How Can We Not ‘Lose It’ if We Still Don’t Understand How to ‘Use It’? Unanswered Questions about the Influence of Activity Participation on Cognitive Performance in Older Age – A Mini-Review

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Key Words

Lifestyle engagement • Activity participation • Cognition • ‘Use it or lose it’ hypothesis

Abstract

The ‘use it or lose it’ hypothesis of cognitive aging predicts that engagement in intellectual, social, and physical activities offers protective benefits from age-related cognitive decline and lowers dementia risk. Although this hypothesis has not yet been supported conclusively, there is some empirical evidence in favor of the proposal. However, a number of questions surrounding the relationship between activity participation and cognitive ability in older adulthood are not yet well answered. This mini-review identifies seven key methodological and theoretical issues that are critical to our understanding and eventual possible promotion of activity participation as a way to maintain cognitive well-being. These include the mechanisms involved, the optimal ways of assessing activity engagement, which cognitive domains receive the most benefit from activity engagement, the temporal nature and the directionality of the relationship, the influence of demographic variables such as age, gender, or education, and whether one activity domain offers the most benefit to cognition. The current knowledge on each of these issues is critically evaluated, including describing what

we already know about the issue, and identifying potential difficulties and opportunities that may exist in finding an answer. More studies need to take on the challenge of specifically targeting these issues, as each is essential to moving the field forward.

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If your brain was a muscle, how would you exercise it to keep it fit? You might challenge it each day, providing frequent cognitive stimulation. You might also aim to provide it with the tools it needs to work effectively, such as oxygen-rich blood attained through physical activity [e.g. 1]. You might also pay attention to how you are treating it, and make sure to participate in satisfying social relationships, rather than stressful ones which are more likely to produce the detrimental hormone cortisol [e.g. 2]. Clearly, the environment would play a lead role in exercising the brain. Further, external stimuli would be even more important in older adulthood, when cognitive abilities begin to show noticeable weaknesses [see 3, 4 for reviews].

The ‘use it or lose it’ hypothesis of cognitive aging predicts that engagement in physical, social, and intellectual activities in older adulthood prevents the deterioration of cognitive abilities by ‘exercising’ them through their ap-

plication in various environments [5] (also termed the engagement hypothesis). Individuals who participate in many activities are predicted to perform better on cognitive tests, experience less cognitive decline over time, and possibly even have a reduced likelihood of developing neurodegenerative disorders (e.g. Alzheimer's disease, AD) compared to inactive individuals [see 6, 7 for reviews].

The expected relationship between activity and cognition offers an optimistic picture of aging by suggesting that older adults have some control over changes in their cognitive ability. It is perhaps for this reason and the ensuing potential significance of this hypothesis in the lives of older adults that a large body of research already exists in this area. For example, several cross-sectional studies have found the expected relationship between activity participation and *differences* in cognitive ability among older adults. Higher levels of participation in activities such as reading the newspaper predicted stronger memory, fluid, and crystallized cognitive abilities [8], and having frequent contact in a large social network and receiving greater emotional support from those relationships was associated with better performance on a test of general cognitive functioning [9]. Further, increased participation in activities such as bowling or cycling was associated with higher cognitive performance [10], and greater frequency of sweat-inducing physical activity was associated with faster response times and better response accuracy on tasks requiring greater executive control [11]. Many other studies support these findings [e.g. 12–18], but a few have not found a positive concurrent relationship [e.g. 19, 20]. For example, Hambrick et al. [21] found individuals who spent more time working on crossword puzzles did not show smaller age-related losses in reasoning ability.

Longitudinal research represents a more stringent test of the engagement hypothesis by assessing whether baseline activity participation reliably precedes or predicts *changes* in cognitive performance. In fact, there is substantial longitudinal support for the relationship. For example, higher frequencies of participating in activities like reading, playing chess, and completing crosswords were related to more gradual 5-year declines in perceptual speed [22], and each hour increase in television viewing (a poor provider of cognitive stimulation) during middle adulthood resulted in a 30% increased likelihood of later AD diagnosis [23]. Similarly, low baseline numbers of social relationships, poor emotional support, and little social integration in the community were associated with poorer cognitive performance and greater decline in

cognitive ability over 4 years [24]. It has even been found that a high level of strenuous domestic chores around the home (e.g. yard work) and a high peak pulmonary expiratory flow rate predicted less overall cognitive decline 2 years later [25]. Similar findings exist throughout the literature [26–36].

Consistent with the disparity among cross-sectional findings, however, there is also longitudinal evidence in opposition of the engagement hypothesis [e.g. 37]. However, the number of studies failing to find a significant relationship are substantially fewer than those in support of the hypothesis, and most tend to be examples of failing to find significant effects of a particular activity domain [e.g. 22], or are related to a particular time frame [e.g. 38], rather than a complete lack of support for the activity-cognition relationship. Further, the discrepancies in the research findings at both the cross-sectional and longitudinal levels, and among the activity domains, are likely perpetuated by the substantial differences in the methodologies employed across the studies (e.g. how and which activities are assessed; whether the duration and intensity of participation is taken into account; how the activities are categorized; which cognitive domain is used as the outcome measure; which covariates are taken into account, etc.), which may potentially mask or distort relationships between activity and cognition. However, Salthouse, a leading researcher in the field, has noted substantial gaps still remain in the currently available evidence on activity participation and cognitive change, and that as such we still do not have definitive proof of the positive relationship [39, 40]. Therefore, although there is indeed support for the 'use it or lose it' hypothesis [7, 39–42], it cannot yet be considered conclusive.

There are a number of methodological and theoretical aspects of the activity and cognition relationship that are not yet well understood, but are essential to moving the field forward. The present paper identifies seven such issues: (1) the mechanisms involved in the relationship; (2) the best way to assess activity engagement; (3) which cognitive domain receives the most benefit from activity; (4) the temporal nature of the relationship (i.e. the time lag of activity on cognition); (5) the directionality of the relationship; (6) whether the relationship varies according to age, gender, or education, and (7) whether one activity domain offers the most benefit. These issues represent where future research attention needs to be directed. The literature surrounding each aspect will be critically reviewed, including identifying what is already known, and both potential difficulties, and possible opportunities that may exist in resolving the issue.

How Does Activity Engagement Impact Cognition?

The precise mechanism through which activity engagement is believed to impact cognition is still unclear, but there are a number of popular hypotheses. One of the proposed mechanisms is by way of active cognitive reserve, where the environment (including lifestyle activities, education, lifelong occupation) can influence neural processing and synaptic organization by allowing neurological processes to become more efficient, adaptive, and plastic [43, see 44 for a thorough review]. The exact physiological changes allowing for this reserve are uncertain, but speculations include increases to cerebral blood flow, the number of synapses in the brain, or allowing more optimal neurochemical compositions [e.g. 1]. Environments that involve diverse stimuli require numerous decisions, and include a multitude of factors and apparently contradictory contingencies on those decisions are believed to offer the most environmental complexity [45], and thus may be most conducive to increasing cognitive reserve. This hypothesis relates easily to cognitive activity (e.g. playing chess), but can be applied to social and physical activity as well: A large social network and frequent engagement with others may offer cognitive stimulation through navigating social cues, having to organize social meetings, engaging in new activities or trips, and dealing with complex and sometimes challenging social issues (e.g. disagreements, diverse social personalities) [9, 46]. Further, various types of physical activity may involve complex cognitive thought that can stimulate and exercise the brain (e.g. anticipating your opponent's moves in tennis, remembering a dance routine) [14, 47].

The physical activity literature in particular has identified a comprehensive working model of possible mediators through which physical activity or exercise may impact cognitive ability in older adulthood [see 42]. These mediational pathways include via physiological, behavioral, and psychological changes, and through the disease/health status of the individual [42]. A long list of physiological benefits have been proposed, including changes to hormone levels, improved cerebral blood flow, and an increased number of neuronal synapses. Studies have shown reduced age-related brain tissue loss as a function of cardiovascular fitness [48], and increased task-related brain activity among those who were highly fit or aerobically trained [1], suggesting that physiological changes may be particularly important in explaining the link between physical activity and enhanced cognitive ability. Individuals who are physically active may also have different behaviors than nonactive individuals in re-

lation to their sleep patterns, eating habits, energy, and drug and medication use, which can in turn influence their cognitive ability (e.g. greater vegetable consumption was associated with less 6-year cognitive decline [49]). Physical activity may also work through its psychological benefits, such as lowering stress, promoting psychological well-being [e.g. 50], and improving quality of life. Furthermore, the benefits associated with being physically fit lower one's risk of developing various diseases that are associated with cognitive decline [e.g. 51]. The possibility of an interaction or combination of these mediators is certainly high (e.g. exercise increases well-being which promotes healthy eating behaviors).

The proposed model from the social activity literature is not as well defined, but focuses on emotional well-being. Frequent engagement with others can act to provide support, promote well-being, and decrease stress, all of which may indirectly benefit the cognitive system by decreasing the physical toll on the body (e.g. stress increases cortisol levels), and reducing the risk of developing diseases that can indirectly impact cognition (e.g. cardiovascular diseases, diabetes) [2, 24, 46, 52]. Clearly, there are similar hypotheses across the activity domains.

Although there has been considerable speculation concerning the mechanisms through which activity engagement benefits cognition, there has been little research devoted to thoroughly investigating the plausibility of each mechanism. As such, it has been suggested studies need to further investigate the specific mechanisms by which activities may impact cognitive ability [7, 42, 53], keeping in mind that there may be a combination of mechanisms at work [54], and that different mechanisms may drive the relationship between the various activity domains and cognition [16]. Although informative, demonstrations of the activity and cognition relationship across various time frames, samples, and cognitive and activity domains are only *describing* the association; further explanations and evidence of *how* this relationship works are needed.

What Is the Optimal Way of Assessing Activity Engagement?

Which Activities Should Be Assessed?

Despite the fact that this is possibly the most basic issue in doing research into the engagement hypothesis, there is still no consensus on the best method of assessing activity participation. Although the most common type of activity assessment asks older adults to report their

typical frequency of engagement in a specific list of activities, the activities included on the list and the number assessed varies enormously (e.g. from nearly seventy [38, 55], to twenty or so [19, 23, 56], to as few as six [57] or seven [36, 37, 58]). This is understandable, as no one has investigated whether assessing sixty activities is necessarily better or more informative than using six. Large lists of activities are by no means exhaustive [19], but potentially important activities that impact cognitive functioning may be missed in brief activity questionnaires. Generic questions about activity are not ideal either, as questions may be answered differently depending on the examples provided. For example, participants may report no moderately intense physical activity if the examples are swimming and cycling, even though they may do a different type of moderately strenuous activity such as tennis [59]. Some studies have instead opted to ask open-ended questions including asking the individual to list all the activities they participated in during a specified time frame [e.g. 54], only consider physical activity that made them sweat or feel exhausted [11, 60], if they have *ever* engaged in a specific activity, e.g. social activities [37, 61], and include any 'other' activity they performed for at least 2 h/week that was not on the activity list [19]. These techniques have the obvious benefit of reducing the likelihood that essential activities are missed, but cannot ensure individuals did not forget items, and may have difficulties in later activity categorization.

Studies focusing exclusively on social or physical engagement have their own standards of assessment, with social activity studies typically assessing activity with only a few measures (e.g. size and frequency of engaging with their social network, emotional support [9, 26, 46]), and physical fitness studies sometimes relying exclusively on physiological measures such as VO_{2max} (i.e. maximum oxygen uptake) [48]. However, inconsistency in activity assessment still exists across these domains [e.g. 62].

Some research labs have begun to develop new questionnaires whose psychometric properties have been rigorously tested (e.g. Florida Cognitive Activities Scale [63, 64]; Lifetime Experiences Questionnaire [65]), but only time will tell whether these items provide the optimal evaluation of activity for the purposes of testing the 'use it or lose it' hypothesis. At the moment, there is no single 'best' list, and unfortunately the likelihood of discovering one is complicated due to potential differences relating to socioeconomic status, culture, and geographic region. For example, one of the most frequent vigorous activities reported by lower-educated Italian elderly was

farming [66], an activity more wealthy individuals have likely rarely participated in. The examples given for a type of engagement are influenced by the culture (e.g. physical – tai chi, Singapore Longitudinal Aging Study [67]), and the types of activities participated in likely differ from one geographic region to another (e.g. surfing vs. ice hockey). Differences among cohorts will also likely exist (e.g. playing bridge vs. playing video games), prompting constant reevaluation of the activity assessment. Despite these difficulties, consensus is clearly needed regarding which activities need to be assessed in order to provide easier comparison across research studies.

How Should This Information Be Acquired?

The most frequent method for assessing activity engagement is via self-report, but this method has a number of potential biases in reporting. Participants may choose to answer the activity questionnaire in a socially desirable way, and report being more physically active than they actually are [39]. Salthouse et al. [19] found evidence of this bias when the sum of several of their participants' reported weekly activity (not including sleeping) neared 170 h, a clearly unrealistic estimate. Individuals may also simply forget to report an activity, particularly if they tend to be sporadically active and not have routine activity habits to aid their recollection [68].

Research investigating the impact of early life activity engagement on cognition in later adulthood [e.g. 23, 31, 69–72] has had to rely on particularly distant retrospective self-reports of leisure activity (e.g. nearly 45 years ago [60]; over 70 years ago [72]). Clearly, the accuracy of reporting activity engagement during younger adulthood, decades later, is questionable, especially given the overwhelming evidence that episodic memory declines with age [73]. On the other hand, it could be hypothesized that today's older adult cohorts had far fewer leisure activities available to them in the early part of their lives (e.g. no television, computer activities) and thus are easier to remember.

Even activity research that investigates the effects of more recent activity on cognition is subject to measurement error from retrospective leisure reports [e.g. 13, 26, 29, 35, 38, 55, 56, 74–77]. Substantial changes in activity participation can occur from year to year, and even from month to month. Given that many activity scales do not report asking participants to describe any prolonged shifts in their activity routine over longer time frames (e.g. 2 years) such as illness, traveling, or relocation, the resulting relationships with cognition may be inaccurate. Further, assessing activity participation based on short

time frames (e.g. 2 weeks, yesterday) introduces the possibility that those time frames were abnormally active or inactive for that individual (e.g. had friends or family visiting; the tax deadline was looming).

Retrospective studies investigating dementia risk obviously do not have the option of requesting past activity information from the dementia patients, and instead rely on surrogates such as spouses or close companions to complete the questionnaire [e.g. 70]. Although Friedland et al. [70] found no significant differences in the activity reporting between healthy older adults and their surrogates, surrogate reporting for individuals with dementia introduces new biases. In dementia studies, the surrogate already knows the participant has dementia, and may rate the dementia patient's past activity level as lower, so as to implicitly maintain the idea of the 'use it or lose it' hypothesis (i.e. this person has dementia, so they could not have been very active in the past).

Are there alternatives to self- or informant-report? Salthouse et al. [19] suggested that information about activity engagement should be obtained from both self-report and other observers (e.g. spouse). Fritsch et al. [78] examined the high school yearbooks of mid-1940s graduates of the same high school, and used each individual's involvement in various clubs (i.e. athletics, academics, service) as the basis for their activity level when they were younger adults. However, this approach does not take into account activities that may have been available outside of the school (e.g. piano lessons), social gatherings, or individual activities such as reading. Other possible assessment methods include asking participants to maintain a daily diary of their activities or record activity by electronic monitoring via a pager (i.e. participants receive a message several times a day asking them to report what they were doing when interrupted), but no known studies have attempted these methods. Although these techniques have their own limitations, including potentially higher costs due to the need for more extensive sampling, and the heavy reliance on participant cooperation, these approaches may be very productive and warrant more attention.

Rather than relying on indirect measures of activity, the physical activity literature has used physiological measures to assess physical fitness, such as VO_{2max} [48, 79]. Newson and Kemps [15] even used a regression equation including age, gender, body mass index, and the ranking of person's physical activity level to calculate a reliable and analogous measure of VO_{2max} . These alternative measures have shown significant relationships with cognition in older adulthood, and may even be stronger

predictors than self-reported assessment. Barnes et al. [79] found a direct measure of aerobic fitness was predictive of cognitive decline over 6 years, but self-reported physical engagement was not. Unfortunately, the other activity domains cannot obtain an objective measurement of activity as easily. There is no obvious measure for social engagement, and although simple cognitive activity may be assessed with fMRI (e.g. 2-choice reaction-time task [1]), physiological measures may not be capturing all of the resulting benefits of activity participation (e.g. social benefits from physical activity). Instead, reasonable alternatives may include validation of self-report measures for these domains, using multiple methods of assessment, and investigating the daily diary or pager approaches.

Which Cognitive Domain Derives the Most Benefit from Activity Participation?

The cognitive domains that are used to evaluate possible relationships with an engaged lifestyle are never exactly the same from one study to the next, making it difficult to identify a consistently significant cognitive domain, never mind the strongest one. Further, because certain activities may act to promote only certain cognitive capacities, failure to evaluate those capacities may lead to the incorrect conclusion that the activity type had no effect on cognition [7]. Therefore, the significant associations that are found, or not found, can actually be a byproduct of the choice of which cognitive domains were used to evaluate the hypothesis.

There have been, however, somewhat reliable results found with perceptual speed and activities. Ghisletta et al. [22] argued that perceptual speed may be most attuned to activity engagement because this basic processing domain gradually and normally declines across the life span. Accordingly, they found that changes in perceptual speed, but not changes in verbal fluency, were influenced by past frequency of engaging in media and leisure activities. Similarly, 2-year changes in perceptual speed were significantly affected by changes in social participation [54]. On the other hand, rather than identifying one specific cognitive ability, some have suggested that more complex versions of cognitive tasks show the greatest activity-related benefits, particularly in relation to cognitive activity [e.g. 16]. This proposal is supported by findings that complex reaction time tasks were more attuned to baseline and 6-year activity effects than simple tasks [38].

The physical activity literature is more specific about the optimal cognitive measurement. Colcombe and Kramer [80] concluded that physical activity tends to primarily benefit executive functioning abilities (i.e. planning, inhibition, decision-making), and to a lesser degree controlled (i.e. where effortful rather than automatic processing is required; e.g. Choice RT), visuospatial, and speeded tasks. For example, tasks that required higher levels of executive functioning showed a stronger relationship with physical activity [11] and cardiorespiratory fitness [79] than other tasks. Further, although Bugg et al. [12] found no difference between physically active and sedentary older adults on a simple reaction time task, the sedentary adults' performance decreased across the course of the day on a working memory task, while the active adults' performance was maintained. In contrast, however, Newson and Kemps [15] found aerobic fitness accounted for more variance in the processing resources of attention, working memory, and speed, than in the higher-order functions of executive functioning and memory. Therefore, variations in the physical activity literature still exist.

Studies need to choose a wide range of cognitive domains when investigating the effects of an engaged lifestyle, and note that different activities may affect cognitive domains differently (e.g. social activity may be the most important determinant for processing speed, whereas higher-order cognition may be most affected by physical activity), and act through different mediational pathways. Further, because cognitive abilities decline at varying rates in older adulthood [73], the most receptive cognitive domain may also vary by age. More detailed examination of these potential variations is needed.

How Long Does Past Activity Impact Current Cognition?

A number of studies have found early life activity and the accumulation of activities across the life span are related to cognitive ability in later life. For example, a composite of cognitive activity at various ages (i.e. 6, 12, 18, 40, and current older age) was positively associated with current cognitive performance in older adults [71], and poor early life linguistic ability (i.e. average age of 22) was significantly related to low cognitive test scores nearly 58 years later [81]. Even the level of participation in extra-curricular high school programs that involved mental activity was directly related to verbal fluency in older adulthood [78]. Physical activity early in life also appears to

benefit later life cognitive function, as being physically active between the ages of 15–25 was positively associated with cognitive functioning for older men [60], and regular exercise during midlife (i.e. 25–50 years) was protective against developing dementia in older adulthood [69].

However, the influence of past activity participation does not appear to trump the benefits of current activity levels. Rather, Wilson et al. [72] found that the association between current activity and current cognitive ability was stronger than those with past activity [also see 82]. Moreover, they found the relationships between past activity and current cognition were reduced after controlling for current cognitive activity, but controlling for past engagement did not affect the relationship between current activity and current cognitive ability. Similarly, Richards et al. [83] found physical activity at 43 years of age was a better predictor of verbal memory change from 43 to 53 years of age than the amount of physical activity participated in at age 36. Furthermore, they found little evidence of protection against memory decline for those who stopped exercising after age 36, showing the benefit of past activity was lost if activity was not maintained. On the other hand, those who started physical activity after age 36 were protected, and being physically engaged at both occasions had an additive effect, as the cognitive benefits of past activity were enhanced by more recent activity.

Consequently, there remains a good possibility that positive lifestyle changes can be made in the present and quickly contribute to overall cognitive health. Cognitive ability significantly improved after participation in a 10- to 12-week program that provided opportunities to engage in a wide range of novel problem-solving and creative activities [84], and structural brain benefits were seen after as little as 6 months of aerobic exercise [85]. Other demonstrations of enhanced cognitive ability exist in the training literature (e.g. Advanced Cognitive Training for Independent and Vital Elderly, also known as ACTIVE) [86], demonstrating that even brief periods of increased cognitive stimulation can quickly improve older adults' cognition. However, the precise time lag between activity engagement and the resulting change in cognition has yet to be determined. Further, it is uncertain how long the benefits of more recent past activity (i.e. a few years ago) remain. Bielak et al. [38] found many significant concurrent, but few 6-year change relationships between activity and cognitive speed, leading them to suggest that activity level at one point in time may be a more important predictor of cognition than an individual's

changes in activity participation. This hypothesis fits well with research showing the robust nature of the short-term activity and cognition relationship (i.e. 1 year [22, 67]; 2 years [54]), while significant effects were not apparent over longer intervals (i.e. 7 years [57]). A number of other studies have also lacked correspondence between the baseline and change relationships (e.g. social activity [13, 55]; physical activity [20, 60]), further questioning the duration of the activity benefit.

The question of lag time may be elucidated by longitudinal research with numerous follow-up time points, thus allowing the investigation of both the short-term and long-term nature of activity benefits. However, the lag times may differ according to the different activity domains, as some may be associated with only immediate benefits, while others last for years. For example, older adults who acquired proficient bilingualism in childhood showed less decline in executive processing than monolinguals, demonstrating a substantial life-long cognitive advantage [87]. It may be the case that activities that cause extensive neural branching have the longest lasting effects on cognition. This question remains to be explored.

Does Activity Participation Impact Cognition, or Does Cognition Impact Activity Participation?

The engagement hypothesis predicts that the action of engaging in lifestyle activities precedes and thus causes subsequent changes in cognitive performance in older adulthood. However, there is support for the opposite relationship where changes in cognitive functioning result in changes in activity participation. In this case, activity is an *indicator* of decline, rather than the mechanism, and activity reduction is the *consequence*, rather than the antecedent of cognitive decline [57]. According to this pathway, individuals who have experienced cognitive decline may withdraw from activity participation because they find the same activities more difficult, and instead a cause of frustration and a reminder of their lost abilities. On the other hand, individuals with high levels of cognitive ability have a greater capacity to engage in activities successfully, and may consequently be more motivated to participate in future activities. Another way to view these two alternatives is that the 'use it or lose it' hypothesis is consistent with *differential preservation*, where variations in cognitive ability with increasing age are due to differences in activity level, whereas *preserved differentiation* suggests that active individuals likely always had higher

levels of cognitive functioning, and that their enduring higher cognitive fitness allows them to be more active in older age [39, 88].

Hultsch et al. [55] used structural equation modeling on 6-year longitudinal data and found that both the initial level and changes in participation in novel information processing activities (e.g. playing chess, learning a new language) were significantly related to changes in working memory, and to other cognitive processes via working memory. Therefore, consistent with the engagement hypothesis, individuals who engaged in these activities and maintained their participation were less likely to show cognitive decline. However, Hultsch et al. [55] also found that the model testing the opposite relationship, that cognitive changes affected participation in intellectually challenging activities, fit the data equally well. Therefore, the results showed that it was also plausible that older adults engaged in many intellectual activities until their cognitive ability limited their participation, or that older adults who maintained their activity participation over time were able to do so because their cognitive faculties were relatively well preserved. Other studies investigating the directionality have proved inconsistent, with one concluding information processing speed appeared to affect developmental activity rather than vice versa [37], and another finding the pathway of social participation preceding and predicting 2-year changes in perceptual speed as more powerful than the opposite pathway [54]. However, Lövdén et al. [54] suggested the directionality relationship may be different among higher cognitive domains, as declines in these domains would be more likely to consequently affect the capacity to engage in activities. Ghisletta et al. [22] investigated this idea by testing the influence of all types of activities on perceptual speed and verbal fluency. For perceptual speed, they found significant coupling effects with previous engagement in media and leisure activities, but perceptual speed did not exert an effect on subsequent changes in activity participation. For verbal fluency, however, there were no coupling effects with changes in activity, indicating change in a higher cognitive domain does not necessarily subsequently influence changes in activity participation.

There have also been suggestions that the activity-cognition relationship need not operate as one variable impacting the other, but rather as a dynamic relationship where the changes in one are constantly affected by changes in the other [e.g. 7]. For example, Schooler and Mulatu [89] found evidence of both pathways: Complex cognitive leisure activities influenced the current level of

cognitive functioning, and there was an even stronger effect of cognitive functioning on the complexity of leisure activity participation. Schooler and Mulatu noted that these findings support a type of cyclical directionality: High levels of intellectual functioning led to high levels of complex leisure activity, which in turn raised or maintained levels of intellectual functioning with age. However, it may also be the case that the significant associations between activity and cognition are caused by a third variable, such as general neurophysiological vitality [54].

Tranter and Koutstaal [84] noted that in addition to behavioral evidence to verify the causality of activity participation, corresponding neuroanatomical evidence of change would be required. Moreover, demonstration of the opposite effect would be critical, where removal of activity participation reversed the positive behavioral and brain changes [84]. Future interdisciplinary research would be particularly well suited to addressing these qualifications, and also employing statistical techniques that adequately evaluate the competing pathways, such as dual change score analyses [7]. However, irrefutably demonstrating the directionality of the hypothesis will be challenging.

Does the Relationship Differ according to Age, Education, or Gender?

Although activity research aims to discover the universal effects of an engaged lifestyle on cognition, demographic variables may influence the relationship. For example, the cognitive effort required to complete an activity may increase throughout older adulthood (i.e. due to increased cognitive decline and accruing detrimental effects from lifestyle choices and the environment), and thus the benefit of the same activity may be different at different points in the life span [19]. Furthermore, the impact of activity participation on cognitive functioning may also change according to contextual factors, such as retirement or widowhood [53], which in turn likely vary according to gender or educational attainment.

Regarding age, the benefits of participating in lifestyle activities appear to be greater in later adulthood compared to young or mid-old adulthood [13]. For example, those between the ages of 75–94 years had a greater number of, and stronger correlations at both baseline and 6-year change between activity and cognitive speed than those between the ages of 55 and 74 years [38]. Therefore, activity may begin to have a more powerful effect on cog-

nition in later older adulthood (i.e. 70–75 years), but the influence may remain steady there afterwards, as those aged 70–84 years and 85–103 years had the same 2-year positive relationship between social participation and perceptual speed [54]. However, the effects of activity in early older adulthood likely still differ from the rest of the life span. Parslow et al. [17] showed that while artistic activities were positively correlated with cognitive performance across adulthood, only the older group (i.e. 60–64 years), compared to those in their early 20s and early 40s, also showed significant relationships with social, enterprising, conventional, and investigative activities and cognitive ability.

Particular aspects of social engagement may also have age-dependent effects, as Béland et al. [30] found familial engagement and ties were positively related to maintaining cognitive functioning up to 80 years of age, but the cognitive benefit of social integration with the community was limited to after 75 years of age. A peak for benefits from physical activity may also exist, as Colcombe and Kramer's [80] meta-analysis found the greatest fitness effects for those in mid-older adulthood (i.e. 66–70 years). Consequently, there may be varying critical periods or optimal times to engage in activities depending on the activity domain or type. For example, it may be that the compensatory effects of physical activity are only effective once cognitive ability has reached a certain point of decline; too young, and one's cognitive performance is still relatively intact, rendering physical activity only indirectly beneficial to the cognitive system; too old, and one's ability to engage in physical activity becomes limited. This hypothesis fits with research showing physical activity was associated with better cognitive performance across the life span, but exerted a greater effect on older (i.e. 40–71 years), compared to younger adults' performance [11]. Similar critical periods may also exist across cognitive domains. Christensen et al. [8] found inactivity was associated with poorer fluid intelligence for older-old adults (i.e. 85–89 years), whereas inactive younger-old adults (i.e. 70–74 years) were more likely to have poorer crystallized intelligence.

However, age differences in the activity-cognition relationship are unreliable. The results of Salthouse et al. [19] that cognitive activities did not mediate age-related differences in cognitive performance were true for those both under and over 50 years of age. Further, Newson and Kemps [16] failed to find age differences in the benefits derived from cognitive activity across young and old adulthood (i.e. 18–27 years; 65–92 years), but the physical activity effects increased with age. Overall, our knowl-

edge of the relationship between activity and cognition across the life span is modest. In fact, Salthouse [62] recently made a plea for increased research at several different points in the life span (e.g. 30s, 40s, 50s; rather than only 20s and 60s+), as we may be missing key information by overlooking the fact that a large amount of cognitive decline has already occurred by age 60.

Next, it has also been suggested that the benefits of activity engagement may be limited to low-functioning adults [e.g. 19, 39], as several studies that have failed to find significant relationships between activity and cognition involved participants who were high in both education and intelligence [e.g. 19]. For example, Scarmeas et al. [33] found individuals with both low education (i.e. 8 years or less) and low levels of activity participation were at the greatest risk of developing AD. Further, Christensen et al. [8] found that less well-educated individuals who often read the newspaper, engaged in physical activity, and were involved in interests and hobbies, had significantly higher memory scores than their less active peers, but activity level made little difference for the highly-educated older adults. Despite these findings, significant positive relationships between activity and cognition have been found in highly educated samples [e.g. 38, 55, 72], indicating cognitive gains are possible regardless of educational level. However, because both activity participation and educational attainment are believed to contribute to the index of cognitive reserve [44], the possibility exists that highly educated adults derive a smaller cognitive gain from activity because they already have already accumulated substantial reserve from education.

Varying effects have also been found in relation to gender. Although participation in activities that involved observing and investigating physical, biological, and cultural phenomena were predictive of better cognitive speed scores for younger, middle-aged, and older men, this was true only for middle-aged women [17]. On the other hand, greater participation in intellectual-cultural activities like reading, listening to the radio, and having social visits in early and middle adulthood was associated with protection against developing dementia for women, but not for men [31]. Crowe et al. [31] noted that because most women in their older cohort would not have had a job outside the home, intellectual stimulation obtained from leisure activities may have been more important for them than for men who had work-related intellectual stimulation. A similar conclusion was reached in studies based on a Spanish sample, where engagement with friends was an important protective factor against cogni-

tive decline for women, but not for men [24, 30]. The authors suggested that because a woman's life in Spain is centered on the family, contacts outside the family are important for cognitive stimulation. Therefore, gender differences in the activity-cognition relationship may be specific to the present-day cohort of older adults, because the substantially different gender roles that were predominant throughout the majority of their lives consequently impacted the types of activities they participated in, and possibly the subsequent impact of those activities on cognition. However, variations may also be due to physiological sex differences, primarily those associated with physical activity. For example, early life physical engagement was significantly related to processing speed for men only [60], whereas only women who participated in regular exercise were less likely to develop cognitive impairment [34, 75] and dementia [29].

Although there is evidence of variations in the activity-cognition relationship according to age, education, and gender, all three influences require more attention in the activity literature.

Is There One Activity Type That Offers the Most Cognitive Benefit?

Some findings have corresponded with the hypothesis that the greatest cognitive gain should accordingly come from cognitively stimulating activities [e.g. 20, 22, 36, 38, 55, 58, 70, 77, 78, 90, 91], whereas others do not. For example, Newson and Kemps [56] found tasks with limited cognitive complexity (i.e. household maintenance, domestic chores, volunteer work, and being socially engaged) significantly predicted 6-year cognitive change. Moreover, a number of different domain combinations have been significant: Both social and intellectual activities lowered the risk for cognitive decline [67] and AD [23, 26]; engagement in each activity type significantly lowered the risk of dementia [33, 92], and there was no association between any type of activity and cognition in older adulthood [37].

Consequently, there is no consensus on which activity domain, if any, offers greater cognitive benefit than the others. Rather than focusing on the domain, however, it may be the characteristics of the activity that are most important. Parslow et al. [17] found that participation in artistic (e.g. acting), investigative (e.g. troubleshooting computer software), enterprising (e.g. supervising others), social (e.g. helping others), and conventional activities (e.g. writing business letters) were each associated

Table 1. Unanswered questions about the influence of activity participation on cognitive performance in older age

Questions
1 How does activity engagement impact cognition?
2 What is the optimal way of assessing activity engagement? a Which activities should be assessed? b How should this information be acquired?
3 Which cognitive domain derives the most benefit from activity participation?
4 How long does past activity impact current cognition?
5 Does activity participation impact cognition, or does cognition impact activity participation?
6 Does the relationship differ according to age, education, or gender?
7 Is there one activity type that offers the most cognitive benefit?

with better crystallized intelligence in older adulthood, but conducting activities in the realistic domain (e.g. fixing mechanical things, gardening) was not. It could be argued that the 'realistic' types of interests suit domestic functions that are synonymous with daily maintenance, and thus offer minimal novel stimulation; precisely the types of activities that offer no special enhancement or protection of cognitive abilities [93]. Therefore, rather than a particular domain of activity providing superior cognitive benefit, the amount of novelty offered by an activity may be most important.

Further, pinpointing one domain or activity as the most beneficial is difficult because any activity likely involves some degree of each of the social, physical, and intellectual domains, and possibly other characteristics as well. In fact, coding a certain activity as an indicator of only one domain may neglect other important stimulation provided by participating in that activity (e.g. dancing can be physical, social, and cognitively challenging all at the same time), and mask other possible influences on cognition [e.g. 20]. A novel approach by Karp et al. [14] rated the degree to which 29 different activities involved each of the mental, physical, and social components. Based on the activities they participated in, each individual then received a summed score for each of the various components. Older adults with high participation profiles on all, or two of the three components had the lowest risk of dementia. Therefore, the most important factor was the total accumulation of mental, social, and physical engagement, suggesting that engagement in activities with even small contributions of the various activ-

ity domains can be beneficial [14]. Furthermore, activities that engaged more than one component type appeared to be more beneficial than activities that involved only one type of stimulation. Consequently, activities that cross domains may be the most protective (e.g. orienteering).

Overall, no one single activity domain has been consistently reported as showing significant relationships with cognitive performance in older adulthood. In fact, it is likely that the superior activities will transcend domains and offer more than one type of stimulation [14], or have particular characteristics (e.g. novelty [93]). Additionally, the best activity domain may vary depending on which point in the life span and which cognitive outcome is considered.

Conclusion

Although there are differences of opinion regarding what constitutes definitive support of the engagement hypothesis [39–41], there is a strong possibility that being active in older adulthood does indeed benefit the cognitive system [7, 39–42]. Consequently, we need to refine our knowledge of the relationship between activity participation and cognition, directing attention to both providing stronger support of the hypothesis, and resolving a number of key issues about the hypothesis.

The present paper identified several of the methodological and theoretical issues that remain to be explained in the activity and cognition literature (table 1). However, there are certainly additional issues of concern. For example, very little is known about what duration and intensity of an activity is required to benefit cognition. Although research focusing solely on physical activity has been able to make specific recommendations (e.g. training of 30 min or more is needed to provide cognitive benefit [80]; at least 6 months of aerobic fitness are needed to see neurocognitive benefits [1]; also see [74, 76]), the subjective nature of intensity complicates further research and conclusions. Salthouse et al. [19] noted that the actual intensity of engagement or the cognitive complexity involved in a certain activity can vary from individual to individual (e.g. one person could be passively watching television while another is actively analyzing the actors' acting styles or the plot; reading a book may be quite demanding for someone with a low literacy level or if the book is written in their second language). Similarly, participating in the same activity could require productive engagement for one person (i.e. acquiring new skills) but

receptive behavior for a more experienced individual (i.e. building on familiar skills) [93]. It is unknown to what extent activity duration and intensity matter, making this clearly another potential research focus.

It is hoped that researchers will use this paper as a tool to guide their future studies, by focusing on what is missing from our knowledge base about the engagement hypothesis. Clearly, numerous studies will be required to adequately answer questions surrounding each area, and consequently more studies need to take on the challenge of specifically targeting these issues. Both the research literature and society appear to have recognized the potential opportunity in treating the brain as a muscle, and

exercising it for optimal cognitive health in older age. What is unclear are the exact recommendations for this exercise, and those can only be answered when more of the methodological and theoretical issues are addressed.

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