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Physical Activity and Depressive Symptoms Interact to Predict Executive Functioning Among Community Dwelling Older Adults

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Abstract

Background—Physical activity is beneficial for the executive functioning (EF) of older adults, but may be particularly protective of EF when they are cognitively vulnerable, such as during depressive episodes. Intervention studies support more potent effects of physical activity on EF among clinically depressed older adults, though these results may have limited generalizability to the daily mood and physical activity of healthy, community dwelling older adults.

Methods—The current study aimed to test whether physical activity among older adults was more protective of EF during periods of cognitive vulnerability due to mildly elevated depressive symptoms. Longitudinal data from 150 generally healthy, community dwelling older adults were collected semi-annually and analyzed with multilevel modeling.

Results—Physical activity was more protective of EF within individuals during periods of relatively elevated depressive symptoms.

Conclusions—The power of physical activity to protect EF during periods of cognitive vulnerability may extend to community dwelling older adults with non-clinical levels of depressive symptoms.

Keywords

physical activity; exercise; older adults; executive functioning; cognition; depression

An essential component of successful and independent daily living in older adults is a set of capacities known as executive functioning (EF), which includes working memory, inhibition, and task switching (Cahn-Weiner et al, 2007; Hart & Bean, 2011; Vaughan & Giovanello, 2010). Normal aging is associated with declines in cognitive functioning, particularly EF (Buckner, 2004; Decarli et al, 2005). Physical activity has protective effects against age-related declines in EF (Colcombe & Kramer, 2003) but may be even more potent when older adults are cognitively vulnerable, such as when they are clinically depressed (Emery & Blumenthal, 1991; Khatri & Blumenthal, 1991). Most studies examining the effects of physical activity on EF during periods of cognitive vulnerability

have used randomized controlled trials of physically or cognitively impaired older adults whose mood and physical activity habits may not generalize to most community dwelling older adults. The current study seeks to test whether physical activity is protective of EF particularly during periods of vulnerability using longitudinal, naturalistic data from a sample of generally healthy, non-clinically depressed, community-dwelling older adults.

Physical Activity and Cognitive Functioning in Older Adults

Although longitudinal and intervention studies have found that higher levels of physical activity attenuate age-related declines in cognitive functioning, there is heterogeneity in these findings (Kramer & Erickson, 2007). A meta-analysis concluded that physical activity improves only some forms of cognition among older adults, including and especially EF (Colcombe & Kramer, 2003). It has been suggested that because the physiological integrity of frontal and pre-frontal cortices in particular declines with age, EF shows larger age-related decrements but is also more responsive to increases in physical activity (Hall, Smith, & Keele, 2001). There is neurophysiological evidence to support this hypothesis: Older adults with higher levels of cardiorespiratory fitness have a higher density of gray and white matter in their frontal lobes than their less fit counterparts (Colcombe, et al., 2003). Physical activity interventions that improve cardiorespiratory fitness among older adults have also resulted in greater regional cerebral blood flow to the frontal cortex, an increase that correlated with improvements in EF performance (Colcombe, Kramer, Erickson, et al., 2004).

Physical Activity and Cognitive Vulnerability

Emery and Blumenthal (1991) hypothesized that physical activity may exert a more powerful effect on cognitive functioning at times of greater vulnerability, such as during periods of physical or emotional illness. For example, a 10-week aerobic exercise and strength training intervention among chronic obstructive pulmonary disease patients, a population at high risk for cognitive impairment, showed improvements in EF compared to control groups (Emery, Scheiein, Hauck, & MacIntyre, 1998).

In addition to physical disease, the presence of an emotional disorder, such as clinical depression, has also been shown to disrupt cognitive functioning among older adults, posing a threat to EF in particular (Dotson, Resnick, & Zonderman, 2008). This impairment in EF during depressive episodes may be related to disruption of frontostriatal neural pathways that result in hypoperfusion of the pre-frontal cortex (Dolan, Bench, Brown, et al., 1992). The degree of EF impairment is positively correlated with the severity of depression experienced by older adults (Boone, Lesser, Miller, et al., 1994). In one study, potency of a 4-month aerobic exercise intervention to improve EF was highest for older adults with mild levels of depression compared to those with moderate to severe depression (Khatri, Blumenthal, Babyak, et al., 2001). Another recent study found that the benefits of exercise for cognitive function are relatively greater for those with lower well-being (Allerhand, Gale, & Deary, 2014). These studies raise the possibility that the effect of physical activity on EF may also apply to relatively mild forms of emotional vulnerability for older adults. However, such intervention studies focusing on clinical samples may not generalize to the

vast majority of older adults who have subclinical levels of depressive symptoms and do not suffer from serious physical ailments that would adversely affect EF.

A recent meta-analysis of randomized controlled trials (RCTs) of exercise interventions among healthy older adults found evidence for improvements in EF (Smith, Blumenthal, Hoffman, et al., 2010). However, these studies may not generalize to most older adults whose physical activity patterns do not correspond to those employed by such RCTs. Additionally, few of these studies have employed repeated measures designs that would allow for examining how fluctuations in physical activity and depressive symptoms within individuals impact EF. Therefore, the present study sought to test the effects of natural fluctuations in physical activity, depressive symptoms, and EF with multi-wave, longitudinal data from a sample of community dwelling older adults with generally low levels of depressive symptoms. Based on previous research, we hypothesized that older individuals would demonstrate worse EF than their younger counterparts, but that more physically active individuals would have better EF. It was also hypothesized that within individuals, EF would decline over time and in response to higher than average depressive symptoms, but that the protective impact of physical activity would be greater during periods of vulnerability in the form of higher depressive symptoms.

Method

Participants

Participants were 150 community dwelling older adults (58% female) from a mid-sized city in Kentucky. They were recruited between 2005 and 2006 from a pool maintained by the Sanders-Brown Center on Aging at the University of Kentucky in a longitudinal study of repetitive thought, stress, and immune function. Sample characteristics are displayed in Table 1. Since the parent study was examining immune measures, potential participants were excluded if they had any significant immune system disorder (e.g. rheumatoid arthritis), had undergone chemotherapy or radiation treatment within the past 5 years, were taking immunomodulatory medications (e.g. glucocorticoids), or were taking more than two of the following classes of medications: psychotropics, antihypertensives, hormone replacement, or thyroid supplements. Participants were generally healthy, though they reported disorders consistent with an older adult sample, including diabetes (14%), heart disease (34%), and hypertension (62%).

Procedure

Graduate level research assistants administered measures to participants in their homes semi-annually over a period of four years ($M = 5.76$ visits). There were 150 wave 1 visits; 135 wave 2's; 124 wave 3's; 117 wave 4's; 111 wave 5's; 108 wave 6's; 72 wave 7's; and 47 wave 8's. There was variability in the number of completed waves due to a combination of dropouts, deaths, and varying time from recruitment. Participants received \$20 at each visit. The study was conducted with the approval of the University of Kentucky Institutional Review Board.

Measures

Depressive symptoms were measured with the Geriatric Depression Scale (GDS), an instrument designed to measure depression without inflating scores due to somatic complaints associated with normal aging (Yesavage, Brink, Rose, et al., 1983). The GDS is a well-validated tool for measuring depressive symptoms and is well suited to the measurement of subclinical changes in depressive symptoms, as tools more focused on diagnostic thresholds (e.g., the HAM-D) may result in underreporting of depressive symptoms in older adults (Clayton, Holroyd, Sheldon-Keller, 1997). The grand mean across all waves was 4.01, within the minimally depressed range. Internal consistency was adequate ($\alpha = .85$).

Executive functioning was measured with the Trail Making Test (TMT). TMT Part A asks participants to connect a series of serial numbers as quickly as possible, while TMT Part B asks participants to alternate between numbers and letters. Since both Part A and Part B involve motor speed and visual search, Part B relative to Part A captures EF in the form of cognitive flexibility due to the additional demands involved in alternating between letters and numbers (Arbuthnott & Frank, 2000; Carlina, & Windham, 2002; Cubillo et al., 2009; Kortte, Horner). The score was calculated as Part A – Part B, so higher (less negative) scores reflect better EF. The grand mean across all people and waves was –55.92 seconds, consistent with scores found for older adults in the standardization sample (Drane, Yuspeh, et al., 2002).

Physical Activity was measured with a questionnaire completed at the end of each day over three consecutive days prior to the visit. Participants were asked to track the total duration (in minutes) and intensity (mild = 1; moderate = 2; vigorous = 3) of physical activities performed over each of the three days. A total volume variable was created by multiplying the duration and intensity variables, a system similar to that used by Godin and Shephard (Godin & Shephard, 1985) to derive estimates of total MET-minutes expended. The grand mean of exercise volume for the three days across all waves was 112.45, equivalent to about 35-minutes of moderate-paced walking. This is somewhat less than reports from other studies of community dwelling older adults (Parise, Sternfeld, Samuels, & Tager, 2004), though our sample was somewhat older than participants from these studies.

IQ was estimated using the North American Adult Reading Test (Blair & Spreen, 1989). It was included as a potential covariate in our model. The mean IQ was 112.51 ($SD = 8.70$).

Data Analysis

Multilevel modeling was used with visits at level 1 and people at level 2 (Singer & Willett, 2003). The initial model predicted visit-level EF scores from the person-level variables of age, habitual physical activity (average across all visits), trait depressive symptoms (average across all visits), and IQ; visit-level variables of phasic physical activity and depressive symptoms as measured by deviations relative to each individual's mean across all waves were also included. Visit-level variables were centered around person-level means to facilitate interpretation of within-person change (Singer & Willett, 2003). In the next step, we entered a random effect of visit-level physical activity to explore the possibility that the

relationship between physical activity and EF varied between people. Finally, a visit-level depressive symptoms X visit-level physical activity interaction term was entered to test whether depressive symptoms at each wave moderated the effect of physical activity at that wave. Models were tested using SAS PROC MIXED with maximum likelihood estimation. Results are reported as γ weights, which are similar to unstandardized beta weights.

Results

Older age was associated with poorer EF ($\gamma = -1.48$, $SE = 0.35$, $t(102) = -4.21$; $p < .001$), and those who reported more physical activity than others had better EF ($\gamma = 0.42$, $SE = 0.19$, $t(102) = 2.14$, $p < .05$). Within individuals, participants' EF performance declined over the semi-annual waves ($\gamma = -1.47$, $SE = 0.37$, $t(929) = -4.00$; $p < .001$). In addition, when individuals had higher depressive symptoms than their average, they also had poorer than usual EF ($\gamma = -0.87$, $SE = 0.36$, $t(929) = -2.44$, $p < .05$). There was not a main effect of physical activity on EF within people, meaning that when individuals were more active than was typical for them, they did not have better than usual EF ($\gamma = 0.01$, $SE = 0.02$, $t(929) = 0.40$, $p = 0.69$). However, using -2 log likelihood as a deviance statistic to compare nested models revealed a significant improvement in fit when visit-level physical activity was included as a random effect ($\chi^2(1, 929) = 368$, $p < .001$). This suggests that there was significant variability in the degree to which physical activity was related to EF. Inclusion of an interaction term of visit-level depressive symptoms X visit-level physical activity yielded a positive relationship between physical activity ($\gamma = 0.03$, $SE = 0.01$, $t(929) = 5.29$, $p < .001$). Probing the interaction with simple slopes analysis revealed that the impact of physical activity on EF was significant only when physical activity was higher than one's usual amount combined with depressive symptoms that were higher than one's usual ($\gamma = 0.04$, $SE = 0.02$, $t(929) = 2.06$, $p < .05$). Figure 1 illustrates the activity-EF slopes when depressive symptoms were higher than average (+1 SD) and lower than average (-1 SD).

Discussion

As expected, older individuals had poorer EF than younger individuals, and participants declined in their EF performance over time. Interestingly, individuals slowed by 3 seconds/year on the EF measure, a steeper decline than the 1.5 seconds/year age difference found between people. The flatter slope for age (between individuals) vs. aging (within individuals) may be an artifact of initially selecting a sample of older adults with good health across the entire age range. It should also be noted that the within-person decline in EF scores in our data is likely smaller than the real decline due to practice effects of repeated administrations of the Trails tests. Also consistent with expectations and previous studies, those who reported more physical activity than others had better EF.

Within individuals, more depressive symptoms than their average resulted in poorer than usual EF, though more reported physical activity than average did not result in better EF. Levels of depressive symptoms moderated this effect, however, such that when depressive symptoms were higher than typical for an individual, more physical activity resulted in improved EF. This finding supports the hypothesis that physical activity is more valuable for EF during periods of vulnerability; in this case, during increased depressive symptoms. Such

moderating effects of depressive symptoms have been found in clinically depressed or otherwise cognitively impaired individuals. However, unique to the findings of the current study is that increases in levels of physical activity can attenuate the deleterious effects on EF of minor increases in depressive symptoms among a non-clinical sample of older adults. The hypothesis that physical activity is more valuable during periods of cognitive vulnerability may therefore apply to a much larger population of older adults than has been demonstrated in previous research. The impact of greater physical activity on EF during periods of higher than normal depressive symptoms was approximately 10–15% in terms of normative percentiles, yet these findings are important considering that even small fluctuations in EF can make meaningful differences in the day-to-day ability of older adults to make plans, make decisions, and inhibit urges (Vaughan & Giovanello, 2010).

We used a self-report physical activity questionnaire, where an objective measure (e.g., accelerometry) might have been preferred. However, the content of the questions and the equation used to derive total volume in our questionnaire are similar to those of other physical activity questionnaires such as the Leisure Score Index, which has been validated against other self-report and objective measures of physical activity and physical fitness (Godin & Shephard, 1985; Godin, Jobin, & Bouillon, 1986). Although our physical activity questionnaire was limited to three days, participants were asked to fill out these questionnaires at the end of each day. Since daily reports of behaviors are a better measure of behavior (Verbugge, 1980), this method reduces the risk of retrospective bias that is endemic to most self-report measures of physical activity (Fransson, Kuntsson, Westerholm, Alfredson, 2008). Furthermore, while three days of sampling is less than optimal, a study employing objective measures of physical activity among community-dwelling older adults found that there are not significant day-to-day changes in physical activity patterns over consecutive 7-day periods (Copeland & Eslinger, 2009).

Although we did not measure cardiorespiratory fitness or changes in this variable over time, meta-analytic evidence suggests that increases in physical activity that do not improve fitness parameters still has positive effects on EF (Angevaren, Aufdemkampe, Verhaar, Aleman, & Vanhees, 2008). In this case, the kinds of changes in physical activity represented in Figure 1 are modest. The difference between high and low phasic physical activity is the approximate equivalent of 15 minutes of brisk walking daily, and might not be expected to affect cardiorespiratory fitness.

Although we had only a single measure of EF, Trails A – Trails B has been used previously as a measure of EF among older adults, particularly in its cross-sectional and longitudinal relationship to physical activity (Benedict et al., 2013; Hiyama et al., 2012). Furthermore, among community dwelling older adults, the Trails A – Trails B score is associated with problematic gambling, an important real-world indicator of EF impairment (von Hippel, Abbot, Caldwell, Gill, & Powell, 2009).

Our sample was highly educated and above average in intelligence, although they were typical in their EF and physical activity. Because the interactive effect of physical activity and depressive symptoms was located within people, each person acted as his or her own control for individual differences such as demographics. However, it will be important to

replicate these effects in a more diverse sample of older adults. Finally, the naturalistic design of the current study does not allow for the causal inference of a randomized clinical trial. However, its strength is its ability to capture the typical physical activity habits and depressive symptoms of healthy older adults over a long period of time. Future studies in which healthy older adults with relatively low levels of depressive symptoms are randomized to lower volumes of physical activity interventions are needed to determine whether these effects can be replicated, in addition to how much physical activity is required to produce these protective effects on EF.

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Figure 1. Executive function predicted by physical activity and depressive symptoms: Within-subjects effects.

Table 1

Primary Study Variables by Wave

Variables	Wave							
	1	2	3	4	5	6	7	8
Trails A – B	–56.01 (42.70)	–54.69 (30.98)	–51.47 (28.71)	–50.71 (25.32)	–56.85 (56.78)	–62.81 (54.92)	–61.45 (44.30)	–67.49 (45.27)
GDS	4.19 (4.09)	4.01 (3.81)	4.20 (3.77)	3.77 (3.39)	3.81 (3.33)	3.86 (3.63)	4.41 (3.95)	3.89 (3.42)
MET-minutes	145.59 (219.89)	111.65 (116.34)	109.56 (103.69)	125.92 (146.11)	308.6 (148.2)	102.40 (91.02)	106.37 (90.75)	115.61 (149.95)
Age	74.69 (6.19)	74.46 (5.87)	74.56 (5.72)	75.09 (5.66)	75.51 (5.51)	75.94 (5.77)	76.36 (6.01)	76.82 (6.12)
Family Income	\$80K (55K)	\$82K (58K)	\$80K (56K)	\$71K (63K)	\$86K (60K)	\$86K (61K)	\$80K (56K)	\$85K (62K)
Education	15.93 (2.53)	16.01 (2.49)	15.93 (2.58)	16.05 (2.49)	16.18 (2.39)	15.91 (2.58)	15.93 (2.57)	15.95 (2.36)
Gender (N)								
Male	63	59	55	52	51	51	36	20
Female	87	76	69	65	60	57	36	27
Ethnicity (N)								
White	145	130	119	112	106	104	70	45
Black	5	5	5	5	5	4	2	2

Note. Values for continuous variables expressed as means (SD). GDS = Geriatric Depression Scale. Education = years of formal education. MET-minutes = mean MET-minutes over 3-day period.