 (3.7) | 0.63 | .43 | 0.21 |
| Digit span | 2.2 (1.3) | 1.4 (1.4) | 3.22 | .08 | 0.55 |

*Note:* Better performance was associated with shorter Stroop-test time, shorter Trail Making test time, more words in Verbal Fluency Test, and lower score in Digit-span test. ANCOVA: analysis of covariance. $^*p \leq .05$ between groups.

0.8 points lower in the obese group. No effects of age ($p > .37$) or years of education ($p > .28$) were found for any executive function tests. Scores from executive function tests and gait parameters were comparable with other studies. The mean Stroop-test completion time of 87.8 seconds across both groups in the current study was similar, yet slightly shorter, than 100.4 seconds reported by Jensen (1965) among young adults. The mean Trail Making test completion time of 46.5 seconds across both groups in the current study was again similar and slightly shorter than the value of ~55 seconds reported by Tombaugh (2004) among young adults. The median Digit-span score (difference between forward and backward digit span tests) of 2 across both groups in the current study was slightly larger than the median score of ~1.5 reported by Foster et al. (1998) among a control group of young adults.

Hypothesis 2 was that adding a dual task to walking would increase fall risk in both obese and comparison groups. This hypothesis was supported because adding a dual task to walking decreased MTC 0.46 cm, increased stance time 0.08 seconds, and increased stance time IQR 0.01 seconds (Table 2). Lower MTC (Aldridge, 2009), higher stance time (Lord, Lloyd, & Li, 1996), and higher stance-time IQR (Beauchet, Dubost, Herrmann, & Kressing, 2005; Maki, 1997) have all been associated with a higher tripping/fall risk. Adding a dual task to walking also reduced RCOF 0.01, which suggests a lower risk of slipping (Wu et al., 2012). The mean MTC in the current study was 1.4 cm across all participants during single-task walking, and was comparable with a mean of ~1.5 cm reported for young adults by Aldridge (2009). The current mean RCOF of 0.21 was also comparable with a mean of 0.20 reported for young adults by Yamaguchi, Yana, Onodera, and Hokkirigawa (2013). The mean stance time during single-task walking of 0.67 seconds was also similar to the mean of 0.65 seconds for young adults reported by Ortega and Farley (2007).

Hypothesis 3 was that the increase in fall risk associated with adding a dual task to walking would be more substantial in the obese group than the performed 11.0% worse on the WRAML working memory index (Maayan et al., 2011). The percentage difference for the Stroop test was comparable with that reported here.

The physiological mechanism by which obesity adversely affects executive function has not been determined, but obesity has been shown to affect brain morphology. In particular, obesity is associated with smaller cerebellar volume among children (Miller et al., 2007), atrophy of the cerebral temporal lobe among older women (Gustafson et al., 2004), and atrophy of the frontal, temporal, and subcortical brain regions among older adults (Raji et al., 2010). Moreover, smaller gray matter volume was found to be associated with worse semantic memory (Taki et al., 2011). Willette and Kapogiannis (2015) recently reported a positive association between body fat and frontal gray matter atrophy. Obesity may contribute to compromised cerebellar development and cerebral cortex atrophy through an abnormal accumulation of lipids in the brain (Sriram, Benkovic, Miller, & O'Callaghan, 2002), or a free fatty acid excess resulting in a pathological lipid metabolism in the brain (Whitmer, Gunderson, Barrett-Connor, Quesenberry, & Yaffe, 2005).

Changes in gait due to adding a dual task is thought to result from a competition for attention resources between the two tasks (Woollacott & Shumway-Cook, 2002). In the current study, introducing a dual task to walking increased fall risk based upon a 33% decrease in MTC, 11.8% increase in stance time, and 33% increase in stance-time variability. Aldridge (2009) also reported a decrease (albeit only 4%) in MTC when adding talking on a phone to walking while young adults walked on a treadmill at a self-selected speed. Similarly, Beauchet et al. (2005) reported an increase (albeit only 6%) in stance-time variability when adding backward counting while young nonobese adults walked at a self-selected speed. The substantially larger effect sizes reported here may be due to differences in participant characteristics between studies, such as the current study including 50% participants, whereas prior studies included all normal weight young adults (Aldridge, 2009; Beauchet et al., 2005); the dual task used here requiring more attention and thus drawing more attention away from gait; and a different method to calculate MTC—the current study used the minimum distance between toe marker and the ground during the mid-swing phase, whereas Aldridge (2009) used the minimum distance between the marker on the fifth metatarsal and the surface of the treadmill. The increase in stance time, although not investigated elsewhere during dual-task walking, may suggest a more cautious walking strategy while simultaneously performing the dual tasks, and is associated with increased fall risk (Karwowski, 2006), alterations in sensorimotor function (Maki, 1997; Taylor et al., 2013), and deficits in balance control (Karwowski, 2006).

Adding a dual task to walking did not adversely affect the obese group more than the comparison group as indicated by the nonsignificant group × task interaction. This was unexpected, given the apparent adverse effect of obesity on executive function and the increased demands of dual-task walking on executive function.

fall risk is common, a direct quantitative relationship between these measures and fall risk is not well established. The distribution of body fat was not measured or controlled, but could affect risk of falling (Hilta-Contrearas et al., 2013), and other measures besides BMI used here may better associate with fall risk. MTC was evaluated without any obstacle present on the walkway, as is common in the literature. The presence of an obstacle may elicit changes in gait characteristics if seen by the participant. Finally, as with any cross-sectional study, other differences between groups besides the characteristics reported here could have contributed to the results, and no causal inferences may be drawn.

The results from the current study provide evidence for three conclusions regarding young adults. Obesity was negatively associated with executive functions (selective attention, semantic memory, and working memory). Adding a talking task to walking increased the risk of tripping and negatively affected balance control. Executive function, that is, selective attention and semantic memory, was weakly correlated with gait measures associated with risk of falling during dual-task walking, suggesting altered executive function associated with obesity may contribute to a higher risk of falling.

## Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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## References

Aldridge, J. M. (2009). *The effect of concurrent cell phone use and walking on gait characteristics* (Thesis). University of Nevada, Las Vegas.

Beauchet, O., Dubost, V., Herrmann, F. R., & Kressing, R. W. (2005). Stride-to-stride variability while backward counting among healthy young adults. *Journal of Neuroengineering and Rehabilitation*, *2*, 26.

Brach, J. S., Wert, D., VanSwearingen, J. M., Newman, A. B., & Studenski, S. A. (2012). Use of stance time variability for predicting mobility disability in community dwelling older persons: A prospective study. *Journal of Geriatric Physical Therapy*, *35*(3), 112–117.

Coppin, A. K., Shumway-Cook, A., Saczynski, J. S., Patel, K. V., Ble, A., Ferrucci, L., & Guralnik, J. M. (2006). Association of executive function and performance of dual-task physical tests among older adults: Analyses from the InChianti study. *Age Ageing*, *35*(6), 619–624.

DeVita, P., & Hortobagyi, T. (2003). Obesity is not associated with increased knee joint torque and power during level walking. *Journal of Biomechanics*, *36*(9), 1355–1362.

Elliott, R. (2003). Executive function and their disorders. *British Medical Bulletin*, *65*(1), 49–59.

Lai, P. P., Leung, A. K., Li, A. N., & Zhang, M. (2008). Three-dimensional gait analysis of obese adults. *Clinical Biomechanics*, *23*(Suppl 1), S2–S6.

Lezak, M. D., Howieson, D. B., & Loring, D. W. (2004). *Neuropsychological assessment* (4th ed.). New York, NY: Oxford University Press.

Liu-Ambrose, T., Davis, J. C., Nagamstsu, L. S., Hsu, C. L., Katarynch, L. A., & Khan, K. M. (2010). Changes in executive functions and self-eeficacy are independently associated with improved usual gait speed in older women. *BMC Geriatrics*, *19*(10), 25.

Lord, S. R., Lloyd, D. G., & Li, S. K. (1996). Sensori-motor function, gait patterns and falls in community-dwelling women. *Age Ageing*, *25*(4), 292–299.

Maayan, L., Hoogendoorn, C., Sweat, V., & Convit, A. (2011). Disinhibited eating in obese adolescents is associated with orbitorontal volume reductions and executive dysfunction. *Obesity*, *19*(7), 1382–1387.

Maki, B. E. (1997). Gait changes in older adults: predictors of falls or indicators of fear. *Journal of the American Geriatric Society*, *45*(3), 313–320.

Matter, K. C., Sinclair, S. A., Hostetler, S. G., & Xiang, H. (2007). A comparison of the characteristics of injuries between obese and non-obese inpatients. *Obesity (Silver Spring)*, *15*(10), 2384–2390.

McGraw, B., McClenaghan, B. A., Williams, H. G., Dickerson, J., & Ward, D. S. (2000). Gait and posture stability in obese and nonobese prepubertal boys. *Archives of Physical Medicine and Rehabilitation*, *81*(4), 484–489.

Meckelborough, J., van der Linden, M. L., Richards, J., & Ennos, A. R. (2000). Validity and reliability of a kinematic protocol for determining foot contact events. *Gait Posture*, *11*, 32–37.

Mesulam, M. M. (1998). From sensation to cognition. *Brain*, *121*, 1013–1052.

Miller, J. L., Couch, J., Schwenk, K., Long, M., Towler, S., Theriague, D. W., . . . Farley, C. T. (2007). Individual limb work does not explain the greater metabolic cost of walking in elderly adults. *Journal of Applied Physiology*, *102*(6), 2266–2273.

Ortega, J. D., & Farley, C. T. (2007). Individual limb work does not explain the greater metabolic cost of walking in elderly adults. *Journal of Applied Physiology*, *102*(6), 2266–2273.

Raji, C. A., Ho, A. J., Parikshak, N., Becker, J. T., Lopez, O. L., Kuller, L. H., . . . Thompson, P. M. (2010). Brain structure and obesity. *Human Brain Mapping*, *31*(3), 353–364.

Reinert, K. R. S., Poe, E. K., & Barkin, S. L. (2013). The relationship between executive function and obesity in children and adolescents: A systematic literature review. *Journal of Obesity*, *2013*. doi:10.1155/2013/820956

Rosen, W. G. (1980). Verbal fluency in aging and dementia. *Journal of Clinical and Experimental Neuropsychology*, *2*(2), 135–146.

Schaefer, S., & Lindenberger, U. (2013). Thinking while walking: Experienced high-heel walkers flexibility adjust their gait. *Frontiers in Psychology*, *3*, 316.

Siervo, M., Arnold, R., Wells, J. C., Taqliabue, A., Colanbuoni, A., Albanese, E., . . . Stephan, B. C. (2011). International weight loss in overweight and obese individuals and cognitive function: A systematic review and meta-analysis. *Obesity Reviews*, *12*(11), 968–983.

Springer, S., Giladi, N., Peretz, C., Yogev-Seligmann, G., Simon, E. S., & Hausdorff, J. M. (2006). Dual-tasking effects on gait variability: The role of aging, falls, and executive function. *Movement Disorders*, *21*, 950–957.

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