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Switching it up: Activity Diversity and Cognitive Functioning in Later Life

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Abstract

Participating in a broad and balanced range of daily activities (i.e., activity diversity) has been associated with better cognitive functioning in later life. One possible explanation for this finding is that high levels of activity diversity are merely a proxy for being more physically active, a factor robustly linked to cognitive health. The current study examined whether activity diversity has a unique association with cognitive functioning beyond physical movement. Community-dwelling older adults ($N = 252$, $M_{age} = 73.55$ years, $SD = 6.39$) completed a cognitive battery and then responded to ecological momentary assessments of their participation in 10 common activity types (e.g., reading, chores, social visits) every three hours for 5–6 days. They also wore accelerometers to track daily physical movement. Multiple regression models revealed that greater diversity in daily activities was related to higher cognitive functioning even after adjusting for physical movement and other covariates such as education level. This study further clarifies the unique relationship of activity diversity, beyond physical movement, with cognition.

Keywords

accelerometry; activity variety; cognitive reserve; daily activities; EMA

An active lifestyle is often considered the hallmark of a full and enriched life, but evidence is mixed regarding the association between activity engagement and cognitive aging (Bielak & Gow, 2023; Stine-Morrow & Manavbasi, 2022). One reason for these mixed findings may be the lack of consensus on what constitutes an "active lifestyle," as operationalizations vary widely across studies. A growing number of studies suggest that diversifying one's

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The study preregistration and analytic code are available on the Open Science Framework (https://osf.io/7x98w). The deidentified dataset and materials are available on the National Archive of Computerized Data on Aging (NACDA): https://www.icpsr.umich.edu/web/about/cms/4493. Findings were previously presented at the Gerontological Society of America 2021 Annual Scientific Meeting (https://doi.org/10.1093/geroni/igab046.2222) and the Mobility, Health, and Place (MoHeaP) 2021 virtual workshop (https://vimeo.com/user/141807191/folder/4614218).

repertoire of daily activities (e.g., hobbies, work, exercise, reading, social visits) is a form of enrichment associated with better cognitive health profiles across adulthood (Jackson et al., 2020; Lee et al., 2021; Urban-Wojcik et al., 2022). Such active lifestyles, however, often occur in tandem with physical movement. Given that physical activity is strongly considered as a possible buffer against cognitive decline (Blondell et al., 2014; Park et al., 2019), a key unanswered question is whether activity diversity is related to cognition beyond any underlying physical movement.

What is an Active Lifestyle?

The link between environmental enrichment (e.g., exposure to a wide array of engaging stimuli) and cognitive functioning has been examined across decades of human and animal studies (Fratiglioni et al., 2020; Kempermann, 2019; Rosenzweig & Bennet, 1996). Activity engagement is widely recognized as being part of environmental enrichment, yet the defining features of an active lifestyle remain unclear. Cognitive stimulation through everyday pursuits such as spending more time reading or playing games post-retirement (Lee et al., 2019) or exploring new walking routes in the park (Kolarik et al., 2020) are actively studied as modifiable factors for cognition, leading researchers to consider such daily activities as viable indictors of enriched environments. Engagement in daily activities is not always associated with cognitive functioning, however, with some studies finding that higher activity levels are unrelated to age-related cognitive decline (e.g., Gow et al., 2014; Mitchell et al., 2012). Researchers have raised a number of methodological concerns that make it difficult to reconcile these inconsistent findings, including the need to differentiate the variety of activity from the overall levels of activity, as well as the need to capture common activities more proximal to their occurrence (Bielak & Gow, 2023). The current study aimed to address these concerns.

A few studies have already sought to distinguish activity variety from overall activity, with mixed results. Some studies indicate that greater variety in activities has unique associations with better cognitive health beyond the overall frequency of activities (Carlson et al., 2012; Jeon et al., 2022). Yet, other findings suggest that more varied engagement may be synonymous with simply being more active (Bielak et al., 2019a). The debate between activity variety and overall activity has led researchers to consider a new operationalization, referred to as *activity diversity*. Activity diversity captures both the range of activities (variety) and consistency of engagement across activities (evenness). Considering both variety and evenness is important because this combination captures not only how many activities comprise daily life, but the extent to which each activity is evenly allocated throughout the day. Engaging in diverse activities on a daily basis requires people to shift more regularly between tasks and orient to new environments. These processes are thought to activate the hippocampus – a brain region critically important for orientation, temporal sequencing of events, learning, and memory across a broad number of behavioral tasks (Aronov et al., 2017; Davachi & DuBrow, 2015; Kolarik et al., 2020). Activity diversity is indeed positively associated with hippocampal volume (Urban-Wojcik et al., 2022), although the direction of causation requires further clarification. One longitudinal study across adulthood providing evidence aligned with environmental enrichment theories (Lee et al.,

2021) found that greater activity diversity was associated with higher global and executive functioning at baseline and 10 years later, even after adjusting for activity frequency.

One factor not considered in these studies, however, is that an active lifestyle often implies that people are more physically active. Yet, these studies do not often isolate confounding effects of physical movement. The current study examined the association between cognitive functioning and both activity diversity and an objective indicator of physical movement.

Disentangling Activity Diversity and Physical Movement

Evidence thus far is inconclusive regarding whether activity diversity indeed represents a unique construct, or is simply a byproduct of an active life “on the go.” A number of studies have yielded mixed findings when examining the relative associations of physical activity (e.g., jogging) versus cognitive activities (e.g., taking a course) with cognitive health. A three-year study of older adults found that frequent cognitive activities combined with any amount of physical activity reduced mild cognitive impairment (MCI) risk, whereas frequent cognitive activities alone did not reduce MCI risk (Hughes et al., 2015). In contrast, another study found that more frequent cognitive leisure activity (e.g., reading, games, arts/crafts) attenuated cognitive decline, whereas more frequent physical activity did not (Lee et al., 2019). Results from experimental animal studies have been similarly mixed (e.g., Garthe et al., 2016; Mustroph et al., 2012). Interventions among older adults further show that combining physical and cognitive training may create synergistic effects, or may be equally effective to cognitive training alone (see reviews by Gheysen et al., 2018; Joubert & Chainey, 2018). One explanation for these inconclusive findings could be that physical and mental engagement are typically treated separately, when the two forms of engagement in fact overlap in many common activities (Bielak & Gow, 2023; Tomporowski & Pesce, 2019). An additional goal of the current study, accordingly, was to examine this potential overlap by monitoring physical movement associated with daily activities.

It should be noted that studies attempting to distinguish the effects of cognitive versus physical activity have primarily examined the frequency, rather than diversity, of activities. Moreover, many of these studies used self-reported physical activity and retrospective accounts ranging from the past week to the past year or longer – creating the risk of recall bias and possibly contributing to inconsistent findings. Daily diary studies of activity diversity have narrowed the assessment window to end-of-day reports (e.g., Lee et al., 2021; Urban-Wojcik et al., 2022), but these studies also lacked objective measures of concurrent physical movement. The current study addressed these gaps by narrowing the assessment window further to every three hours and objectively measuring physical movement.

Current Study

The current study examined whether activity diversity was uniquely associated with cognitive functioning, after adjusting for physical movement, among community-dwelling older adults. We expected that greater activity diversity would be uniquely related to higher overall cognitive functioning. Daily activities were assessed every three hours while awake for 5–6 days, providing a near real-time assessment of activities close to the time they occurred and reducing retrospective bias, a concern in this literature across the past 10 years (Bielak & Gow, 2023). We used accelerometers to track daily physical movement. We also included covariates that are often related to either daily activities or cognitive functioning, including education level as well as other sociodemographic factors.

Method

Transparency and Openness

We report how we determined our sample size and describe all data exclusions, manipulations, and measures in the current study. The deidentified dataset and full materials are available on the National Archive of Computerized Data on Aging (NACDA), the data archiving system at the University of Michigan (Fingerman et al., 2022). The analytic code is available at the link provided in the author note. Data were analyzed using SAS software, Version 9.4. The current study hypothesis and analytic plan were pre-registered (Brown & Charles, 2021).

Participants

Participants were from the Daily Experiences and Well-being Study (DEWS) conducted in 2016–2017. Older adults ($N = 333$, ages 65 to 92 years-old) were recruited from the greater Austin area, Texas by the University of Michigan Survey Research Center. Eligibility criteria included being age 65 or older, fluency in English or Spanish, working fewer than 20 hours per week (88% retired/not working, 12% employed part time), and not exhibiting cognitive impairment (based on a six-item screening tool; Callahan et al., 2002).

When determining sample size, we considered issues of missing data and nested data within person. Estimating a conservative response rate of 85% of days, we first determined that including 300 participants over four days would yield a minimum of 1,020 days of data. Based on prior daily diary research (Birditt et al., 2005), and using a design effect of 1.556, the computed effective sample size was calculated at $N = 656$ days (initial total sample of 1,020 days divided by design effect). The total number of participants at baseline ($N = 333$) reflects the additional goal of having greater racial/ethnic minority representation. All participants were recruited from professionally generated contact lists (phone numbers with matched addresses), with stratified sampling of participants from high-density minority zip codes.

For the current study, 81 participants were excluded from analyses due to missing data on key study variables. Among the 252 participants included in the final analytic sample, 224 people responded to the surveys for either 5 or 6 days (89%), with the rest responding for either7 days ($n = 2$) or fewer than 5 days ($n = 26$). We considered excluding $n = 7$ participants who responded for only one or two days, but decided to include them because sensitivity analyses revealed that findings were the same with or without them. Sociodemographic information for the analytic sample is presented in Table 1. The majority of participants identified as non-Hispanic White (75.40%), and the remaining participants identified as both Hispanic/Latinx and White (10.32%), Black/African American (12.30%), or as belonging to another minority group (i.e., American Indian/Alaska Native, Asian, Hispanic/Latinx only, or another mixed race/ethnicity; 1.98%). Compared to the 81 excluded participants, those who were included in analyses ($n = 252$) were more likely to be younger [$t(331) = -2.97$, $p = .003$], non-Hispanic White [$\chi 2(1) = 31.10$, $p < .001$], have a higher education level [$t(118.1) = 3.84$, $p < .001$], and have fewer depressive symptoms [$t(331) = -2.10$, $p = .036$].

Procedure

Participants completed an in-person baseline interview (90–120 minutes) including a cognitive battery and psychosocial questionnaires, and then participated in 5–6 days of intensive data collection. During the intensive data collection period ($M = 5.33$ days, $SD = 1.06$), participants responded to ecological momentary assessment (EMA) surveys using a study-provided Android device every 3 hours while awake. The 3-hour interval strategy was used to capture experiences throughout the day (e.g., morning, afternoon, evening) and the array of activities that comprise these moments of everyday life. The use of frequent, repeated assessments helps to limit retrospective bias and enhance ecological validity. Prior studies support the feasibility of multiple assessments per day among older adults from a variety of backgrounds (Cornwell & Cagney 2017; Fritz et al., 2017; Maher et al., 2018). In addition, participants wore an Actical (accelerometer) on their wrist that recorded their physical movement continuously. A total of 303 participants both took part in the EMA surveys and wore the Actical. Participants received $50 for completing the baseline interview and $100 for completing the intensive data collection period. Interviews were conducted in English and Spanish. Experienced translators and interviewers who were fluent in Spanish administered and scored assessments for Spanish-speaking participants. All study procedures were approved by the Institutional Review Board at the University of Texas at Austin (Title: Daily Experiences and Well-Being; Protocol No.: 2015-02-0123).

Measures

Cognitive Functioning—During the baseline interview, participants completed a battery of short cognitive tasks. Scores on each of the four following tasks were standardized and averaged together to create one composite measure ($\alpha = .58$), with higher values indicating better overall cognitive functioning.

First, in the Hopkins Verbal Learning Test: Form 3 (HVLT; Brandt, 1991), interviewers read a list of 12 nouns from three semantic categories (musical instruments, fuels, food flavorings) and participants recalled the words in any order, a process repeated three times. After 20–25 minutes, participants again recalled all the words they could remember. The sum of correct items across all three trials (i.e., total recall) and the number of correct items generated in delayed recall trial (i.e., delayed recall) were standardized and averaged together, with higher scores indicating better performance.

Second, in the Controlled Oral Word Association Test (COWAT; Benton, 1968), participants were asked to generate as many words starting with a particular letter in one minute, excluding proper nouns and different forms of the same word (e.g., run, running). This process was repeated for three different letters (F, A, S for English-speaking participants; or P, M, R for Spanish-speaking participants; Artiola et al., 1999). A trained research assistant recorded and assessed participants' responses on all three trials. The total number of correct words across all three trials were summed, with higher scores indicating better performance.

Third, we administered the Trail Making Test – Trails A and B (Army Individual Test Battery, 1944). In Trails A, participants drew a continuous line as quickly as possible connecting numbers 1 through 25 in sequential order. In Trails B, participants alternated between numbers (1–13) and letters (A-L) in sequential order (e.g., 1-A-2-B-3-C…12-L-13). The amount of time (in seconds) required to correctly complete each trail was recorded. In the composite score for overall cognitive functioning, we used the difference between completion times of each trail (Trails B-A) to control for the effect of psychomotor speed required by both trails (Corrigan & Hinkeldey, 1987; Drane et al., 2002). Difference scores (B-A) were reverse coded before standardizing so that higher scores indicate better functioning.

Finally, participants completed the Shipley Institute of Living Scale – Vocabulary subtest (Shipley, 1940), which has been validated and widely used in previous research (e.g., Wynn & Carpenter, 2020). Across 40 items, participants circled one of four possible words which had the most similar meaning to the prompting word. Total number of correct items were summed, with higher scores indicating better performance.

Activity Diversity—Every 3 hours while awake, participants responded to the prompt "Check any of the activities below that you did in the past 3 hours," followed by a list of activity types including: reading/puzzles/music, shopping/errands, using computers or electronics, volunteering/work, religious activities, driving a vehicle, riding in a vehicle, exercise, chores, and visiting someone. These activity types were selected based on prior studies of daily experiences in midlife and older age (Almeida et al., 1996–1997; Ram et al., 2014; Skehan et al., 2014). Although they may not capture all domains or details of someone's daily life comprehensively, these categories were intended to capture a range of daily activities common in late adulthood. From these responses, we constructed scores to represent activity diversity across each day using Shannon's (1948) entropy:

$$Activity\ diversity_{di} = -\left(\frac{1}{\ln(m)}\right)\sum_{j=1}^{m} p_{ij} \ln p_{ij}$$

where m is the number of possible activity types ($m = 10$), and p_{ij} is the proportion of individual i's engagement of each activity type to their total activity engagement across a given day ($d = 1$ to 7) that were spent in each possible activity type, $j = 1$ to m. For example, a participant who engaged in activities 20 times across a day (i.e., 20 "yes" responses), three of which were spent visiting someone and none of which were spent volunteering, would receive proportions $p_{ij} = 3/20$ for visiting, $p_{ij} = 0/20$ for volunteering, and so on for each of the 10 possible activity types. Resulting daily activity diversity scores can range from 0 (*no diversity*) to 1 (*complete diversity*). This approach captures both variety and evenness of activity engagement, such that complete diversity is defined as engaging in every activity type with an even number of times across the day.

Intraclass correlations revealed that the majority (72%) of the variation in daily activity diversity was due to between-person differences, with only 28% due to day-to-day fluctuations within-person. Additionally, the reliability of activity diversity across days was strong (α = .82), suggesting that participants' level of activity diversity was consistent across days. Therefore, to facilitate cross-sectional analyses (given that cognitive functioning was assessed only once at baseline), we averaged these daily activity diversity scores across the study period for each participant to obtain one score per participant reflecting their average daily activity diversity.

Physical Movement—Amount of physical movement was objectively assessed using Phillips Respironics Actical Zs accelerometers. The device is waterproof, unobtrusive, and similar to a standard wristwatch. Participants strapped the Actical on their wrist using a plastic hospital band for the entire study period. The Actical measures motion in multiple directions and calculates the intensity of physical movement continuously, with data available in 1-minute epochs or hourly averages. Data are also time-stamped, allowing the accelerometer data to be averaged across the same 3-hour intervals as the self-report data from the EMA. Physical movement was assessed using accelerometer indices of energy expenditure (which we used to calculate movement duration) and step count, both of which have been validated as indicators of physical activity (Esliger et al., 2007; Troiano, 2006) and were positively associated with self-reported physical activity in our data (*rs* = .2 to .3; *ps* < .01) as well as in previous studies (Maher et al., 2018).

Movement Duration.: We calculated movement duration using device indices of energy expenditure per minute. The Actical device records energy expenditure as kilocalories per minute adjusted by weight (kcal/min/kg). We first summed the total minutes of energy expenditure greater than zero (> 0 kcal/min/kg) across all 3-hour intervals. This level of energy expenditure captures all physical movement from light upper body activity (e.g., playing cards) to vigorous full body activity (e.g., jogging). We then divided that sum by the number of days participated in to obtain one score per participant reflecting their average daily movement duration (in minutes).

Given the current study goal to distinguish activity diversity from the physical movement that underlies it, it was important to capture the level of overall physical movement (both during and between all activity types). We, therefore, present findings for movement duration because this indicator continuously captured all physical movement throughout all 3-hour intervals.

Step Count.: Although not all activity types assessed in this study involve steps, we also examined models substituting movement duration with step count, given that walking is the most common type of physical activity among older adults (Dai et al., 2015). The device records step counts available in matching 3-hour intervals. We summed the total number of steps across all intervals and divided it by the number of days participated in to obtain one score per participant reflecting their average daily step count.

Covariates—Based on prior literature linking demographic and psychosocial factors to either activity or cognitive functioning (e.g., Bielak et al., 2019a; Wang et al., 2002), we included age, sex, racial/ethnic minority status, marital status, education, self-rated health, depressive symptoms, and extraversion as covariates in all of our models. Covariates coded dichotomously included sex (0 = *female*, and 1 = *male*), racial/ethnic minority status (0 = *minority*, and 1 = *non-minority*), and marital status (0 = *not married/partnered*, and 1 = *married/partnered*). Covariates treated as continuous included education (1 = *no formal education*, 2 = *elementary school*, 3 = *some high school*, 4 = *high school*, 5 = *some college/ vocation or trade school*, 6 = *college graduate*, 7 = *post college*, and 8 = *advanced degree*) and self-rated health (1= *poor*, 2 = *fair*, 3 = *good*, 4 = *very good*, and 5 = *excellent*). Depressive symptoms were assessed using the 11-item Center for Epidemiological Studies Depression (CES-D) scale (Kohout et al., 1993), where participants rated the frequency of symptoms (e.g., could not get going, sleep was restless, felt lonely) in the past week using a scale from 1 (*rarely or none of the time*) to 4 (*most or all of the time*); items were summed, with higher scores indicating greater depressive symptoms (α = .78). Participants also completed a personality scale of the Big Five personality traits (Lachman & Weaver, 1997); the current study included only extraversion because recent analyses with the same dataset (DEWS) revealed that extraversion was the only personality trait related to activity diversity in this sample of older adults (Lee et al., 2023). Participants rated the extent to which five items (outgoing, friendly, lively, active, talkative) described them on a scale from 1 (*not at all*) to 5 (*a great deal*); items were averaged with higher scores indicating greater extroversion (α = .85).

Results

Descriptive Analyses of Activity Diversity

Descriptive information and correlations among key study variables are presented in Table 1. For illustrative purposes, a snapshot of one day's activities for two participants are shown in Figure 1. Chores and using computer/electronics were the most common activities (M = 71% and 69% of days, respectively), with volunteering/work and religious activities being the least common (M = 11% and 12% of days, respectively). Age was not associated with the percentage of days engaged in activity types, with the exception of volunteering/work, such that older age was associated with less frequent volunteering/work ($r = -.15$, p = .02). Full descriptive information for the percentage of days engaged in each activity type, along with their intercorrelations by age are presented in the Supplementary Material, Table S1. Overall, the intercorrelations among activity types were not clearly patterned, which is consistent with prior evidence that activity selections tend not to be strongly correlated with each other (Adams et al., 2011).

Regarding individual differences in activity diversity, average daily activity diversity did not differ among men and women [$t(250) = 1.83$, $p = .07$]. Activity diversity was greater among participants who were married or partnered ($M = .56$, $SD = .14$) compared to those who were not ($M = .52$, $SD = .16$; $t(250) = -2.14$, $p = .03$), and activity diversity was greater among non-Hispanic Whites ($M = .56$, $SD = .13$) compared to racial/ethnic minority groups [$M = .50$, $SD = .17$; $t(86.488) = -2.76$, $p = .007$].

Descriptive Analyses of Physical Movement

Regarding accelerometer measures of physical movement, average daily movement duration (in minutes) was higher among women ($M = 117.90$, $SD = 44.37$) compared to men [$M = 99.79$, $SD = 43.24$; $t(250) = 3.25$, $p < .01$], whereas average daily step count did not differ by sex [$t(249.73) = 1.69$, $p = .09$]. Neither movement duration [$t(250) = .66$, $p = .51$] nor step count [$t(250) = -.68$, $p = .49$] differed by marital status. Finally, neither movement duration [$t(250) = .26$, $p = .80$] nor step count [$t(128.7) = -1.83$, $p = .07$] differed by racial/ethnic minority status.

Activity Diversity and Overall Cognitive Functioning

We examined the association between activity diversity and overall cognitive functioning using linear regression models, adjusting for age, sex, racial/ethnic minority status, marital status, education, self-rated health, depressive symptoms, extraversion, and physical movement. The first model included movement duration to capture physical movement; results from this model are presented in Table 2. Consistent with the hypothesis, greater activity diversity was uniquely associated with better overall cognitive functioning ($b = 1.04$, $SE = .27$, $p < .001$). The effect size of activity diversity was similar to that of education (see standardized betas in Table 2). Movement duration, in contrast, was not uniquely associated with overall cognitive functioning. We also ran a parallel model using step count instead of movement duration to capture physical movement, which revealed the same pattern of results (see Supplementary Material, Table S2).

Sensitivity Analyses of Activity Diversity and Separate Cognitive Tasks

We conducted sensitivity checks to examine whether the results were consistent for each of the four cognitive tasks in our composite measure of overall cognitive functioning (i.e., HVLT, COWAT, Trails B-A, and Shipley). Results of these sensitivity tests are provided in the Supplementary Material. Initial bivariate correlations revealed that activity diversity was positively correlated with performance on all four cognitive tasks; movement duration was not correlated with performance on any of these tasks; and step count was correlated only with Trails B-A (see Table S3). Linear regression models, adjusting for movement duration and covariates, showed that activity diversity was positively associated with performance on three of the cognitive tasks (HVLT, COWAT, and Shipley) at $p < .05$, but not with Trails B-A (see Table S4). Parallel models using step count instead of movement duration to capture physical movement, again, revealed the same pattern of results (see Table S2). For transparency, and because some researchers have examined Trails A and B separately (e.g., Classen et al., 2013; Gaudino et al., 1995), we include these results as notes under the supplementary tables. Consistent with the difference score (B-A), the separate trails were unrelated to activity diversity. In all models, with the one exception of Trails A, the physical movement variables were not uniquely related to performance on any of the separate cognitive tasks.

Supplemental Analyses

Given that many previous studies have examined activity variety (i.e., simple count of different activities), whereas the current study used activity diversity (i.e., entropy scores), we explored supplemental analyses to compare findings between these two metrics. First, we calculated a *daily activity variety* index as the total number of activity types engaged in each day (possible range = 0–10), and then we averaged across days in order to obtain one variety score for each participant (given that our analyses with cognitive functioning were necessarily cross-sectional). Average daily activity variety and average daily activity diversity were strongly correlated with each other ($r = .96$, $p < .001$) and exhibited similar bivariate correlations with each of the cognitive outcomes (all $ps < .05$), as shown in Table S3. A regression model with daily activity variety as the main predictor, adjusting for movement duration and covariates, revealed a similar pattern of results with regard to overall cognitive functioning ($b_{\text{variety}} = .11$, $SE = .03$, $p < .001$). When we examined each cognitive task separately, daily activity variety was uniquely associated with performance on three tasks (HVLT, COWAT, and Shipley; see Supplementary Material, Table S5), consistent with the sensitivity analyses of daily activity diversity. In all models of daily activity variety, with the one exception of Trails A, movement duration was again not uniquely associated with any cognitive outcomes.

In addition, the current study used daily activity diversity scores (averaged across days), as opposed to one diversity index across the entire study period, because we expected that activity diversity each day would better capture participants' level of shifting between activities. In contrast, activity diversity measured across longer periods of time (as in prior studies) might capture a broader range (given that more activity types can be accomplished in multiple days vs. one day) yet be less balanced overall and less active each day. Given that previous daily diary studies using end-of-day reports were limited to one diversity index across days, we explored whether our findings would change if we calculated a single diversity index across days as previous studies have done. We also explored whether distinctive effects of activity diversity vs. variety would become apparent when doing so. Therefore, we constructed *weekly activity diversity* scores (i.e., one entropy score across the study period) and *weekly activity variety* scores (i.e., simple count across the study period). Linear regression models, adjusting for corresponding movement duration scores (total minutes across the study period) and covariates, revealed that neither weekly diversity nor weekly variety were uniquely associated with overall cognitive functioning (see notes under Tables S4 and S5, respectively). Thus, as we expected, it is possible that activity diversity across the week (whether measured as entropy or count variables) captures something different from daily activity diversity.

Discussion

Engaging in diverse daily activities is related to levels of cognitive functioning years later (Lee et al., 2021), but previous findings are unclear regarding whether greater activity diversity may be a proxy for simply being more physically active. When assessing both daily activities and physical movement every three hours for 5–6 days in an older adult sample, we found that greater activity diversity was related to higher cognitive functioning even after adjusting for objective measures of physical movement. Results suggest that the association between activity diversity and cognitive functioning is not attributable to the well-replicated link between physical activity and cognition.

Popular messaging often emphasizes “staying active” in later life, yet the defining features of an active lifestyle remain unclear. Results from the current study indicate that diversifying daily activity is a crucial component of an active lifestyle that is associated with cognitive functioning. Moreover, physical movement was not associated with cognitive functioning (the composite measure or when examining the four tasks separately) independent of activity diversity. These findings help to shed light on discrepancies in previous research comparing cognitive and physical activity, as those studies commonly used self-reported physical activity and longer retrospective assessments (e.g., past week or longer; Hughes et al., 2015), whereas the current study used objective physical movement assessments in real-time. It should be noted, however, that our sample had levels of movement and steps, averaging 2318 steps per day, that were quite low. For comparison, a six-year study of healthy adults found that the minimum number of daily steps for dementia risk reduction was 3800 (del Pozo Cruz et al., 2022). It is possible, therefore, that physical movement in our sample was too low to exhibit cognitive associations independent of activity diversity.

Although we did not assess contextual factors such as mobility constraints or geographic restrictions (e.g., non-aging friendly environments, low neighborhood walkability), they are important to consider, as they represent some barriers to staying active that older adults may experience. Moreover, people with low socioeconomic status or who face discrimination may be differentially impacted by these barriers. The extent to which individuals may differentially access, or benefit from, activity diversity would be important to consider in future studies.

Our findings also have theoretical implications for cognitive reserve. The cognitive reserve hypothesis suggests that engaging in more cognitively stimulating activities across the lifespan builds neurophysiological resources that support resilience against cognitive decline (Stern, 2002). Studies emerging from this line of research have tended to focus on leisure-time activities posited to stimulate cognition (such as traveling, learning a new language, visiting museums), many of which require investment of time and resources not always available to the typical older adult. Similarly, many behavioral interventions targeting cognitive reserve involve special interest activities, such as video games, choreography, or conceptual art (Brown et al., 2021; Herholz et al., 2013). Such efforts provide opportunities for truly novel and exciting experiences but are often limited to the intervention period due to logistical and funding constraints that hinder program sustainability. A notable feature of the current study is that we measured activity diversity using commonplace activities. Whether activity diversity stimulates cognition, or vice versa, is a question requiring further investigation. Future studies can examine, for example, the extent to which specific features of these activities (e.g., novelty and learning) may drive cognitive stimulation, as these data were not collected in the current study. The current findings, nonetheless, highlight the importance of considering participants’ personal routines and preferred activities – contributing to the growing evidence that cognitive reserve may be associated with more accessible activities than previously theorized.

Potential Mechanisms

We did not address possible mechanisms explaining why activity diversity might relate to better cognitive functioning, so our reasoning is speculative. Jackson and colleagues (2020) argue that "a life filled with many different activities requires some management. […These individuals] must hold varied goals and subgoals in mind and update the goal structure in response to what has been accomplished, as well as to environmental demands such as calendar changes" (p. 1085). Juggling these varied goals requires cognitive effort, including shifting between tasks, coordinating schedules, keeping track of time, and navigating across potentially changing landscapes of traffic and social interactions. This interpretation is consistent with the link between activity diversity and hippocampal volume (Urban-Wojcik et al., 2022). The hippocampus is a brain region important for not just visual spatial navigation, but also to track continuous, task-relevant environmental factors (Aronov et al., 2017). Daily activity diversity in contemporary life may provide micro-doses of spatial navigation and orienting to constantly changing task-relevant details in the environment, stimulating this vital brain function. The alternative direction cannot be ruled out, however, as people with higher cognitive functioning may be better able to juggle multiple shifting tasks.

This cross-sectional analysis provides no indication of causality, and trait-like qualities might also be related to both higher levels of cognitive functioning and greater desire to live a life with more daily variety. For example, openness to experience is a personality trait identified across many cultures, with high levels found among people who prefer variety, enjoy intellectual challenges, pursue novel experiences, and have many interests (DeYoung, 2015). Although activity variety partially mediated the positive association between openness and cognitive functioning in one study (Jackson et al., 2020), activity diversity was unrelated to openness in the current dataset (Lee et al., 2023). Perhaps novelty in daily activities, rather than their diversity per se, underlies the link between openness to experience and activities. For instance, older participants in an arts-based intervention reported a shift in their perception of everyday activities, describing this increased openness as not only seeking new experiences, but finding novelty in familiar situations (Brown et al., 2021). Future studies could investigate the ways in which novelty may be integrated into routine experiences.

Methodological Considerations

The entropy metric used to calculate activity diversity in the current study captures both variety and evenness of activity engagement, but previous studies have often used only activity variety (i.e., simple count of different activity types). Our supplemental analyses revealed that the two metrics were nearly identical in our dataset. More detailed methodological and statistical comparisons of each measure are needed, however, as previous studies comparing activity diversity versus variety (e.g., Lee et al., 2021) suggest that activity diversity is a more rigorous measure of human behavior. Capturing evenness, in addition to variety, provides information about the extent to which participants had consistent exposure to different types of cognitive stimulation. Given that time in a day is finite (24 hours/day), spending longer hours in one activity often results in fewer engaged activities. Therefore, finding an optimal balance between the number of activities and time spent in each activity may be important to ensure that the potential costs of activity variety (e.g., stress of switching between multiple tasks; cf. Cornwell, 2013) do not outweigh the benefits – particularly when scheduling conflicts or health constraints are at play. The current study did not measure time spent in each activity per se, but the calculation of both evenness and variety provides some insight into the extent to which participants exhibited such balance. Taken together, the current findings suggest that activity variety (count) measures are sufficient when intensive data are not available, but that activity diversity (entropy) metrics provide additional granularity and insight into how daily life is linked with cognitive health.

Limitations and Future Directions

Despite the study's strengths, findings must be interpreted in the context of some limitations. First, given the high percentage of non-Hispanic Whites in the current sample, our findings may not generalize to different racial or ethnic minority groups. Second, the cross-sectional analyses preclude any causal inferences. It is possible that older adults with lower cognitive functioning would choose to engage in fewer types of activities, selecting perhaps a narrower range of specific activities in which they feel comfortable or capable of engaging. Parikh and colleagues (2016) found that individuals experiencing cognitive decline may avoid certain activities due to feeling embarrassed, frustrated, or being excluded by others. Participants being cognitively intact in the current study helps to minimize the potential for such reverse causation but limits the extension of our findings to older adults with different cognitive statuses. The bidirectional effects between cognitive ability and activity engagement are indeed complex, and more work is needed to unpack social and motivational factors at play. Fluctuations in levels of activity diversity across time (e.g., during economic shifts, life transitions, or a global pandemic) may also impact cognitive aging. Longitudinal studies are needed, therefore, to determine whether daily activity diversity has long-term impacts on neurocognitive disease outcomes, including timing and risk of dementia onset.

Analyses were also limited to between-person models because cognitive assessments were not administered daily. A surprising finding by Bielak et al. (2019b) showed that older adults had worse working memory on days when they played games for more time than usual. These nuanced findings suggest that activity-cognition links may operate differently on the daily level versus across time. Within-person models could help to illuminate how activity diversity may influence daily cognition.

Another limitation to consider is that the current study design precluded knowing whether activities were engaged in simultaneously or sequentially. For example, if a participant endorsed puzzles and using electronics in the same three-hour period, we were unable to distinguish whether these were done separately (e.g., doing a jigsaw puzzle, then checking emails) or in combination (e.g., playing word puzzles online). Future studies using event-contingent designs or specifically assessing complex combinations of activity types could help clarify these issues.

Future research can also provide more clarity on the areas of cognitive performance most strongly associated with activity diversity. For example, our sensitivity analyses revealed that activity diversity was significantly associated with performance on all cognitive tasks except for the Trail Making Test. This task is typically used to assess attention and processing speed, but also requires basic functions such as visual search and motor control (Gaudino et al., 1995) that could be confounded by external factors unrelated to cognitive functioning (e.g., not wearing reading glasses, difficulty holding pencil due to arthritis). Such confounding factors could have contributed to null findings with this task in the current study. This result differs from another study finding significant associations between activity variety and all aspects of cognitive functioning, including processing speed (Jackson et al., 2020). Another study, however, found that activity diversity was not robustly related to all aspects of cognitive functioning, with episodic memory (measured using a verbal learning task) becoming nonsignificant after including sociodemographic covariates (Lee et al., 2021). In contrast, activity diversity was related to performance on our verbal learning task (HVLT) in the current study. The differential findings may be due to sample age differences, as Lee et al. (2021) included primarily middle-aged and younger adults. We are hesitant to draw strong conclusions about different cognitive domains, however, given that the current study included only one task per domain, and single-task markers may be misleading (Bielak & Gow, 2023). Future studies using more tests to examine each domain would help to further illuminate whether activity diversity is differentially related to specific cognitive domains.

Conclusion

Humans need to stay both mentally and physically active. DeYoung (2015) further asserts that the need to explore and adapt is fundamental for the health of any complex organism. The current study provides clarity to the complex question of how to best stay mentally active. People must constantly adapt to their world, even when engaged in routine activities that provide structure and meaning to daily life. The current study suggests that even daily routine activities, if combined with each other in a rich and balanced schedule, are related to higher levels of cognitive functioning that cannot be explained by the physical activity that accompanies these activities.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Public Significance Statement

Researchers emphasize the importance of “staying active” in later life. Our findings indicate that greater diversity in daily activities is related to older adults’ cognitive functioning, and this link is not attributable to underlying physical movement. More research is needed to determine causal effects, but this study adds to the growing literature on activity diversity as a promising avenue for accessible, customizable interventions for brain health.

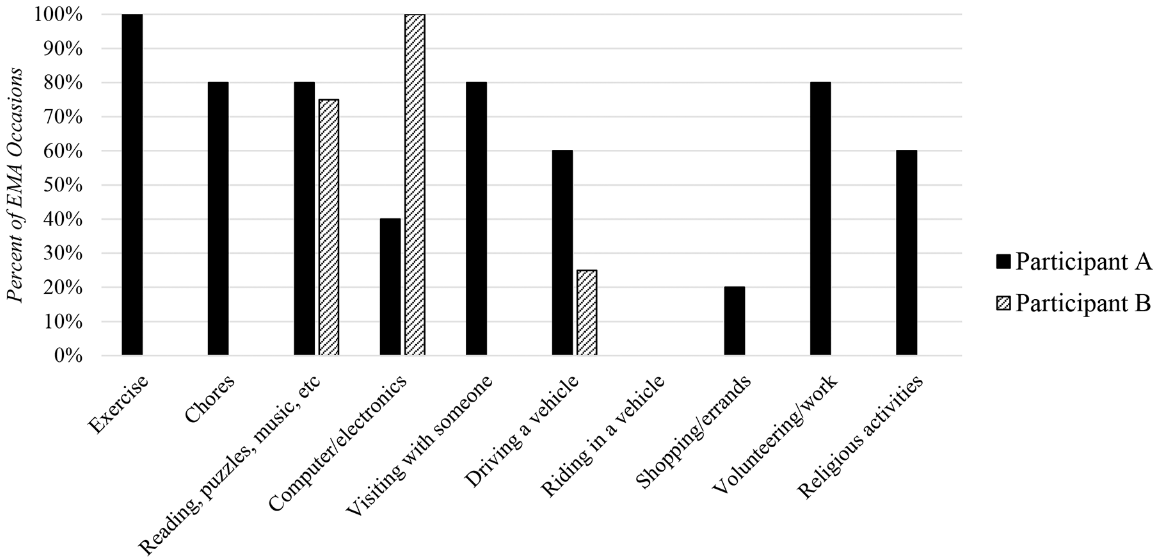

Figure 1.

Activity Diversity on a Given Day for Two Participants

Note. On a given day, Participant A engaged in 9 out of 10 activity types with fairly even consistency, reflecting near complete activity diversity (.92) that day. In contrast, Participant B engaged in only 3 out of 10 activity types with uneven consistency, resulting in a lower activity diversity score (.42) that day.

Table 1

Means, Standard Deviations, Ranges, and Intercorrelations for the Study Variables

	M (SD)	Range	1	2	3	4	5	6	7	8	9	10	11
Covariates													
1. Age	73.55 (6.39)	65 – 89	-										
2. Sex[a]	56% female	-	.03	-									
3. Minority status[b]	75% non-minority	-	.21***	−.02	-								
4. Marital status[c]	59% married	-	−.19**	.43***	.01	-							
5. Education[d]	6.08 (1.48)	2 – 8	.05	.19**	.29***	.11	-						
6. Health status[e]	3.60 (1.00)	1 – 5	−.04	.04	.30***	.03	.27***	-					
7. Depressive symptoms	5.12 (4.43)	0 – 22	−.01	−.05	−.20 **	−.13*	−.23**	−.37***	-				
8. Extraversion	3.67 (.80)	1 – 5	−.07	.07	−.08	.08	−.03	.22***	−.24***	-			
Predictors													
9. Activity diversity	.55 (.15)	.04 - .85	−.00	−.11	.19**	.13*	.26***	.31***	−.14*	.09	-		
10. Movement duration (min.)	110.01 (44.71)	3.33 – 222.20	−.18**	−.20**	−.02	−.04	−.08	.11	.01	.08	.35***	-	
11. Step count	2318 (1391)	57.50 – 8457	−.18**	−.10	.10	.04	.07	.19**	−.09	.13*	.35***	.79***	-
Outcomes													
12. Cognitive functioning	0.00 (0.66)	−2.30 – 1.27	−.10	−.04	.41***	.14*	.40***	.34***	−.22***	−.08	.41***	.13*	.16*

Note. N = 252.

[a]Coded as 0 = *female*, and 1 = *male*.

[b]Racial/ethnic minority status coded as 0 = *minority*, and 1 = *non-minority*.

[c]0 = *not married/partnered*, and 1 = *married/partnered*.

[d]1 = *no formal education* to 8 = *advanced degree*.

[e]1 = *poor to 5* = *excellent*.

* $p < .05$.

** $p < .01$.

*** $p < .001$.

Table 2

Linear Regression of Movement Duration and Activity Diversity with Overall Cognitive Functioning

	Overall cognitive functioning			
	Standardized		Unstandardized	
	β(SE)	95% CI	*b(SE)*	95% CI
Intercept	.09 (.06)	[−.02, .21]	0.11 (.52)	[−0.92, 1.13]
Age	−.10 (.04)**	[−.17, −.03]	−0.02 (.01)**	[−0.03, −0.00]
Sex	.09 (.08)	[−.06, .25]	0.09 (.08)	[−0.06, 0.25]
Minority status	−.41 (.09)***	[−.58, −.24]	−0.41 (.09)***	[−0.58, −0.24]
Marital status	−.11 (.08)	[−.26, .05]	−0.11(.08)	[−0.26, 0.05]
Education	.15 (.04)***	[.08, .22]	0.10 (.03)***	[0.05, 0.15]
Health status	.08 (.04)*	[.00, .16]	0.08 (.04)*	[0.00, 0.16]
Depressive symptoms	−.04 (.04)	[−.11, .03]	−0.01 (.01)	[−0.03, 0.01]
Extraversion	−.08 (.04)*	[−.15, −.02]	−0.11 (.04)*	[−0.19, −0.02]
Movement duration (min.)	.02 (.04)	[−.05, .10]	0.00(.00)	[−0.00, 0.00]
Activity diversity	.15 (.04)***	[.07, .23]	1.04 (.27)***	[0.50, 1.57]
Adjusted R^2	.37			
F statistic	15.55***			

Note. $N = 252$. CI = confidence interval.

* $p < .05$.

** $p < .01$.

*** $p < .001$.