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Do Changes in Lifestyle Engagement Moderate Cognitive Decline in Normal Aging? Evidence from the Victoria Longitudinal Study

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Abstract

Objective—Do lifestyle activities buffer normal aging-related declines in cognitive performance? The emerging literature will benefit from theoretically broader measurement of both lifestyle activities and cognitive performance, and longer-term longitudinal designs complemented with dynamic statistical analyses. We examine the temporal ordering of changes in lifestyle activities and changes in cognitive neuropsychological performance in older adults.

Method—We assembled data ($n = 952$) across a 12-year (5-wave) period from the Victoria Longitudinal Study. Latent Change Score models were applied to examine whether (and in which temporal order) changes in physical, social, or cognitive lifestyle activities were related to changes in three domains of cognitive performance.

Results—Two main results reflect the dynamic coupling among changes in lifestyle activities and cognition. First, reductions in cognitive lifestyle activities were associated with subsequent declines in measures of verbal speed, episodic memory, and semantic memory. Second, poorer cognitive functioning was related to subsequent decrements in lifestyle engagement, especially in social activities.

Conclusions—The results support the dual contention that (a) lifestyle engagement may buffer some of the cognitive changes observed in late life, and (b) persons who are exhibiting poorer cognitive performance may also relinquish some lifestyle activities.

Keywords

aging; latent change score models; longitudinal changes; lifestyle activities; Victoria Longitudinal Study

Some recent neuropsychological and epidemiological studies of normal cognitive aging, mild cognitive impairment, and dementia have converged in their attention to a set of risk

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and protection factors from the everyday lives of many older adults. Among these are lifestyle factors that reflect the extent of concurrent and past engagement in activities, often clustered in three categories: (a) physical activities or fitness, (b) cognitive activities that deliberately or inadvertently constitute practice or enrichment, and (c) social activities typically requiring complex cognitive functioning, as well as general cognitive engagement. Recent reviews have suggested that elevated levels of selected lifestyle activities may be associated with a variety of favorable activity-cognition relationships. These include (a) maintenance or improved cognition related to self-reports of physical activity or activity interventions (for reviews see Kramer & Erickson, 2007; Rockwood & Middleton, 2007), (b) socially engaged lifestyles linked to delayed dementia diagnosis (e.g., Fratiglioni, Paillard-Borg, & Winblad, 2004), and (c) patterns of enrichment activities potentially promoting cognitive maintenance in normal aging (Hertzog, Kramer, Wilson, & Lindenberger, 2008; Lövdén, Bäckman, Lindenberger, Schaefer, & Schmiedek, 2010). Potential mechanisms associated with this cluster of protective factors include improved cerebrovascular health, decreased neuroinflammation, and enhanced cognitive reserve (e.g., Cotman, Berchtold, & Christie, 2007; Middleton, Kirkland, & Rockwood, 2008; Stern, 2002, 2009, 2007). These and other possible mechanisms require further attention, but are united to the extent that they may mediate the degree of brain pathology (versus brain health and compensatory networks) associated with normal aging and even neurodegenerative diseases (Dixon, 2011).

Clinical observations (e.g., Cosentino, Brickman, & Manly, 2011) and theoretical reviews (e.g., Luszcz, 2011) confirm (a) the complexity of influences on cognitive change among older adults, but (b) the inevitability of some degree of aging-related decline. Nevertheless, there are both individual differences in the extent of decline and domain-related differences in the timing, trajectories, and outcomes of late-life changes (Craik & Salthouse, 2007; Hofer & Alwin, 2008; Small, Dixon, & McArdle, 2011). Although it is not precisely a new area of research, recent attention to the potential role of everyday protective factors in modulating decline and dementia has benefited from new clinical, theoretical, and methodological developments. Thus, research has focused on the extent to which older adults' everyday lifestyle, enrichment, and educational activities may buffer aging-related decline or lessen age-related deficits in cognitive performance (Salthouse, 2006; Small, Hughes, Hultsch, & Dixon, 2007; Zahodne et al., in press). Recent reviews have concluded that engaging in cognitively enriching activities may have the effect of (a) slowing rates of normal cognitive decline, (b) enhancing levels of cognitive functioning among older adults not compromised with neurodegenerative disease or other neurological risk factors, and (c) delaying or mitigating decline associated with impairment or dementia (e.g., Fratiglioni, et al., 2004; Hertzog, et al., 2008; Middleton, et al., 2008).

However, observers have also identified several important limitations in the current literature. These include (a) lack of breadth and dimensionality in the construct and measurement of lifestyle activities as predictors, (b) restriction of domains of cognitive performance used as performance and outcome indicators, (c) limitations on observing and inferring directionality of the theoretical relationships with cross-sectional designs, (d) limitations with available longitudinal designs in any of the above aspects, and (e) the lack of change data and dynamic models with which to test temporal relationships. In the current study, we address these shortcomings by examining changes and dynamic relationships among three established domains of lifestyle activities as they relate to changes in three domains of neurocognitive performance. Moreover, our longitudinal data set follows participants for up to 12 years, enough to develop and test statistical models that allow us to compare alternative hypotheses of directionality. Specifically, we test dynamic models corresponding to whether declines in activity participation “lead” or “lag” declines in

cognitive function, a key theoretical and clinical question in aging, impairment, and dementia.

Inconsistencies in the literature may be due in part to cross-study variations in (a) number of dimensions of lifestyle activities represented, (b) breadth of domains of cognitive neuropsychological functions tested, (c) replicability and validity of measurement operations involved in activities and cognition, and (d) match between the element(s) selected for lifestyle activities and cognitive domains. For example, studies assessing self-reports of lifestyle activities have used single-item indicators, single-domain scales, and multi-domain psychometrically developed scales (e.g., Bielak, 2009; Bielak, Hughes, Small, & Dixon, 2007; Hultsch, Hertzog, Small, & Dixon, 1999; Schinka et al., 2005). In the current study, we use the VLS Activities Lifestyle Questionnaire (VLS-ALQ; Hultsch, et al., 1999), a factorially valid instrument with multi-item scales representing all three principal dimensions, including cognitive, physical, and social activities. As a result, we are able to test whether participation in all three dimensions of lifestyle activities has potential benefit to changes in cognitive functioning, or whether one dimension is especially helpful in maintaining cognitive health with aging.

Regarding cognitive neuropsychological performance, previous research in this area has again used a wide range of measurement operations, including subjective ratings of performance (Schooler & Mulatu, 2001), intelligence test scores (Pushkar Gold et al., 1995), global measures of general cognitive status (Middleton, et al., 2008), and specific measures of cognitive abilities (Hultsch, et al., 1999; Richards, Hardy, & Wadsworth, 2003) increasingly organized by theoretical domain (e.g., Bielak, et al., 2007). The match between the types of cognitive skills engaged by lifestyle activities and the types of cognitive skills tested may be critical for observing these effects. In cognitive intervention research, gains in cognitive functioning among older adults have been observed, but the positive benefits of training are generally associated with the trained domain and do not transfer to untrained abilities (Willis et al., 2006). This implies that the benefit of less-specific practice through engagement in lifestyle activities may be contingent upon the match between the cognitive domains that are accessed and practiced in everyday life and those tested in laboratory settings. For example, if an older adult regularly enjoys cross-word puzzles then their performance on measures of lab tests of verbal ability may be more affected than their performance on speed of processing or nonverbal episodic memory tasks. In the current study, we use three distinct domains of cognitive performance as outcomes, namely, episodic memory, semantic memory, and verbal speed. Accordingly, we evaluate whether the beneficial effects of lifestyle activities are domain specific or are more broadly observed.

Previous researchers have addressed several key elements required to examine these dynamic relationships, including the temporal ordering of changes in activity patterns and changes in cognitive performance (Ghisletta, Bickel, & Lövdén, 2006). Three methodological requirements are (a) multivariate longitudinal data, (b) psychometrically sound measures of both lifestyle activities and cognitive neuropsychological performance at all waves, and (c) a statistical procedure that permits the analysis of dynamic and differential relationships between the two main domains. In the current study, we examine the relationship between changes in active lifestyle and changes in cognitive functioning using a Latent Change Score models (LCS) approach (Ferrer & McArdle, 2010; McArdle, 2009; McArdle et al., 2004). These models provide a number of advantages, as compared to traditional approaches. First, the models examined here build upon the general theme of structural equation models for latent growth and we are able to use all available data across the follow-up period, not just cases that have complete longitudinal data. This is an important feature of these types of methods and it allows all participants to contribute to the relationships that are examined, even if they do not return across all follow-up periods.

Second, we can compare models corresponding to four specific hypotheses, each representing alternative versions of the potential dynamic relationships. First, we test a “no-coupling” model representing no relationship between changes in activity lifestyle and changes in cognitive performance. Second, we test the lifestyle engagement model representing the possibility that active lifestyles are a “leading indicator” of cognitive performance in that they precede changes in cognitive functioning. Third, we test the corresponding cognitive-first hypothesis representing the possibility that cognitive performance is the “leading indicator” of changes in activity participation. Fourth, the “dynamic coupling” hypothesis is that both domains show evidence of leading and lagging the other, such that changes in both domains of variables changes in both variables influence changes in the other.

Previous research with dynamic statistical models is limited but methodologically appropriate in this area of the neuropsychology of aging (Rockwood, 2007). Using similar models, Lövdén and colleagues (2005) examined 8-year data relating changes in two variables only, namely, social participation (e.g., restaurant visits, sports, hobbies) and perceptual speed. The promising results indicated that changes in social participation were related to subsequent changes in perceptual speed, but that preceding changes in perceptual speed were not related to changes in social participation. Ghisletta and colleagues (2006) also examined the 5-year relationship between changes in participation in lifestyle activities and perceptual speed, but this study included an additional cognitive outcome measure (verbal fluency). The results indicated that changes in lifestyle activity, measured by frequency of media activities (e.g., reading a book) and leisure activity (e.g., playing a game) were related to subsequent changes in perceptual speed. However, the results also indicated that other categories of lifestyle activities—including manual (e.g., gardening), external-physical (e.g., going for walks), social (e.g., attending cultural events), and religious (e.g., praying)—were unrelated to changes in perceptual speed. Moreover, changes in the measure of verbal fluency were unrelated to changes in any of the six lifestyle activity domains.

The goal of the present study is to examine the relationships between 12-year changes in three dimensions of lifestyle activities and 12-year changes in three dimensions of neuropsychological performance. The measures of cognitive neuropsychological performance include verbal speed (representing cognitive reserve), episodic memory (a key early marker of cognitive decline and impairment), and semantic memory (a domain in which older adults often show preserved functioning). The measures of active lifestyle were selected to represent all three key domains, physical, social, and cognitive activities. Finally, we fit LCS models to enable us to test hypotheses regarding the temporal order of changes in lifestyle activities and cognitive performance.

Methods

Participants

Participants were drawn from Samples 1 and 2 of the Victoria Longitudinal Study (VLS; see Small, et al., 2011 for more information). The VLS follows a longitudinal-sequential research design in which participants are tested every three-four years on an extensive battery of cognition, health, physical, neuropsychological, sensory, psychosocial and other tests (Dixon & de Frias, 2004). In order to test dynamic relationships over a uniquely long follow-up period, we assembled VLS data from the first 5 waves for Sample 1 (12-year follow-up period) and the first 3 waves (6-year follow-up period) for Sample 2. Sample 1 began in the late 1980s with 484 white, community-dwelling adults (288 women and 196 men) initially ranging between 55 and 85 years of age ($M = 69.2$ years). Sample 2 began in the 1990s with 530 predominantly white participants (355 women, 175 men) initially

ranging between 55 and 94 years of age ($M = 68.25$ years of age). The mean intervals between waves were similar (Sample 1 = 3.1 yrs; Sample 2 = 3.3 yrs).

Prior to assembling the data set we applied a set of exclusionary criteria. The goal was to ensure that the sample was relatively typical for older adults and free of concurrent neurodegenerative disease. At intake, all participants were community-dwelling, with corrected vision and hearing sufficient to engage the VLS battery. In addition, the intake protocol confirmed that all participants had no Alzheimer's disease (or other dementia), no psychiatric condition (with no medications), and no history of serious cardiovascular or cerebrovascular disease. The demographic characteristics for both samples are listed in Table 1. There were significant differences between the samples in terms of gender composition and years of education. Sample 2 contained proportionally more men and had a higher mean level of education, as compared to Sample 1. Age (years), gender, and education (years) and self-reported health status (described below) from baseline were used as covariates in all of the statistical models. The average rate of return for participants across all waves was over 70%. Previous analyses (Hultsch, Hertzog, Dixon, & Small, 1998) has suggested that participants who returned for retesting were positively selected in terms of demographic, self-reported health, and cognitive characteristics.

Measures

The measures of cognitive performance were selected based on three considerations. First, we sampled three complementary aspects of cognitive aging: (a) verbal speed (indicating basic reserve and typically undergoing long-term decline), (b) episodic memory (indicative of cognitive aging and neurocognitive decline), and (c) semantic memory (representing longer-term possibility of cognitive maintenance). Second, we sought to examine a range of cognitive abilities so to test more broadly the extent to which participation in different lifestyle activities may generalize across more than one domain of cognition. Third, we ensured that all cognitive tests were fully measured at each wave in Samples 1 and 2. We operationalized cognitive performance by constructing composite scores for three domains of functioning: verbal speed, episodic memory, and semantic memory, based upon previous confirmatory factor analysis on these measures (Hertzog, Dixon, Hultsch, & MacDonald, 2003).

Verbal Speed

We used two standard VLS tasks to measure this domain (see Dixon et al., 2007). This domain was indexed by the *lexical decision task* (Baddeley, Logie, & Nimmo-Smith, 1985) in which participants were asked to decide as rapidly as possible whether a 5- to 7- letter stimulus appearing on the computer screen was an English word (e.g., island vs. nabion), and by the *semantic decision task* (Palmer, MacLeod, Hunt, & Davidson, 1985), whereby participants were asked to decide whether a sentence appearing on the computer screen was plausible in the world as we know it. Examples of plausible and implausible sentences were "The tree fell to the ground with a loud crash" versus "The pig gave birth to a litter of kittens this morning." In both cases, median latency was converted to a T-score composite from each longitudinal wave. These composite scores were standardized based upon test-specific means and standard deviations at the initial wave. These values were summed and serve as the outcome examined here.

Episodic Memory

We used standard VLS tasks to measure this domain (see Dixon et al., 2004). For the *word recall* task, two lists of 30 nouns from six taxonomic categories (five words per category) were studied for 2 minutes with 5 minutes for free recall. For the *story recall* tasks, two narrative stories from a set of 25 parallel texts were used (Dixon, et al., 2004). Written recall

was scored using a gist-based system (Kintsch & van Dijk, 1978). The outcome examined was a T-score composite of these two tests at each wave of measurement standardized based upon test-specific means and standard deviations at the initial assessment.

Semantic Memory

Fact recall was measured by two sets of 40 questions that tested individuals' recall of world knowledge (Nelson & Narens, 1980). The questions were presented in booklets, and participants wrote their answers under self-paced timing conditions. The *Vocabulary* measure consisted of performance on a 54-item multiple-choice (recognition) vocabulary test derived from the ETS Kit of Factor Referenced Tests (Ekstrom, French, Harman, & Dermen, 1976). The outcome examined was a composite of the number of correct items on both of these tests at each longitudinal wave, standardized based upon test-specific means and standard deviations at the initial wave.

Lifestyle Activities

We used the *VLS-ALQ* (Hultsch, et al., 1999) to measure the frequency and type of everyday cognitive, social, and physical activities in which participants engaged. Participants rated their typical frequency of participation in 70 activities over the past two years. In the current study, we focus on three broad domains of lifestyle activities (with sample items and number of total items in parentheses): (a) physical activities [e.g., jogging, gardening ($n = 4$)], (b) social activities [e.g., attending concerts, visiting friends ($n = 7$)], and (c) cognitive activities [e.g., using the computer, playing bridge ($n = 39$)]. The frequency of participation was rated on a 9-point scale (*never, less than once a year, about once a year, 2 or 3 times a year, about once a month, 2 or 3 times a month, about once a week, 2 or 3 times a week, daily*). Responses were scaled such that higher scores indicated greater frequency of activity. One year test-retest reliability obtained from a sample of 160 adults ranging in age from 55 to 75 years was $r = .85$ (Hultsch, et al., 1999).

Self-reported Health

This domain was used only as a covariate in the analyses. It was indexed by three measures: chronic illness, instrumental health, and self-rated health (Wahlin, MacDonald, de Frias, Nilsson, & Dixon, 2006). For chronic illness the presence and severity of 26 chronic conditions were assessed. Instrumental health required participants to rate the extent to which their health caused them to change their level or pattern of daily activity in eight domains over the past 2 years. Finally, self-rated health consisted of two items that asked participants to rate their own health on a 5-point scale (very good, good, fair, poor, or very poor) compared with a perfect state of health and compared with other people their own age. Scores on each item were standardized and summed to create a composite self-reported health score.

Statistical Analyses

The analyses followed a two-stage procedure. First, we applied univariate LCS models (see Ferrer & McArdle, 2010; McArdle, 2009 for reviews) to describe changes in each cognitive outcome and measure of lifestyle activities across the 12-year follow-up period. For each outcome, age at baseline, gender, years of education, and self-reported health served as covariates. Next, we examined the dynamic relationships among the measures of cognitive performance and lifestyle activities by applying bivariate LCS models that paired changes in one cognitive outcome with changes in one lifestyle activity. The bivariate LCS is most consistent with the present goal of testing dynamic lifestyle-cognition relationships because it has the advantage of evaluating whether the changes in a variable were dependent on its previous state and/or the previous state of another variable. As described above, four

sequential hypotheses for each set of longitudinal relationships were tested and corresponded to no relationship between outcomes, changes in activities predicting changes in cognition, changes in cognition predicting changes in activities, or a dual coupling between the two variables. For some models (i.e., social activities/neurocognitive speed, social activities/episodic memory, physical activities/semantic memory), the residual variances were allowed to be freely estimated across measurement occasions (Grimm & Widaman, 2010) to help with model convergence.

Results

Longitudinal Changes in Cognitive Performance and Lifestyle Activities

Table 2 provides the parameter estimates for each of the six univariate LCS models. As a guide to this table, the Level mean (μ_0) represents the value at the start of the study. The slope mean (μ_s) and proportion (β) describe constant changes over time or those that are dependent on previous levels of performance, respectively. The level variance (σ_0^2) and slope variance (σ_s^2) gauge the extent of individual differences in initial performance, as well as constant change over time. The residual variance (σ_e^2) represents the amount of unexplained variance and the relationship between level and slope is scaled as a correlation (ρ , μ_0 , μ_s). Finally, the influence of each of the covariates (i.e., age, gender, years of education, self-reported health) is shown in the table.

Figure 1 displays the predicted means for the measures of cognitive performance (panel a) and lifestyle activities (panel b) across the 12-year follow-up period. Note that the increases in verbal speed reflect increases in response latency; hence the participants exhibited the expected slowing over time. Declines were seen for all of cognitive outcome variables, but the extent of change varied across the three cognitive domains. Episodic memory performance declined by over two-thirds a standard deviation unit across the follow-up period, whereas semantic memory declined by less than .5 SD units. Moreover, these effects were independent of age, gender, years of education, and self-reported health at baseline. Estimates for changes in the three domains of lifestyle activities are shown in Figure 1 (bottom panel). The losses (in activity involvement) over time, independent of covariates at baseline, were not as large as those seen in cognitive performance, but were slightly less than .5 standard deviation units.

Bivariate LCS: Linking Changes in Activities to Changes in Cognition

We constructed bivariate pairs across the longitudinal waves. Specifically, each cognitive measure was paired with each lifestyle activity measure. For each cognitive/lifestyle activity pair, we systematically examined four specific hypotheses regarding the nature of time-dependent changes. First, we specified a no coupling (NC) model, testing whether changes in one variable were not dependent on the prior status of the second and vice versa. This model served as a baseline; statistical fit parameters (i.e., χ^2 , CFI) were inspected to evaluate whether the addition of subsequent paths improved model fit. For the next two hypotheses, either a path predicting change in cognitive performance from lifestyle activities ($A \rightarrow C$) or a path predicting change in lifestyle activities from cognitive performance ($C \rightarrow A$) were added. The fourth hypothesis, a dual coupling (DC) model, specified whether changes in each variable were predicted by the prior status of the other.

The main results are displayed in three complementary representations. First, Table 3 displays a summary of the model fit indices for each of the activity/cognition comparisons. In this table, the change in chi-square (ΔX^2) provides the metric to allow us to determine whether any improvement in model fit is statistically significant, relative to the number of additional parameters that have been added to the model. Second, in Table 4, we provide a

summary of the best fitting model that was identified for each of the activity/cognition model pairs. The table presents the predominant coupling (leading-lagging or dual/no coupling) observed relationship. Third, the dynamic relationships between the paired variables are illustrated by vector field plots in Figure 2. Specifically, vector field plots (Boker & McArdle, 1995) were constructed to portray the dynamic relationship between the measures of lifestyle activities and measures of cognitive performance. As a guide to interpreting these figures, for a given pair of activity and cognitive performance scores, the arrow indicates the expected changes in both activity and cognition at the next measurement occasion. The direction of the arrows indicates whether future changes will be negative, positive, or neutral and the relative size of the arrow relates to the relative size of predicted changes. Details of the results, as specifically reflected in the vector field plots, are presented separately by cognitive domain.

Verbal Speed—For all of the lifestyle activities, the full dual coupling (DC) model provided the best fit to the data. This decision reflected the fact that for every pair of variables, the DC model provided a statistically better fit to the data, related to the unidirectional coupling ($A \rightarrow C$, $C \rightarrow A$) or no coupling models. For physical and cognitive activities, higher activity was related to fewer losses in verbal speed (physical activities: Est. = -3.43 , SE = 1.12 , $p < .01$; cognitive activities: Est. = -2.19 , SE = $.57$, $p < .001$), but this relationship was reversed for social activities (Est. = 5.38 , SE = 2.65 , $p < .05$). In terms of the relationship between verbal speed and subsequent changes in activity participations, slowing speed was related to fewer declines in activity participation longitudinally for physical and cognitive activities (physical activities: Est. = $.58$, SE = $.21$, $p < .01$; cognitive activities: Est. = $.37$, SE = $.14$, $p < .01$), but slower verbal speed led to greater declines in social activities (Est. = -1.09 , SE = $.38$, $p < .01$). The vector field plots describing these relationships are shown in Figure 2 (panel a).

Episodic Memory—For physical activities the full dual coupling model provided the best fit to the data, with higher activity being associated with lesser decline in episodic memory (Est. = 1.10 , SE = $.33$, $p = .001$), but higher memory performance was associated with greater declines in physical activities longitudinally (Est. = $-.79$, SE = $.34$, $p < .05$). For cognitive activities, the $A \rightarrow C$ model provided the best statistical fit with higher activity frequency being associated with lesser decline in episodic memory performance longitudinally (Est. = 1.13 , SE = $.31$, $p < .001$). Finally, for social activities the $C \rightarrow A$ model fit the data best, with lower episodic memory scores being related to greater declines in social activities longitudinally (Est. = $.71$, SE = $.25$, $p < .01$). Vector field plots describing these relationships are shown in Figure 2 (panel b).

Semantic Memory—For physical activities, the inclusion of coupling parameters failed to result in a better fitting model, so the no coupling model was accepted as final. For social activities, both the $A \rightarrow C$ (Est. = $.39$, SE = $.16$, $p = .015$) and $C \rightarrow A$ (Est. = $-.53$, SE = $.19$, $p = .007$) models provided a better fit to the data, as compared to the NC model. However, the fit of these models was not improved with the inclusion of both sets of paths and the individual coupling parameters were no longer statistically significant once included in the same model ($A \rightarrow C$: Est. = $.25$, SE = $.16$, $p = .149$; $C \rightarrow A$: Est. = $.32$, SE = $.23$, $p = .168$). Finally, for social activities the $C \rightarrow A$ model provided the best fit to the data (Est. = $.97$, SE = $.31$, $p = .002$), such that lower semantic memory scores were associated with greater declines in social activities longitudinally. Vector field plots describing these relationships are shown in Figure 2 (panel c).

Discussion

The global goal of the present study was to systematically examine the temporal ordering of changes in three dimensions of lifestyle activities and changes in three domains of cognitive neuropsychological performance in older adults. Overall, the results provide 12-year dynamic evidence consistent with the interpretation that ongoing participation in lifestyle activities may serve to protect older adults from some degree of cognitive decline. Regarding verbal speed, dual coupling models dominated the results, such that activity participation influenced subsequent change in cognitive performance and vice versa. For episodic memory, changes in physical and cognitive activities were the leading indicators for subsequent declines in episodic memory. However, models with changes in cognitive performance as the leading indicator were also significant for physical and social activities. Finally, for semantic memory, physical activities were unrelated to changes in this cognitive domain. However, cognitive activities were a leading indicator of changes in semantic memory, and changes in semantic memory were a leading indicator of changes in participation in social activities. The vector field plots (Fig. 2) provide a vivid representation of the temporal dynamics of these relationships.

The overall results are consistent with recent observations of an association between the participation in everyday leisure activities, especially those that emphasize cognitively engaging pursuits, and cognitive performance among older adults (Ghisletta, et al., 2006; Lövdén, et al., 2005; Schooler & Mulatu, 2001; Wilson et al., 2003). In addition, the results extend these observations in new and significant directions by using a 12-year (5-wave) multi-faceted data set from the VLS. These theoretically novel and clinically interesting directions include establishing that lifestyle-cognition relationships are related (a) dynamically over time and (b) differentially by domain. For example, changes in physical activities were more strongly associated with more basic verbal speed (Kramer, Bherer, Colcombe, Dong, & Greenough, 2004). Future research could test whether such relationships extend across the domain of speeded tasks.

The results complement those from several recent shorter-term longitudinal investigations, including two previous studies that used the LCS-type models to examine selected subsets of the relationships between lifestyle activities and cognitive functioning that were examined here. Both Lövdén and colleagues (2005) and Ghisletta and colleagues (2006) observed a relationship between lifestyle activities and select measures of perceptual speed. One interesting difference is that Lövdén and colleagues reported a promising effect in which social engagement appeared to lead short-term changes in speeded performance. Using a different measure of social activities and alternative indicators of cognition, we observed the opposite pattern. Specifically, over a longer term we found declines on several cognitive abilities preceded declines in social activities, which is a sensible direction of effects but not the one favored by the guiding protective factor hypothesis in epidemiological research.

In general, the social engagement hypothesis may be the most complex one (of the three investigated here) to detect, although some reports are indeed promising (e.g., Bassuk, Glass, & Berkman, 1999; Fratiglioni, et al., 2004; Hughes, Andel, Small, Borenstein, & Mortimer, 2008). In addition to the already mentioned methodological considerations, we have considered a practical one related to the salience of changes in cognitive abilities for the everyday functioning of older adults. Conceivably, for participants in some previous studies (e.g., Lövdén et al., 2005) it may be difficult to perceive the typically steady and long-term slowing of perceptual speed, but for participants in other studies, declines in episodic recall may be more relevant, both socially and clinically. As a result, challenges to memory functioning may have a greater impact on a person's social life, as compared to the relatively minor decrements associated with neurocognitive slowing. Not surprisingly,

cognitive-based activities may be more closely related to cognitive outcomes and changes in late life than are physical activities, at least as measured by self-reports (as in the current study; see Kramer et al., 1999; Middleton, et al., 2008). Future research in larger scale studies such as the VLS may benefit by supplementing or shifting assessments to more performance-based or biological-fitness markers (Anstey, 2008; MacDonald, DeCarlo, & Dixon, 2011; Prakash et al., 2011).

To some extent, our results (along with those of above-noted complementary studies and perspectives) may help shift neuropsychological research attention from cross-sectional association studies of concurrent levels of lifestyle activities and cognitive performance in special populations (e.g., older adults, dementia patients). Although these studies have been valuable in identifying a promising epidemiological factor in aging and dementia, future research will benefit from expanded consideration of whether and how changes in level and variety of lifestyle activities are related to longer-term changes in rate and variety of cognitive decline and impairment with aging. Accordingly, a key issue for further study is the question of the mechanisms by which changes in lifestyle activities may lead to changes in cognitive performance.

Some observers (e.g., Small, et al., 2007; Stern, 2002, 2009) have explored the concepts of passive and active cognitive reserve, which may hold promise for at least placing the growing body of results in context. Models of passive reserve suggest that the basis for cognitive reserve is generally reflected by neuron and synapse number, brain size and volume, cortical thickness, and other objective indices. Consequently, passive reserve is determined primarily by genetics, although it also may be influenced by accumulating environmental risk and protection factors. By contrast, the active model of reserve is concerned more with neural processing and synaptic organization (including potential for re-organization and plasticity) than by sheer neuroanatomical characteristics and differences. Among the derived constructs of interest is that of compensation, which is a type of active reserve whereby alternative brain structures or networks, and other factors) become active following brain pathology, damage, or neurocognitive impairment (see also Dixon, Garrett, & Bäckman, 2007; Lövdén, et al., 2010). Kemperman and colleagues (Kempermann, Gast, & Gage, 2002) reported research that is relevant to the pattern of results that we have observed. They found increased neurogenesis in the hippocampus, as well as behavioral improvements, of older animals exposed to an enriched environment. Moreover, these changes occurred in animals that were not enriched for the first 10 months of their lives, suggesting that there is still potential to modify brain structure in middle and old age by participating in stimulating activities. Cotman and colleagues (2007) conjectured that physical exercise contributes to brain health through, among other things, decreased inflammation. At least one intervention effort has been launched to explore similar issues in humans (Carlson et al., 2009). Clearly, our promising neuropsychological results will benefit in future research from expanded linkages with neurobiological and neurogenetic domains.

Although the results of the present study are novel and informative, several strengths and limitations should be acknowledged. Among the strengths is the basic design and implementation of the study, which examined changes across multiple domains of cognitive performance and the relationship to changes in multiple domains of lifestyle activities. Corollary strengths are the methodological details of 12-year follow-up period and the use of LCS models to test specific dynamic hypotheses regarding the leading-lagging relationships between changes in lifestyle activities and changes in cognitive performance. In the literature on lifestyle activities and cognitive performance, such design features provide a unique opportunity to evaluate the dynamic and complex relationships among these domains. On the other hand, several limitations should be noted. First, the VLS recruits initially healthy and generally well-educated older adults, although participants' cognitive

and medical health decline across longitudinal waves, and trajectories of cognitive decline and impairment are observed over time (e.g., Dixon et al., 2007). We used the present heterogeneous, relatively normal longitudinal sample, as it represents the best opportunity to test the dynamic relationships across all three aspects of lifestyle engagement. However, the lack of a formal dementia screening or diagnostic evaluation made us unable to evaluate whether some persons were beginning the transition into probable cognitive impairment. Notably, the fact that we were able to observe statistically significant effects of lifestyle activities on cognitive performance in a group of typically aging older adults is promising, and arguably a more conservative test of the intriguing lifestyle-cognition hypothesis. Second, the domains of lifestyle activities measured by the VLS-ALQ were oriented towards cognitively engaging activities and may not fully capture different physical and social realms or activities. Indeed, social activity has been operationalized by measures of social resources, measures of social support (Bassuk, et al., 1999; Seeman, Lusignolo, Albert, & Berkman, 2001), as well as participation in social activities like those measured in the current study. Overall, the concept of social engagement—as it relates to maintenance of cognitive neuropsychological functioning in older adults—will require further conceptual refinement and improved methodological procedures. Intervention studies, manipulating key aspects of social (and lifestyle) engagement, may be useful (Carlson, et al., 2009). Similarly, the physical activity measurement may not reflect all types and intensities of activity, nor does it provide us with a more objective measure of physical activity intensity (e.g., metabolic equivalent units). Finally, the domains of cognitive performance that were examined here did not include other potential relevant cognitive domains, such as executive functions, working memory, or attention. In the current study, we selected three complementary cognitive domains that (a) represent a breadth of cognitive neuropsychological functions, (b) typically follow somewhat different aging-related patterns, (c) are relevant to transitions of normal and neurodegenerative aging, and (d) were measured consistently across the 12-year follow-up period.

In summary, the results of the present study lend support to the general hypothesis that maintaining an active lifestyle can serve to promote maintenance of cognitive functions with normal advancing age. We also found select evidence that individuals who may possess poorer cognitive abilities can relinquish lifestyle activities, perhaps because of these limitations, a dynamic that could lead to further decline and impairment. Taken together, the results also suggested that the relationship between lifestyle activities is dynamic and complex, in the sense that not all lifestyle activities were related to changes in all cognitive abilities. Thus, the match between what types of activities are done and what types of cognitive abilities are tested may be critical to observing these relationships. Further longitudinal research with populations of older adults classified as cognitively impaired will be valuable.

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Figure 1. Implied Means from the Univariate LCS models for Cognitive Performance (panel a) and Lifestyle Activities (panel b)

a) Verbal Speed as the Cognitive Outcome

b) Episodic Memory as the Cognitive Outcome

c) Semantic Memory as the Cognitive Outcome

Figure 2.

Vector Field Plots for Lifestyle Activities and the Three Cognitive Domains

Table 1

Demographic Characteristics of Sample 1 and Sample 2 of the VLS

	Total	Sample 1	Sample 2
n	952	446	506
Age (years)			
M	68.59	68.97	68.25
SD	6.74	5.77	7.48
Gender (% Female)	63.4	59.6	66.8 [*]
Years of Education			
M	14.18	13.44	14.82 ^{***}
SD	3.09	3.09	3.09
<u>Sample Size & Average Follow-up from Baseline</u>			
Wave 1			
n	952	446	506
M years of follow-up	---	---	---
Wave 2			
n	714	320	394
M years of follow-up	3.09	2.92	3.22
Wave 3			
n	569	241	328
M years of follow-up	6.32	5.90	6.62
Wave 4			
n	171	171	---
M years of follow-up	8.91	8.91	---
Wave 5			
n	126	126	---
M years of follow-up	12.28	12.28	---

^{*}
p < .05

^{***}
p < .001

Univariate LCS for Cognitive Performance and Lifestyle Activities, with years of age, gender, years of education, and self-reported health as covariates

Table 2

	Cognitive Performance			Lifestyle Activities		
	Verbal Speed	Episodic Memory	Semantic Memory	Physical Activities	Social Activities	Cognitive Activities
Proportion, β	.01 (.08)	.59 (.11) ***	.45 (.11) ***	.48 (.20) *	.12 (.25)	-.02 (.09)
Level mean, μ_0	50.24 (.37) ***	49.86 (.32) ***	47.12 (.35) ***	48.72 (.42) ***	50.67 (.44) ***	47.75 (.34) ***
Slope mean, μ_s	.12 (3.81)	-30.44 (5.41) ***	-21.49 (5.2) ***	-24.10 (9.54) *	-6.47 (12.50)	.15 (4.30)
Level variance, σ_0^2	7.10 (.23) ***	6.56 (.19) ***	7.49 (.19) ***	7.90 (.25) ***	8.45 (.26) ***	6.79 (.19) ***
Slope variance, σ_s^2	2.64 (.24) ***	3.87 (.69) ***	3.37 (.80) ***	4.08 (1.47) **	1.69 (.90)	.93 (.16) ***
Residual variance, σ_e^2	19.91 (1.05) ***	14.71 (.66) ***	7.92 (.34) **	32.76 (1.34) ***	29.93 (1.41) ***	11.43 (.54) ***
ρ , $\mu_0\mu_s$	-.08 (.20)	-.97 (.02) ***	-.99 (.01) ***	-.99 (.01) ***	-.63 (.88)	-.16 (.63)
<u>Covariates</u>						
Age $\rightarrow$ Level	.43 (.04) ***	-.40 (.04) ***	-.11 (.04) **	-.20 (.05) ***	.02 (.05)	-.24 (.04) ***
Age $\rightarrow$ Slope	.13 (.04) **	.15 (.06) *	-.01 (.03)	.08 (.05)	-.06 (.02) *	-.06 (.03) *
Gender $\rightarrow$ Level	-.21 (.55)	-3.47 (.49) ***	3.05 (.53) ***	3.74 (.62) ***	-2.64 (.66) ***	2.57 (.50) ***
Gender $\rightarrow$ Slope	.04 (.31)	2.26 (.48) ***	-1.47 (.42) ***	-2.20 (.72) **	.33 (.70)	.01 (.28)
Education $\rightarrow$ Level	-.31 (.08) ***	.80 (.08) ***	.94 (.08) ***	-.01 (.10)	.23 (.10) *	.72 (.08) ***
Education $\rightarrow$ Slope	-.01 (.05)	-.51 (.10) ***	-.44 (.11) ***	.05 (.06)	-.01 (.08)	-.03 (.07)
Health $\rightarrow$ Level	1.89 (.39) ***	-1.28 (.35) ***	-.74 (.37) *	-1.92 (.44) ***	-.47 (.47)	-.36 (.36)
Health $\rightarrow$ Slope	-.12 (.27)	.63 (.28) *	.28 (.21)	.61 (.54)	-.10 (.23)	-.16 (.13)
<u>Fit Statistics</u>						
χ^2 (26)	165.75	67.07	83.15	35.31	46.96	55.28
χ^2 , p	<.001	<.001	<.001	.105	.007	<.001
CFI	.899	.980	.979	.992	.982	.986

* p < .05

** p < .01

*** p < .001

Table 3**Bivariate LCS Model Results for the Three Cognitive Domains**

Lifestyle Activity/Coupling Model	X²	df	ΔX² (df)	CFI
a) Verbal Speed				
Physical Activity				
No coupling	224.60	71		.938
Activity → cognition	215.02	70	9.58 (1) **	.942
Cognition → activity	217.14	70	7.46 (1) *	.941
Dual coupling	171.03	69	53.57 (2) ***	.959
Cognitive Activity				
No coupling	243.59	71		.950
Activity → cognition	218.01	70	26.58 (1) ***	.957
Cognition → activity	241.17	70	2.42 (1)	.950
Dual coupling	207.68	69	35.91 (2) ***	.960
Social Activity				
No coupling	248.07	71		.932
Activity → cognition	245.42	70	2.65 (1)	.932
Cognition → activity	238.64	70	9.43 (1) ***	.935
Dual coupling	166.15	69	81.92 (2) ***	.963
b) Episodic Memory				
Physical Activity				
No coupling	118.68	71		.985
Activity → cognition	106.97	70	11.71 (1) ***	.988
Cognition → activity	113.81	70	4.87 (1) *	.986
Dual coupling	97.48	69	21.20 (2) ***	.991
Cognitive Activity				
No coupling	153.12	71		.980
Activity → cognition	137.21	70	15.91 (1) ***	.984
Cognition → activity	143.68	70	9.44 (1) **	.982
Dual coupling	136.76	69	16.36 (2) ***	.984
Social Activity				
No coupling	104.41	63		.987
Activity → cognition	98.40	62	6.01 (1) *	.989
Cognition → activity	91.52	62	12.89 (1) **	.991
Dual coupling	90.23	61	14.18 (2) ***	.991
c) Semantic Memory				
Physical Activity				
No coupling	108.19	63		.988
Activity → cognition	108.07	62	.12 (1)	.988

Lifestyle Activity/Coupling Model	X²	df	ΔX² (df)	CFI
Cognition → activity	105.63	62	2.56 (1)	.989
Dual coupling	104.72	61	3.47 (2)	.989
Cognitive Activity				
No coupling	152.66	71		.983
Activity → cognition	146.16	70	6.50 (1) *	.984
Cognition → activity	146.61	70	6.05 (1) *	.984
Dual coupling	144.46	69	8.20 (2) *	.984
Social Activity				
No coupling	149.84	71		.980
Activity → cognition	149.43	70	.41 (1)	.980
Cognition → activity	139.15	70	10.69 (1) **	.982
Dual coupling	138.52	69	11.32 (2) **	.982

*
p < .05

**
p < .01

p < .001

Table 4

Best Fitting LCS Models for each Activity and Cognitive Performance Pair

Lifestyle Activity	Cognitive Domain		
	Verbal Speed	Episodic Memory	Semantic Memory
Physical Activity	A → C	A → C	NC
	C → A	C → A	
Cognitive Activity	A → C	A → C	A → C
	C → A		
Social Activity	A → C	C → A	C → A
	C → A		

A → C = Activities predicting cognitive performance; C → A = Cognition predicting activities; NC = No coupling was observed