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**Cross-Lagged Relation of Leisure Activity Participation to Trail Making Test Performance Six Years Later: Differential Patterns in Old Age and Very Old Age**

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## **Abstract**

*Objective:* We investigated cross-lagged relations between leisure activity participation and Trail Making Test (TMT) performance over six years, and whether those reciprocal associations differed between individuals.

*Method:* We analyzed data from 232 participants tested on performance in TMT parts A and B as well as interviewed on leisure activity participation in two waves six years apart. Mean age in the first wave was 73.42 years. Participants were also tested on vocabulary (Mill Hill scale) as a proxy indicator of crystallized intelligence and reported information on early- and midlife cognitive reserve markers (education and occupation). Latent cross-lagged models were applied to investigate potential reciprocal activity-TMT relationships.

*Results:* The relation of leisure activity participation predicting TMT performance six years later was significantly larger than the relation of TMT performance predicting later leisure activity participation. Statistically comparing different moderator groups revealed that this pattern was evident both in individuals with low education and in those with high education, but, notably, only emerged in young-old adults (but not in old-old adults), in individuals with a low cognitive level of job in midlife (but not in those with a high cognitive level of job in midlife), and in individuals with high scores in vocabulary (but not in those with low scores in vocabulary).

*Conclusions:* Late-life leisure activity participation may predict later cognitive status in terms of TMT performance, but individuals may markedly differ with respect to such effects. Implications for current cognitive reserve and neuropsychological aging research are discussed.

*Keywords:* cognition; cognitive reserve; activities; life course; longitudinal study

### **Public Significance Statement**

With respect to ongoing debates in gerontological neuropsychology of whether activity predicts cognitive functioning over time, present cross-lagged investigations over six years suggest that late-life leisure activity participation may predict later cognitive status in terms of Trail-Making-Test performance, but, notably, only in certain individuals such as in young-old adults, in individuals who had less cognitively demanding jobs in midlife, and in those with high vocabulary (as proxy of crystallized intelligence).

## Introduction

A major goal in current gerontological neuropsychology is to understand how interindividual differences in cognitive health in old age emerge (Opdebeeck, Martyr, & Clare, 2016). In particular, with respect to an individual's potential for preserving cognitive functioning in old age, the cognitive reserve concept postulates that lifelong experiences, including educational and occupational attainment, and leisure activities in later life, stimulate brain development which increases the reserve capacity that may compensate for brain damage, neurological loss, and pathological decline such as dementia (Stern, 2002, 2017). Specifically, interindividual differences in the effective recruitment of neural networks and cognitive processes are hypothesized to explain differences in individuals' capacity to cope with or compensate for age-related decline or pathology (Stern, 2009, 2012; see also e.g. Barnett, Salmond, Jones, & Sahakian, 2006; Bartres-Faz & Arenaza-Urquijo, 2011; Pernecky et al., 2011; Sole-Padulles et al., 2009). In individuals with healthy cognitive functioning, these mechanisms contribute to the adaptation of brain activity when task difficulty level is increased and thereby enhance cognitive performance (Stern, 2012). Empirically corroborating the predictions of the cognitive reserve concept, evidence showed that greater cognitive stimulation throughout the life course such as longer education in early life, cognitively demanding jobs in midlife, and current cognitively stimulating leisure activities in midlife and old age contributes to the accumulation of cognitive reserve over the life course and is related to better cognitive functioning such as memory and executive functioning in old age as well as a lower risk of developing dementia and later age at dementia onset (Adam, Bonsang, Grotz, & Perelman, 2013; Hertzog, Kramer, Wilson, & Lindenberger, 2008; Ihle et al., 2015; Karp et al., 2006; Paillard-Borg, Fratiglioni, Xu, Winblad, & Wang, 2012; Schneeweis, Skirbekk, & Winter-Ebmer, 2014; Wilson et al., 2013).

However, a large part of evidence on relations between late-life leisure activity and cognitive functioning in old age is based on cross-sectional data only that does not allow

specifying the direction of relations observed (see Opdebeeck et al., 2016, for a recent meta-analysis). Specifically, from a longitudinal perspective relations between stimulating leisure activities and cognitive functioning in old age may be reciprocal. Therefore, it is necessary to disentangle two pathways, i.e., on the one hand, that activity engagement may preserve later cognitive functioning, and, on the other hand, that cognitive functioning may determine later activity engagement (Aartsen, Smits, van Tilburg, Knipscheer, & Deeg, 2002; Hultsch, Hertzog, Small, & Dixon, 1999). In other words, two central, though so far unanswered and still debated questions in cognitive reserve research concern (a) whether activity predicts cognitive functioning over time when also taking the reciprocal relation of cognitive functioning predicting activity over time into account, and, (b) which factors may moderate this relation in determining which of these two pathways is predominant (Lifshitz-Vahav, Shrira, & Bodner, 2017).

For instance, Lifshitz-Vahav and colleagues (2017) recently showed that greater leisure activity participation predicted better cognitive performance four years later when controlling for the reciprocal cognition-activity relation in a two-wave cross-lagged model (see Köhncke et al., 2016; Newson & Kemps, 2005; Thomas, 2011; Wang et al., 2013, for other studies that also found relations of activity engagement to cognitive functioning over time). However, other studies did not support this view. For example, Aartsen and colleagues (2002) found with a cross-lagged model approach that activities did not predict cognitive functioning (but instead that cognitive functioning determined activity) six years later (see also Bielak, Anstey, Christensen, & Windsor, 2012; Bielak, Cherbuin, Bunce, & Anstey, 2014; Vaughan et al., 2014, for other studies that did not observe relations of activity engagement to cognitive functioning over time; see e.g. Ritchie, Tucker-Drob, Starr, & Deary, 2016, for a discussion).

This puzzle of inconsistent results suggests that longitudinal relations between activities and cognitive functioning in old age are complex and may be moderated.

Addressing this issue, Lifshitz-Vahav and colleagues (2017) examined potential moderation effects by individuals' literacy level (as a proxy indicator of basic cognitive level). They revealed that participation in leisure activities predicted better cognitive functioning four years later only among older adults with low literacy level, while cognitive functioning predicted later participation in leisure activities only among higher literacy level older adults. This pattern dovetails with the suggestion of Hultsch and colleagues (1999) that individuals with high intellectual abilities lead intellectually active lives until cognitive decline in old age limits their activities. Yet, a comprehensive cross-lagged investigation whether reciprocal activity-cognition relations differ by individuals' basic cognitive level (based on performance measures) is missing so far. Moreover, Lifshitz-Vahav and colleagues (2017) also investigated potential moderation effects by age and education. Yet, they did not observe differences between young-old adults and old-old adults, nor between low-educated and high-educated individuals in their study. Conceptually, such moderation effects seem plausible. First, with respect to age group, following the model of third versus fourth age (Baltes, 1998; Baltes & Smith, 2003), (in contrast to young-old age) in old-old age decline reaches a critical threshold that does not allow compensating anymore. Consequently, possible preserving effects of activity participation on later cognitive functioning may be observed in young-old adults only, but, however, should be absent in old-old adults. Second, with respect to potential moderation effects by markers of cognitive reserve (such as education), recent cross-sectional evidence suggests that especially those individuals may benefit from stimulating activities in later life who had accumulated only little cognitive reserve in prior life phases (such as those with low educational attainment, see e.g. Ihle et al., 2015; Lachman, Agrigoroaei, Murphy, & Tun, 2010; Soubelet, 2011). Likewise, with respect to longitudinal relations, potential beneficial effects of activity participation on later cognitive functioning may be pronounced in individuals with low education (compared to those with high) education (and similarly



possibly also regarding other markers of cognitive reserve such as low cognitive level of job in midlife compared to high cognitive level of job in midlife).

Taken together, it remains unclear so far whether the cross-lagged pattern of reciprocal activity-cognition relations differs between young-old adults and old-old adults, between individuals with different amount of cognitive reserve accumulated in early and midlife, and by individuals' basic cognitive level. Therefore, to extend the literature we investigated cross-lagged relations between leisure activity participation and Trail Making Test (TMT) performance across six years and whether those reciprocal associations differed between young-old adults versus old-old adults and according to early- and midlife cognitive reserve markers (i.e., education and occupation) and by individuals' vocabulary (as a proxy indicator of crystallized intelligence, see also e.g. Djapo, Kolenovic-Djapo, Djokic, & Fako, 2011; Rabbitt, Lunn, Pendleton, & Yardefagar, 2011).

## **Methods**

### **Participants**

Data come from the two waves of the Vivre-Leben-Vivere (VLV) survey (Ihle et al., 2015; Ludwig, Cavalli, & Oris, 2014), which is a part of the research program LIVES on vulnerability processes across the life course. Respondents were first interviewed during 2011 (Wave 1; W1) using a face-to-face computer-assisted personal interview method (CAPI) and questionnaires. The main sample in W1 included 3080 participants who were randomly selected in the cantonal Swiss administrations' records and stratified by age (65-69, 70-74, 75-79, 80-84, 85-89, and 90+), sex, and canton (Basel, Bern, Geneva, Ticino, and Valais). A subsample of 1059 participants from four cantons (Basel, Bern, Geneva, and Valais) was interviewed again during 2017 (Wave 2; W2). In W1, a subset of 1312 participants completed assessments of TMT performance (TMT parts A and B) and leisure activity participation, and 385 did so in W2. Present analyses were based on those 232 participants with completed

assessments in these variables in both waves. Among these respondents, mean age was 73.42 years ( $SD = 5.96$ , range 65-93) in W1.

With respect to the longitudinal study design, we acknowledge that our sample is clearly a survival sample. From the 1312 participants in W1 with completed assessments of TMT performance and leisure activity participation, the 232 participants who were followed up in W2 were slightly younger ( $M = 73.42$  years in W1,  $SD = 5.96$ ) than the 1080 individuals who were not followed up in W2 ( $M = 77.54$  years in W1,  $SD = 7.93$ ;  $p < .001$ ). However, importantly, we still had a considerable number of respondents in the two highest age categories of 85 years and older (15.9% among the 232 participants who were followed up in W2; in comparison, 16.8% among the 1312 initial participants in W1 with completed assessments in the investigated variables). Moreover, the 232 participants who were followed up in W2 did not differ from the 1080 individuals who were not followed up in W2 with regard to sex (53.4% men among the 232 participants followed up in W2; 54.2% men among the 1080 individuals not followed up in W2;  $p = .899$ ; see e.g. Aartsen et al., 2002, for a comparable maintenance of the initial sample stratification distribution over six years in the Longitudinal Aging Study Amsterdam; see e.g. Hultsch et al., 1999, for a similar follow-up of participants over six years in the Victoria Longitudinal Study; see e.g. Lifshitz-Vahav et al., 2017, for a similar follow-up of participants over four years in the Survey of Health, Ageing and Retirement in Europe).

All participants gave their written informed consent for inclusion before they participated in the study. The present study was conducted in accordance with the Declaration of Helsinki, and the protocol had been approved by the ethics commission of the Faculty of Psychology and Social Sciences of the University of Geneva (project identification codes: CE\_FPSE\_14.10.2010 and CE\_FPSE\_05.04.2017).

## **Materials**

### *Trail Making Test Performance*

We administered in both waves the Trail Making Test part A (TMT A; Reitan, 1958). After one exercise trail (connecting the numbers from 1 to 8), participants had to connect the numbers from 1 to 25 as fast as possible and without error in ascending order. The TMT A completion time was the time in seconds needed to correctly connect the 25 numbers.

In addition, we administered in both waves the Trail Making Test part B (TMT B; Reitan, 1958). After one exercise trail (connecting 1-A-2-B-3-C-4-D), participants had to connect the numbers 1 to 13 in ascending order and the letters A to L in alphabetic order while alternating between numbers and letters (i.e., 1-A-2-B-3-C ... 12-L-13) as fast as possible and without error. The TMT B completion time was the time in seconds needed to correctly connect the 25 numbers / letters.

For analyses, to achieve that higher values represented better performance (as common in correlative studies), for TMT A and TMT B the distribution of completion time of all participants was reversed based on the sample mean so that interindividual differences remained identical.

#### *Leisure Activity Participation*

We interviewed participants in both waves regarding their participation in 18 leisure activities such as physical exercises, going to the cinema, going to conferences, journeys, artistic activities, table games, and municipality activities. For each of the 18 activities, participants reported in W1 and W2 current frequency of participation at that time, respectively, using a five-point Likert-type scale with values of 0 ('never'), 1 ('at least once a year'), 2 ('at least once a month'), 3 ('at least once a week'), or 4 ('every day or almost every day'). To derive an overall measure of leisure activity participation in each wave, we averaged frequency scores across all 18 leisure activities in W1 and W2, respectively (possible range 0-4; for a validation see e.g. Jopp & Hertzog, 2010; see Paggi, Jopp, & Hertzog, 2016, for the same approach).

#### *Moderator Variables*

For moderator analyses, we distinguished the sample into two groups regarding age group, education, cognitive level of job, and vocabulary (as a proxy indicator of crystallized intelligence, see also e.g. Djapo et al., 2011; Rabbitt et al., 2011). Specifically, age groups were young-old adults ( $\leq 75$  years) versus old-old adults ( $\geq 76$  years; see e.g. Boccardi et al., 2017; Constantinidou, Christodoulou, & Prokopiou, 2012; Schnitzspahn & Kliegel, 2009, for the same approach).

Low education versus high education were distinguished according to the two categories of low educational attainment (i.e., primary and inferior secondary school levels) and apprenticeship graduation, both leading mainly to blue collar and/or unskilled jobs versus higher (advanced) educational attainment (i.e., superior secondary school level, technical college or superior vocational college, and university degree), typically leading to white collar jobs (Gabriel, Oris, Studer, & Baeriswyl, 2015).

Low cognitive level of job versus high cognitive level of job regarding individuals' last profession practiced in midlife were distinguished according to the two categories of lower cognitive demands (i.e., blue collar or unskilled jobs such as factory work, plumbing, carpentry, farming, etc.) versus higher cognitive demands (i.e., white collar jobs such as teacher, clerical work, lawyer, medical practice, etc.; see e.g. Kesse-Guyot et al., 2013; Opdebeeck et al., 2016, for similar ratings reflecting the degree of intellectual involvement at work as marker of cognitive reserve).

Low vocabulary versus high vocabulary were distinguished based on scores in the Mill Hill scale (Deltour, 1993), which we had assessed in W1 (high: more than 70% correct answers; low: respectively below; Rabbitt et al., 2011).

### **Statistical Analyses**

Following Lifshitz-Vahav and colleagues (2017) we applied a two-wave cross-lagged design, using the R package lavaan (Rosseel, 2012). We used a latent variable of TMT performance constructed from scores in TMT parts A and B and the composite score of

leisure activity participation (see Lifshitz-Vahav et al., 2017, for the same approach).

Specifically, this model of cross-lagged reciprocal relationships included (1) autoregressive paths, (2) cross-sectional paths between leisure activity participation and TMT performance, and (3) cross-lagged reciprocal paths between leisure activity participation and TMT performance over time (see Figure 1).

First, we tested this model in the overall sample. To evaluate model fit, we used the following criteria:  $\chi^2$  test (good models:  $p$  value  $> .10$ ), Comparative Fit Index (good models:  $CFI > .95$ ), Incremental Fit Index (good models:  $IFI > .95$ ), Root Mean Square Error of Approximation (good models:  $RMSEA < .06$ ), and Standardized Root Mean Square Residual (good models:  $SRMR < .08$ ; see e.g. Hu & Bentler, 1999, for a discussion on recommended cutoff criteria for fit indexes). To evaluate whether the cross-lagged reciprocal activity-TMT relationships (i.e., leisure activity participation in W1 predicting TMT performance in W2 versus TMT performance in W1 predicting leisure activity participation in W2) differed in size, we compared the model without constraints with a constrained model, in which these two reciprocal activity-TMT paths were constrained to be of equal size. For this purpose, we statistically tested the difference in model fit between the unconstrained model and the constrained model ( $\Delta\chi^2$ ), including testing for significance. In case the constrained model would have a significantly worse fit than the unconstrained model, that would mean that the two cross-lagged reciprocal activity-TMT relationships differed in size.

Second, we investigated whether this pattern was moderated by age group / education / cognitive level of job / vocabulary. For this purpose, we used a multiple-group approach, in which all relations were estimated separately for the two respective moderator subgroups (simultaneously in a model that comprised both moderator subgroups). Specifically, we compared the moderator model without constraints with a constrained model, in which the two reciprocal activity-TMT paths (i.e., the path from leisure activity participation in W1 to TMT performance in W2 and the path from TMT performance in W1 to leisure activity

participation in W2) were each constrained to be of equal size across both moderator subgroups. Note that to be able to appropriately test the moderation effect the two reciprocal activity-TMT paths overall were allowed to differ freely in size, but each of them was constrained to be of equal size across the two moderator subgroups. In case the constrained moderator model would have a significantly worse fit than the unconstrained moderator model, that would mean that the pattern of cross-lagged reciprocal activity-TMT relationships differed between the two moderator subgroups.

To investigate the moderation pattern in more detail, we subsequently examined the pattern of reciprocal activity-TMT relationships within each moderator subgroup separately. Specifically, we constrained the two reciprocal activity-TMT paths to be of equal size within one of the two moderator subgroups. In case the moderator model with the reciprocal activity-TMT paths being constrained within one moderator subgroup would have a significantly worse fit than the unconstrained moderator model, that would mean that the two cross-lagged reciprocal activity-TMT relationships differed in size within that moderator subgroup.

To take potential relations of medical conditions such as cardiovascular diseases, metabolic syndromes such as diabetes mellitus, and musculoskeletal disorders such as osteoarthritis to leisure activity participation and/or cognitive functioning into account, we controlled all analyses for medical conditions (including cardiovascular diseases, metabolic syndromes such as diabetes mellitus, and musculoskeletal disorders such as osteoarthritis). Moreover, we controlled moderation analyses also for potential interrelations of the different moderator variables. Specifically, for the moderation analysis with age group as moderator, we simultaneously controlled for medical conditions, education, cognitive level of job, and vocabulary. For the moderation analysis with education as moderator, we simultaneously controlled for medical conditions, age, cognitive level of job, and vocabulary. For the moderation analysis with cognitive level of job as moderator, we simultaneously controlled for medical conditions, age, education, and vocabulary. For the moderation analysis with

vocabulary as moderator, we simultaneously controlled for medical conditions, age, education, and cognitive level of job. For all these control analyses, we controlled for the respective covariates by controlling for their relations to leisure activity participation and to TMT performance in both waves as well as for the interrelations of all covariates.

## Results

### Descriptive Statistics

Mean completion time in TMT A was 51.55 seconds ( $SD = 23.56$ ) in W1 and 51.68 seconds ( $SD = 20.90$ ) in W2. Mean completion time in TMT B was 110.09 seconds ( $SD = 41.77$ ) in W1 and 109.74 seconds ( $SD = 44.22$ ) in W2 (see e.g. Godefroy et al., 2008; Tombaugh, 2004, for normative data with regard to similar demographic characteristics in terms of age and education as in the present study showing similar average completion time in TMT parts A and B). Mean frequency of activity participation was 1.32 ( $SD = 0.34$ ) in W1 and 1.33 ( $SD = 0.43$ ) in W2.

### Cross-Lagged Analyses: Overall Sample

First, we applied the two-wave cross-lagged model with reciprocal activity-TMT relationships (controlling for medical conditions) in the overall sample. This model provided a good account of the data ( $\chi^2 = 3.49$ ,  $df = 6$ ,  $p = .745$ ,  $CFI > .99$ ,  $IFI > .99$ ,  $RMSEA < .001$ ,  $SRMR = .02$ ). In this model, the autoregressive paths were significant ( $\beta = .63$ ,  $p < .001$  for TMT performance and  $\beta = .58$ ,  $p < .001$  for leisure activity participation). Regarding cross-sectional relations, TMT performance was not related to leisure activity participation in any wave ( $\beta = .09$ ,  $p = .214$  in W1 and  $\beta = .03$ ,  $p = .766$  in W2). However, most importantly, with respect to cross-lagged relations over time, greater leisure activity participation in W1 significantly predicted better TMT performance in W2 ( $\beta = .21$ ,  $p = .001$ ), while TMT performance in W1 did not predict leisure activity participation in W2 ( $\beta = -.05$ ,  $p = .396$ ).

Next, we evaluated whether these cross-lagged reciprocal activity-TMT relationships differed in size. Constraining these two reciprocal activity-TMT paths to be of equal size

resulted in a significantly worse model fit compared to the aforementioned unconstrained model ( $\Delta\chi^2 = 10.07$ ,  $\Delta df = 1$ ,  $p = .002$ ). Together with the previously mentioned pattern of relationships in the unconstrained model, this finding indicated that the relation of leisure activity participation in W1 predicting TMT performance in W2 was significantly larger than the relation of TMT performance in W1 predicting leisure activity participation in W2.

### **Cross-Lagged Analyses: Moderation**

#### *Age Group*

We investigated whether the pattern of cross-lagged reciprocal activity-TMT relationships was moderated by age group (simultaneously controlling for medical conditions, education, cognitive level of job, and vocabulary). This moderator model provided a good account of the data (see first panel of Table 1). With respect to the cross-lagged reciprocal activity-TMT relationships, in young-old adults, greater leisure activity participation in W1 significantly predicted better TMT performance in W2, while TMT performance in W1 did not predict leisure activity participation in W2. In contrast, in old-old adults both reciprocal relations were not significant.

Next, we evaluated whether this pattern of cross-lagged reciprocal activity-TMT relationships differed between young-old adults and old-old adults. Constraining each of the two reciprocal activity-TMT paths to be of equal size across both moderator subgroups resulted in a significantly worse model fit compared to the beforehand mentioned unconstrained moderator model (see right panel of Table 1). This finding indicated that the pattern of cross-lagged reciprocal activity-TMT relationships significantly differed between young-old adults and old-old adults. To investigate this finding in more detail, constraining the two reciprocal activity-TMT paths to be of equal size within young-old adults resulted in a significantly worse model fit compared to the previously mentioned unconstrained moderator model. In contrast, constraining the two reciprocal activity-TMT paths to be of equal size within old-old adults did not result in a significantly worse model fit compared to the



unconstrained moderator model. Together with the observed pattern of relationships in the unconstrained moderator model, this finding indicated that (in contrast to old-old adults) in young-old adults the relation of leisure activity participation in W1 predicting TMT performance in W2 was significantly larger than the relation of TMT performance in W1 predicting leisure activity participation in W2.

### *Education*

We examined whether the pattern of cross-lagged reciprocal activity-TMT relationships was moderated by individuals' education (simultaneously controlling for medical conditions, age, cognitive level of job, and vocabulary). This moderator model provided a good account of the data (see second panel of Table 1). With respect to the cross-lagged reciprocal activity-TMT relationships, both in individuals with a low education and in those with a high education, greater leisure activity participation in W1 significantly predicted better TMT performance in W2, while TMT performance in W1 did not predict leisure activity participation in W2 in any group.

Next, we evaluated whether this pattern of cross-lagged reciprocal activity-TMT relationships differed between individuals with a low education and those with a high education. Constraining each of the two reciprocal activity-TMT paths to be of equal size across both moderator subgroups did not result in a significantly worse model fit compared to the aforementioned unconstrained moderator model (see right panel of Table 1). This finding indicated that the pattern of cross-lagged reciprocal activity-TMT relationships did not differ between individuals with a low education and those with a high education. To investigate this finding in more detail, constraining the two reciprocal activity-TMT paths to be of equal size within individuals with a low education resulted in a significantly worse model fit compared to the previously mentioned unconstrained moderator model. Constraining the two reciprocal activity-TMT paths to be of equal size within individuals with a high education also resulted in a significantly worse model fit compared to the beforehand mentioned unconstrained

moderator model. Together with the observed pattern of relationships in the unconstrained moderator model, this finding indicated that both in individuals with a low education and in those with a high education the relation of leisure activity participation in W1 predicting TMT performance in W2 was significantly larger than the relation of TMT performance in W1 predicting leisure activity participation in W2.

### *Cognitive Level of Job*

We investigated whether the pattern of cross-lagged reciprocal activity-TMT relationships was moderated by individuals' cognitive level of job (simultaneously controlling for medical conditions, age, education, and vocabulary). This moderator model provided a good account of the data (see third panel of Table 1). With respect to the cross-lagged reciprocal activity-TMT relationships, in individuals with a low cognitive level of job, greater leisure activity participation in W1 significantly predicted better TMT performance in W2, while TMT performance in W1 did not predict leisure activity participation in W2. In contrast, in individuals with a high cognitive level of job both reciprocal relations were not significant.

Next, we evaluated whether this pattern of cross-lagged reciprocal activity-TMT relationships differed between individuals with a low cognitive level of job and those with a high cognitive level of job. Constraining each of the two reciprocal activity-TMT paths to be of equal size across both moderator subgroups resulted in a significantly worse model fit compared to the aforementioned unconstrained moderator model (see right panel of Table 1). This finding indicated that the pattern of cross-lagged reciprocal activity-TMT relationships significantly differed between individuals with a low cognitive level of job and those with a high cognitive level of job. To investigate this finding in more detail, constraining the two reciprocal activity-TMT paths to be of equal size within individuals with a low cognitive level of job resulted in a significantly worse model fit compared to the beforehand mentioned unconstrained moderator model. In contrast, constraining the two reciprocal activity-TMT

paths to be of equal size within individuals with a high cognitive level of job did not result in a significantly worse model fit compared to the previously mentioned unconstrained moderator model. Together with the observed pattern of relationships in the unconstrained moderator model, this finding indicated that (in contrast to individuals with a high cognitive level of job) in those with a low cognitive level of job the relation of leisure activity participation in W1 predicting TMT performance in W2 was significantly larger than the relation of TMT performance in W1 predicting leisure activity participation in W2.

### *Vocabulary*

We examined whether the pattern of cross-lagged reciprocal activity-TMT relationships was moderated by individuals' vocabulary (simultaneously controlling for medical conditions, age, education, and cognitive level of job). This moderator model provided a good account of the data (see fourth panel of Table 1). With respect to the cross-lagged reciprocal activity-TMT relationships, in individuals with high scores in vocabulary, greater leisure activity participation in W1 significantly predicted better TMT performance in W2, while TMT performance in W1 did not predict leisure activity participation in W2. In contrast, in individuals with low scores in vocabulary, both reciprocal relations were not significant.

Next, we evaluated whether this pattern of cross-lagged reciprocal activity-TMT relationships differed between individuals with low scores in vocabulary and those with high scores in vocabulary. Constraining each of the two reciprocal activity-TMT paths to be of equal size across both moderator subgroups resulted in a significantly worse model fit compared to the beforehand mentioned unconstrained moderator model (see right panel of Table 1). This finding indicated that the pattern of cross-lagged reciprocal activity-TMT relationships significantly differed between individuals with low scores in vocabulary and those with high scores in vocabulary. To investigate this finding in more detail, constraining the two reciprocal activity-TMT paths to be of equal size within individuals with high scores

in vocabulary resulted in a significantly worse model fit compared to the previously mentioned unconstrained moderator model. In contrast, constraining the two reciprocal activity-TMT paths to be of equal size within individuals with low scores in vocabulary did not result in a significantly worse model fit compared to the beforehand mentioned unconstrained moderator model. Together with the observed pattern of relationships in the unconstrained moderator model, this finding indicated that (in contrast to individuals with low scores in vocabulary) in those with high scores in vocabulary the relation of leisure activity participation in W1 predicting TMT performance in W2 was significantly larger than the relation of TMT performance in W1 predicting leisure activity participation in W2.

### **Discussion**

Addressing open questions regarding the predictors of cognitive health in old age, the present study investigated cross-lagged relations between leisure activity participation and TMT performance over six years and whether those reciprocal associations differed across older individuals. For the overall sample, with respect to cross-lagged relations over time, we found that greater leisure activity participation predicted better TMT performance six years later, while the opposite direction, i.e. TMT performance predicting leisure activity participation six years later, was not evident. Model comparisons indicated that the relation of leisure activity participation predicting later TMT performance was markedly larger than the relation of TMT performance predicting later leisure activity participation. This finding corroborates prior evidence suggesting that greater leisure activity participation predicts later cognitive performance when controlling for the reciprocal cognition-activity relation (Lifshitz-Vahav et al., 2017). Conceptually, this finding seems in line with the view that late-life cognitive stimulation may be associated with cognitive reserve, thereby being related to better cognitive functioning in old age (Hertzog et al., 2008; Köhncke et al., 2016; Newson & Kemps, 2005; Stern, 2012; Wang et al., 2013).

With respect to the factors determining which of the two pathways in the reciprocal activity-cognition relationship is predominant, we tested potential moderators. First, with respect to age group, we found that in young-old adults the relation of leisure activity participation predicting TMT performance six years later was larger than the reciprocal TMT-activity relation. Moreover, model comparisons revealed that this pattern in young-old adults markedly differed from that observed in old-old adults. Specifically, in old-old adults, none of the cross-lagged relations over time was evident. Conceptually, this pattern is in line with the model of third versus fourth age (Baltes, 1998; Baltes & Smith, 2003), which postulated that (in contrast to young-old age) decline in old-old age reaches a critical threshold that does not allow compensating anymore. This pattern may apply also to possible preserving effects of leisure activity participation on later cognitive status. It may be partly due to the particular difficulties of old-old adults to maintain a stimulating active life when suffering from growing health constraints (Hultsch et al., 1999; Janke, Davey, & Kleiber, 2006). In addition, in highly advanced age the cognitive system typically shows an accelerated decline (Rabbitt et al., 2011). Consequently, cognitively stimulating activities may not allow compensating the approaching breakdown of cognitive functioning anymore as soon as decline reaches a critical threshold (see for example evidence on steeper rate of cognitive decline in individuals with greater cognitive reserve as soon as the phase of terminal decline is reached, e.g., Stern, 2002, 2009; Thorvaldsson, Skoog, & Johansson, 2017).

Second, we investigated potential moderation effects by early- and midlife markers of cognitive reserve. With respect to education, model comparisons revealed that irrespective of individuals' educational level the relation of leisure activity participation predicting TMT performance six years later was larger than the reciprocal TMT-activity relation. Notably, with respect to occupation, this pattern was moderated. We found that in individuals with a low cognitive level of job in midlife the relation of leisure activity participation predicting TMT performance six years later was larger than the reciprocal TMT-activity relation.

Moreover, model comparisons revealed that this pattern in individuals with a low cognitive level of job markedly differed from that observed in those with a high cognitive level of job. Specifically, in the latter group, none of the cross-lagged relations over time was evident. Conceptually, this pattern with cognitive level of job as moderator corroborates the view that stimulating activities may especially show strong relations to cognitive functioning in those individuals who had accumulated only little cognitive reserve in prior life phases (Ihle et al., 2015; Lachman et al., 2010; Soubelet, 2011) and extends those cross-sectional studies with longitudinal data. Thereby, late-life activity may be associated with an additional built-up of cognitive reserve in individuals who had blue collar or unskilled jobs in midlife (see Coe, Von Gaudecker, Lindeboom, & Maurer, 2012; Ihle et al., 2016b, for a discussion). Interestingly, present cross-lagged activity-TMT relations did not differ by individuals' education. On first glance this observation may seem to contrast with prior studies that reported education-related patterns (Ihle et al., 2015; Lachman et al., 2010; Soubelet, 2011). Yet, all these studies were limited by their cross-sectional design. In contrast, present longitudinal investigations (also taking the reciprocal TMT-activity relation into account) suggest that relations of cognitive functioning to leisure activities in old age as late-life marker of cognitive reserve may not vary according to education as early-life cognitive reserve marker (see also Lifshitz-Vahav et al., 2017).

Third, with respect to individuals' level of crystallized intelligence in terms of vocabulary, we found that in individuals with high scores in vocabulary the relation of leisure activity participation predicting TMT performance six years later was larger than the reciprocal TMT-activity relation. Moreover, model comparisons revealed that this pattern in individuals with high scores in vocabulary markedly differed from that observed in those with low scores in vocabulary. Specifically, in the latter group, none of the cross-lagged relations over time was evident. Conceptually, this pattern dovetails with the disuse hypothesis (Hultsch et al., 1999; Orrell & Sahakian, 1995), which postulated that a cognitively engaged

lifestyle during adulthood preserves and possibly even increases cognitive functioning while not using one's intellectual resources would decrease the buffer against cognitive impairment. In this regard, present cross-lagged investigations suggest that contributions to cognitive reserve through leisure activities in late adulthood may possibly favor individuals who are at a high level in terms of crystallized intelligence since those may prefer and/or be more able to pursue cognitively demanding activities. In contrast, individuals with a low basic cognitive level may likely not prefer and/or be less able to engage in cognitively demanding activities, which should have less benefit for preserving cognitive functioning (Aartsen et al., 2002; Hultsch et al., 1999).

Taken together, with respect to the different moderation patterns observed we argue that the investigated moderators - depending on the specific life course phase they concern - may differentially affect the activity-TMT relationships. Specifically, age group (in terms of young-old adults versus old-old adults) and level of crystallized intelligence (in terms of low scores in vocabulary versus high scores in vocabulary) concern the individual's current status in old age. Here, individuals with a "better" current status (i.e., young-old adults and individuals with high scores in vocabulary) may be able to take more advantage of leisure activity participation in late adulthood than those individuals with a "poorer" current status (i.e., old-old adults and individuals with low scores in vocabulary), which is in line with the model of third versus fourth age (Baltes, 1998; Baltes & Smith, 2003) as well as with the disuse hypothesis (Hultsch et al., 1999; Orrell & Sahakian, 1995). In contrast, cognitive level of job concerns the phase of an individual's working life in middle adulthood. Here, individuals with a low cognitive level of job in midlife may benefit more from leisure activity participation in old age than those individuals with a high cognitive level of job in midlife. This pattern is in line with empirical evidence suggesting that individuals who had accumulated only little cognitive reserve in prior life phases may particularly benefit from stimulating activities in later life (Ihle et al., 2015, 2016b; Lachman et al., 2010; Soubelet,

2011). Finally, education concerns early phases of an individual's life (i.e., childhood, adolescence, and young adulthood). Here, individuals, irrespective of their level of education in early life, may equally benefit from leisure activity participation in old age (see also Lifshitz-Vahav et al., 2017). Thus, present findings on cognitive level of job in midlife and education in early life further corroborate the conceptual view that cognitive reserve is built up across different phases during an individual's life course (e.g., Stern, 2002, 2009). Yet, notably, as present data suggest, the build-up of cognitive reserve during the life course may be differentially shaped by several factors, depending on the specific phase of an individual's life that those factors concern (see a recent conceptual proposal on the development of reserves over the life course; Cullati, Kliegel, & Widmer, in press).

In conclusion, with respect to the ongoing debate in gerontological neuropsychology and cognitive reserve research of whether activity predicts cognitive functioning over time when also taking the reciprocal cognition-activity relation into account (Aartsen et al., 2002; Hultsch et al., 1999; Lifshitz-Vahav et al., 2017; Thomas, 2011), present cross-lagged investigations over six years suggest that late-life leisure activity participation may indeed predict later cognitive status in terms of TMT performance, but, notably, only in young-old adults, in individuals with little midlife contribution to cognitive reserve, and in individuals with high crystallized intelligence in terms of vocabulary.

In the context of the latter notions, we acknowledge that the present correlative study does not allow drawing causal inferences. With respect to the applied statistical approach we further acknowledge that cross-lagged models have been debated in the literature (see e.g. Hamaker, Kuiper, & Grasman, 2015; Rogosa, 1980). Specifically, in line with Hamaker and colleagues, we acknowledge the issue that the present two-wave cross-lagged design only provides indications regarding status in activity engagement and TMT performance but does not allow drawing conclusions regarding decline (i.e., intraindividual changes over time). Moreover, we acknowledge that the current study is limited by a relatively short assessment



of cognitive performance. The battery of cognitive tests in the present study contained only measures on TMT performance and vocabulary. Thus, future studies will have to examine whether the present pattern of results holds also for a larger set of cognitive abilities such as episodic memory, working memory, and a broader range of executive functions and thereby apply to the broader domain of cognitive functioning.

One may debate whether age should be treated as a continuous variable or as a grouping variable as in the present analyses. To clarify, breaking the groups into above and below age 75 in present analyses followed conceptual and empirical reasons. First, conceptually, the model of third versus fourth age (Baltes, 1998; Baltes & Smith, 2003) postulated that the two groups of young-old versus old-old age differ qualitatively rather than differing only on a single quantitative dimension 'age' per se. Specifically, according to this model, in young-old age individuals are in relatively good health and thereby still have, on average, rather substantial amounts of resources that help to compensate age-related losses. In contrast, in old-old age decline reaches a critical threshold that does not allow compensating anymore. Thus, the model of third versus fourth age (Baltes, 1998; Baltes & Smith, 2003) argues that aging in advanced age is not a continuous process, but that instead one needs to qualitatively differentiate between young-old and old-old age due to discontinuity in aging. Second, empirically, age 75 has been suggested as cutoff age for distinguishing young-old from old-old age. Specifically, to identify the mark that distinguishes between young-old and old-old age, a demographic, population-based approach represents the chronological age at which 50% of the birth cohort are no longer alive. The logic behind this approach is that people beyond that cutoff age show substantial losses in multiple health domains (Baltes & Smith, 2003). This method empirically identified the beginning of old-old age in developed countries at about age 75 (e.g., Olshansky, Carnes, & Desesquelles, 2001; Oris & Lerch, 2009; Vaupel et al., 1998). Besides such demographic approaches, performance-based empirical evidence showed that models that considered qualitative differences between

young-old versus old-old age better explained interindividual differences in old age than models that treated age differences as being continuous (e.g., Ihle, Jopp, Oris, Fagot, & Kliegel, 2016a). In line with the model of third versus fourth age (Baltes, 1998; Baltes & Smith, 2003) these findings suggest that models conceptualizing aging as a continuous development may not suffice to adequately represent the qualitative differences between the distinct groups of young-old and old-old age due to discontinuity in late adulthood.

With respect to frequency of leisure activity participation one may argue that on average activity scores were relatively low and that this may be related to range restriction (see Descriptive Statistics section). Yet, note that we averaged frequency scores across all 18 leisure activities to derive an overall measure of leisure activity participation (for a validation see e.g. Jopp & Hertzog, 2010; see Paggi et al., 2016, for the same approach). Thus, low frequency scores do not necessarily mean that an individual only very rarely engaged in activities since low scores can also emerge if an individual often pursues some activities but never engages in several other activities (e.g., Jopp & Hertzog, 2010; Paggi et al., 2016). Besides that, there was considerable variance in participation frequency, which suggests that individuals differed with respect to activity engagement and, notably, this variance was sufficient to allow detecting relationships to TMT performance six years later.

One may also argue that musculoskeletal disorders such as osteoarthritis as well as visual impairment may be reasons for poor TMT performance that may be independent of cognitive functioning and that therefore may diminish test-retest reliability of TMT scores. Yet, in general the TMT has been found to be a reliable instrument with test-retest reliabilities of scores in TMT parts A and B typically ranging from .75 to .85 (e.g., Giovagnoli et al., 1996). Compared to those test-retest correlations over relatively short time (typically across weeks or months), as expected we found test-retest correlations of moderate size regarding TMT scores between both waves that were six years apart (TMT A:  $r = .34, p < .001$ ; TMT B:  $r = .47, p < .001$ ) since many factors affect cognitive aging and result in large interindividual

differences in aging trajectories (e.g., Christensen et al., 1994; Ghisletta & Lindenberger, 2004; Lindenberger & Chicherio, 2008; Ram, Gerstorf, Lindenberger, & Smith, 2011). Besides that, all relations observed in the present study held after simultaneously controlling for potential relations of medical conditions (including musculoskeletal disorders such as osteoarthritis) to TMT performance in both waves. We acknowledge the limitation that the present survey did not include tests of acuity, which may be considered as additional covariate in future research. More generally, one may argue that medical conditions such as cardiovascular diseases, metabolic syndromes such as diabetes mellitus, and musculoskeletal disorders such as osteoarthritis may potentially influence individuals' leisure activity participation and/or cognitive functioning. Moreover, one may argue that the investigated moderator variables age group, education, cognitive level of job, and vocabulary may potentially be interrelated. Yet, importantly, the pattern of differential reciprocal activity-TMT relationships held after simultaneously controlling for potential relations of medical conditions (including cardiovascular diseases, metabolic syndromes such as diabetes mellitus, and musculoskeletal disorders such as osteoarthritis) to leisure activity participation and to TMT performance in both waves as well as for potential interrelations of the different moderator variables. Therefore, the present study may stimulate future longitudinal research assessing changes in a comprehensive set of cognitive domains, activities, and medical conditions in multiple measurement waves over a large time scale to gain further insights into the detailed processes underlying the relationship of an active lifestyle and cognitive aging.

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**Conflict of interest**

We declare that there is no conflict of interest.

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Table 1

*Results of cross-lagged analyses: moderation*

	Group 1	Group 2	
<b>Moderator age group</b> <sup>a</sup> (model fit: $\chi^2 = 5.98$ , $df = 10$ , $p = .817$ , $CFI > .99$ , $IFI > .99$ , $RMSEA < .001$ , $SRMR = .02$ )			
cross-lagged reciprocal activity-TMT paths	young-old	old-old	between-group comparison
$\beta$ activity W1 predicting TMT W2	.21*	.11 ns	$\Delta\chi^2 = 78.56$ ( $\Delta df = 2$ ) ***
$\beta$ TMT W1 predicting activity W2	-.07 ns	-.09 ns	
within-group comparison	$\Delta\chi^2 = 5.93$ ( $\Delta df = 1$ ) *	$\Delta\chi^2 = 1.12$ ( $\Delta df = 1$ ) ns	
<b>Moderator education</b> <sup>b</sup> (model fit: $\chi^2 = 6.27$ , $df = 10$ , $p = .792$ , $CFI > .99$ , $IFI > .99$ , $RMSEA < .001$ , $SRMR = .01$ )			
cross-lagged reciprocal activity-TMT paths	low	high	between-group comparison
$\beta$ activity W1 predicting TMT W2	.25*	.20*	$\Delta\chi^2 = 0.77$ ( $\Delta df = 2$ ) ns
$\beta$ TMT W1 predicting activity W2	-.10 ns	.01 ns	
within-group comparison	$\Delta\chi^2 = 5.81$ ( $\Delta df = 1$ ) *	$\Delta\chi^2 = 5.64$ ( $\Delta df = 1$ ) *	
<b>Moderator cognitive level of job</b> <sup>c</sup> (model fit: $\chi^2 = 8.72$ , $df = 10$ , $p = .559$ , $CFI > .99$ , $IFI > .99$ , $RMSEA < .001$ , $SRMR = .02$ )			
cross-lagged reciprocal activity-TMT paths	low	high	between-group comparison
$\beta$ activity W1 predicting TMT W2	.40*	.11 ns	$\Delta\chi^2 = 29.81$ ( $\Delta df = 2$ ) ***
$\beta$ TMT W1 predicting activity W2	-.14 ns	-.06 ns	
within-group comparison	$\Delta\chi^2 = 19.90$ ( $\Delta df = 1$ ) ***	$\Delta\chi^2 = 2.41$ ( $\Delta df = 1$ ) ns	
<b>Moderator vocabulary</b> <sup>d</sup> (model fit: $\chi^2 = 12.20$ , $df = 10$ , $p = .272$ , $CFI > .99$ , $IFI > .99$ , $RMSEA = .04$ , $SRMR = .02$ )			
cross-lagged reciprocal activity-TMT paths	low	high	between-group comparison
$\beta$ activity W1 predicting TMT W2	.11 ns	.25*	$\Delta\chi^2 = 71.80$ ( $\Delta df = 2$ ) ***
$\beta$ TMT W1 predicting activity W2	-.12 ns	.14 ns	
within-group comparison	$\Delta\chi^2 = 2.31$ ( $\Delta df = 1$ ) ns	$\Delta\chi^2 = 5.15$ ( $\Delta df = 1$ ) *	

*Note.* Results of moderation analyses to investigate whether the pattern of cross-lagged reciprocal relationships between leisure activity participation and Trail Making Test (TMT) performance differed by age group / education / cognitive level of job / vocabulary (simultaneously controlling for covariates; see below, for further details).  $\beta$  activity W1 predicting TMT W2 = standardized coefficient for the relation of leisure activity participation in W1 predicting TMT performance in W2.  $\beta$  TMT W1 predicting activity W2 = standardized coefficient for the relation of TMT performance in W1 predicting leisure activity participation in W2.

Model fit indices are given for the unconstrained moderator model;  $CFI$  = Comparative Fit Index,  $IFI$  = Incremental Fit Index,  $RMSEA$  = Root Mean Square Error of Approximation,  $SRMR$  = Standardized Root Mean Square Residual.

Between-group comparison =  $\Delta\chi^2$  test statistic for comparing the unconstrained moderator model with a constrained model, in which the two reciprocal activity-TMT paths (i.e., the path from leisure activity participation in W1 to TMT performance in W2 and the path from TMT performance in W1 to leisure activity participation in W2) were each constrained to be of equal size across both moderator subgroups (i.e., testing the moderation effect).

Within-group comparison =  $\Delta\chi^2$  test statistic for comparing the unconstrained moderator model with a constrained model, in which the reciprocal activity-TMT paths were constrained to be of equal size within one moderator subgroup (i.e., testing the difference of the two cross-lagged reciprocal activity-TMT relationships within that moderator subgroup).

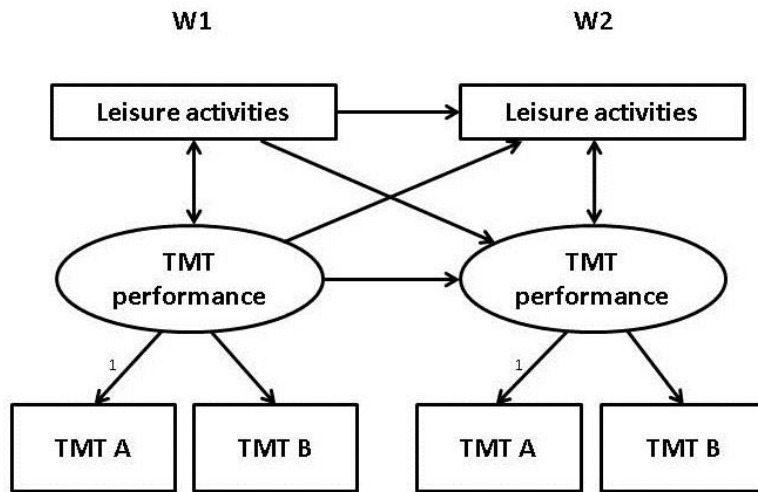
<sup>a</sup> Simultaneously controlling for medical conditions, education, cognitive level of job, and vocabulary.

<sup>b</sup> Simultaneously controlling for medical conditions, age, cognitive level of job, and vocabulary.

<sup>c</sup> Simultaneously controlling for medical conditions, age, education, and vocabulary.

<sup>d</sup> Simultaneously controlling for medical conditions, age, education, and cognitive level of job.

\*\*\*  $p < .001$ ; \*  $p < .05$ ; ns = non-significant,  $p > .05$ .



*Figure 1.* Specification of the tested cross-lagged model to investigate the pattern of reciprocal relationships between leisure activity participation and Trail Making Test (TMT) performance (i.e., the path from leisure activity participation in W1 to TMT performance in W2 and the path from TMT performance in W1 to leisure activity participation in W2).