



HAL
open science

Influence of current physical exercise on the relationship between aging and episodic memory and fluid intelligence

Hajer Kachouri, Séverine Fay, Lucie Angel, Michel Isingrini

► **To cite this version:**

Hajer Kachouri, Séverine Fay, Lucie Angel, Michel Isingrini. Influence of current physical exercise on the relationship between aging and episodic memory and fluid intelligence. *Acta Psychologica*, 2022, 227, 10.1016/j.actpsy.2022.103609 . hal-03719727

HAL Id: hal-03719727

<https://hal.science/hal-03719727>

Submitted on 11 Jul 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Influence of current physical exercise on the relationship between aging and episodic memory and fluid intelligence[☆]

Hajer Kachouri^{*}, Séverine Fay, Lucie Angel, Michel Isingrini

Centre de Recherches sur la Cognition et l'Apprentissage (CeRCA) UMR-CNRS 7295, Université de Tours, France

ARTICLE INFO

Keywords:

Physical exercise
Aging
Episodic memory
Fluid intelligence
Cognitive reserve

ABSTRACT

The present study examined the effects of current physical exercise and age on episodic memory and fluid intelligence, assessed with a free-recall task and the Culture Fair Intelligence Test (Cattell, 1963) respectively, while statistically controlling for other cognitive reserve factors (educational level, leisure activities, and vocabulary level). Two hundred and eight participants aged 20 to 85 participated in the study. Physical exercise level was indexed by weekly frequency over the last 12 months using self-reported measurement (from none to 4 times a week). Overall, results show a beneficial effect of physical exercise especially from a weekly practice of 2 times, and significant interaction between physical exercise and age on episodic memory and fluid intelligence capacities indicating a reduced effect of age in more physically active participants. These results reinforce the view that physical exercise is a strong and specific reserve factor that reduces decline in some cognitive functions during aging.

1. Introduction

Cognitive aging is a heterogeneous phenomenon since many cognitive functions (e.g. episodic memory, fluid intelligence) show a marked reduction with aging that may begin early, while others (e.g. semantic memory, implicit memory, vocabulary) are preserved or even tend to improve with aging (Angel & Isingrini, 2015; Salthouse, 2009). Episodic memory (EM) and fluid intelligence (FI) are among the functions that are most impaired by the aging process. Numerous studies have consistently reported that EM, which involves conscious retrieval of personal experiences associated with a particular temporal and spatial context (Ghetti & Bunge, 2012; Tulving, 1972), declines sharply during aging (for meta-analysis see Old & Naveh-Benjamin, 2008). FI, which refers to the ability to think logically and solve problems in new situations independently of acquired knowledge, also undergoes a marked decline with advancing age (Horn & Cattell, 1966; Isingrini & Vazou, 1997; Salthouse, 1991). One of the main hypotheses of the decline of EM and FI during aging is based on age-related executive dysfunction (West, 1996). Executive functions consist of a set of control processes, including

planning, inhibition, updating, and switching, that are used to monitor other cognitive operations (Scarmeas & Stern, 2003), explaining the age-related decline of EM (Angel et al., 2010; Ardiale & Lemaire, 2012; Isingrini & Tacconnat, 2008) and FI abilities (Barbey et al., 2012; Conway et al., 2002; De Frias et al., 2006; Isingrini & Vazou, 1997; Jeantin & Pennequin, 2006; Kyllonen & Christal, 1990; Salthouse & Salthouse, 1992; Salthouse, 1993).

There are also large individual differences in the degree of cognitive decline with advancing age. These differences across individuals can be influenced by participant attributes such as age and gender. Evidence on gender differences in age-related cognitive changes comes from a study on the structure of the brain, in which more pronounced atrophy with age in men than women (Gur et al., 1991) was noted, suggesting gender-related differences in cognitive functioning notably for memory (e.g. Zelinski et al., 1993) and intelligence capacities (Lindenberger & Baltes, 1997; Meinz & Salthouse, 1998). Interindividual differences can also be explained by cerebral and cognitive protective mechanisms that may limit the cognitive decline associated with advancing age (Scarmeas & Stern, 2003) known under the term of reserve. The proposal of the

Abbreviations: (EM), Episodic memory; (FI), Fluid intelligence; (min), Minute; (s), Second; (Fig), Figure; (WAIS), Wechsler Adult Intelligence Scale; (MMSE), Mini-Mental State Examination.

^{*} All authors have participated in (a) conception and design, or analysis and interpretation of the data; (b) drafting the article or revising it critically for important intellectual content; and (c) approval of the final version.

^{*} Corresponding author at: 3 Rue des Tanneurs, 37041 Tours, France

E-mail addresses: hajer.kachouri@univ-tours.fr (H. Kachouri), severine.fay@univ-tours.fr (S. Fay), lucie.angel@univ-tours.fr (L. Angel), michel.isingrini@univ-tours.fr (M. Isingrini).

<https://doi.org/10.1016/j.actpsy.2022.103609>

Received 4 May 2021; Received in revised form 9 April 2022; Accepted 4 May 2022

Available online 13 May 2022

0001-6918/© 2022 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

cognitive reserve theory has inspired an amount of empirical work to refine the cognitive reserve concept and related constructs (Nilsson & Lövdén, 2018). Two models have been proposed (Stern, 2002, 2009). The passive model of reserve also called “brain reserve” suggests that the reserve derives from the structural characteristics of the brain (brain size, neuronal and synapse count). In contrast, the active model of reserve refers to the “cognitive reserve” which concerns functional brain, cognitive and strategic changes in order to cope with deleterious age effects (Stern, 2002, 2009). Several factors are likely to index cognitive reserve by reducing the effect of aging on cognition such as educational attainment (Hatch et al., 2007; Richards & Deary, 2005), knowledge attainment (Christensen et al., 1997), and lifetime participation in cognitively stimulating leisure activities (for review see Wang et al., 2012). Some theoretical models have been proposed in the literature in order to explain how the effect of these cognitive reserve factors would be illustrated, in particular the Salthouse model (Salthouse, 2006; Salthouse et al., 1990). In this model, two hypotheses have been put forward to explain the protective effect of reserve factors on cognitive functioning with advancing aging. The first corresponds to a differential preservation profile, indicating a moderating effect of the reserve component on the relationship between age and the evaluated performance, with reduced age-related cognitive differences in high reserve participants. By contrast, the second hypothesis corresponds to preserved differentiation in which the effect of the reserve factor on EM and FI capacities would be the same regardless of age, and age-related differences would not be modulated by the reserve level. Statistically, the differential preservation profile is associated with a significant interaction between age and the reserve factor, leading to a larger effect of this reserve factor with advancing age and the hypothesis of preserved differentiation postulates no interaction between age and reserve factor. Among reserve factors, particularly cognitive reserve factors, physical exercise has been of particular interest to researchers. An increasing number of studies suggest that physical exercise could protect against age-related cognitive decline (for a review see Albinet et al., 2008; Soggard & Ni, 2018; for a meta-analysis see Colcombe & Kramer, 2003). Following this theoretical approach, the main objective of the present study was to further examine whether the current level of physical exercise has a protective effect against the age-related decline of EM and FI, over and above other reserve factors. Physical exercise is generally defined as a planned, structured, and voluntary behavior that increases energy expenditure in addition to everyday physical activity in order to improve or maintain physical fitness (Chodzko-Zajko et al., 2009). The beneficial effect of physical exercise on cognitive functions, including EM and/or FI has been shown in a number of studies with younger and/or older adults taking different methodological approaches, including interventional studies (for EM: Labban & Etnier, 2011; Nanda et al., 2013; Peig-Chiello et al., 1998; for FI: Elsayed et al., 1980; see for review Angevaren et al., 2008) and non-interventional studies (Aichberger et al., 2010; Perrot et al., 2009) using self-report measures (for EM and FI: Elsayed et al., 1980; Labban & Etnier, 2011) or objective measures (for EM and FI: Nanda et al., 2013; Peig-Chiello et al., 1998, Perrot et al., 2009). However, no definitive conclusion can be drawn about the effect of physical exercise on the cognitive functions of young adults, as some but not all studies found a significant positive association (see for review Cox et al., 2016). Numerous cross-sectional studies have also demonstrated that physical exercise is associated with better cognitive performance, including EM and FI, in older adults (see for review Voelcker-Rehage & Niemann, 2013). Thus, physically active older adults could expect that their cognitive performance for EM and FI would be better than that of their non-active or less active counterparts. However, Loprinzi and Kane (2015) and Van de Rest et al. (2014) failed to find this beneficial effect. Overall, studies show that the benefits of physical exercise for cognition tend to increase with age (Newson & Kemps, 2006; Stones & Kozma, 1988), leading to increasing advantage in older adults (Gombart et al., 2018; Salthouse, 2006; Salthouse et al., 1990; Tucker-Drob et al., 2009), and few or contradictory results in young adults. This

seems consistent with the differential preservation model (Salthouse, 2006; Salthouse et al., 1990) suggesting a moderation effect associated with physical exercise. The novel contribution of this study is that it evaluated the effect of physical exercise on EM and FI, across the adult lifespan, when partialling out the effect of other cognitive reserve factors, an issue that has as yet not been fully investigated. In most previous studies, the effects of gender and reserve factors such as educational level, knowledge, and/or leisure activities have not always been statistically partialled out concurrently. Thus, the effect of physical exercise may be confounded with the effect of these other reserve factors. A recent study examined the respective contribution of multiple reserve factors (educational level, leisure activities, and physical exercise) over the lifetime to cognitive performance among older adults (Rouillard et al., 2017). The findings showed that educational level and leisure activity were the main predictors of cognitive functioning in tasks evaluating overall cognitive efficiency and a number of cognitive abilities during aging. The authors suggested that the absence of effect of physical exercise on cognitive abilities, especially in older adults, could be explained by the fact that no positive effect would be shown if the older adults had discontinued their physical activity (Rouillard et al., 2017). Based on this observation, it would be interesting to assess the effects of recent physical exercise for the last 12 months according to age during adult lifespan. To this end, self-report measures could provide more precise information than objective measures about long-term physical exercise (over a period of a year or more). Self-report measures have shown that physical exercise can be beneficial for memory and executive functioning in older adults (Dregan & Gulliford, 2013). It should be noted that studies typically explore the effects of physical exercise on cognitive functioning during aging by including only older adults or sometimes by comparing older to younger adults. To our knowledge, no study has yet examined the effect of physical exercise on EM and FI across the adult lifespan.

To fill this gap, the present study aimed to examine the effects of current physical exercise on EM and FI performance according to age across the adult lifespan. To this end, we assessed the EM and FI performance of 208 participants aged from 20 to 89 years with a frequency of current weekly physical exercise that varies from none to 4 times a week. Our aim was to determine the effect of age and physical exercise on EM and FI performance, and a possible moderating effect of physical exercise on the relationship between aging and EM and FI performance, when partialling out other reserve factors. One original aspect of the present study was that it determined the effect of current physical exercise while controlling, statistically, for gender and three reserve factors (educational level, leisure activities, and general knowledge) that may influence age-related changes in EM and FI. We hypothesized first that EM and FI performance would decrease with age. Secondly, we hypothesized that physical exercise would have a beneficial effect on EM and FI, demonstrated by better cognitive performance with a high frequency of physical exercise. Finally, we expected to observe a significant interaction between age and physical exercise, with a reduced age-related effect on EM and FI (protective effect) for participants with a high weekly frequency.

2. Method

2.1. Participants

Two hundred and eight individuals aged from 20 to 85 years old participated voluntarily in this study.

The study was approved by the ethics committee of the University of Tours, France, and all participants gave approval for their participation and signed a consent form. The characteristics of the general population are presented in Table 1. As in previous studies (Aichberger et al., 2010; Dregan & Gulliford, 2013; Hamer et al., 2014; Musich et al., 2017), physical exercise practice was based on the self-reported number of sessions per week of physical exercise outside of daily physical activities,

Table 1
Characteristics of the general population.

	Mean (SD)	Min-max
Age (years old)	57.44 (19.14)	20–85
Physical exercise level (weekly frequency)	1.40 (1.38)	0–4
Gender (male/female)	72/136	
Educational level (years of study)	11.88 (3.21)	8–24
Leisure activity index	1.78 (0.51)	0.55–3.18

of any intensity, over the last 12 months (from none to at least four times a week). None of the participants had a neurological or psychiatric history and all reported being free of medication known to affect the central nervous system. Participants who scored below 27 on the Mini-Mental State Examination (MMSE; Folstein et al., 1975) were excluded from the study. To estimate the level of general knowledge, we calculated a general knowledge index for each participant by averaging the z-scores of the Mill Hill vocabulary test (Deltour, 1993) and the information test, which assesses knowledge capacity (WAIS III; Wechsler, 1997). An overall leisure index was then calculated for each participant by averaging all the leisure activity scores. Variables namely gender, educational level, general knowledge and cognitive leisure activity, were partialled out in subsequent statistical analyses.

2.2. Material and procedure

2.2.1. Episodic memory (EM) and fluid intelligence (FI) measures

2.2.1.1. Free-recall task. EM was assessed using a free-recall task. Participants were asked to memorize a list of 16 concrete words presented orally and successively in a pre-established order. Immediately after the presentation phase, they had to recall all the words orally in any order, with no time limit. The score was the number of correctly recalled words, with a maximum score of 16.

2.2.1.2. Culture Fair Intelligence Test (Cattell, 1963). FI was assessed using the Culture Fair Intelligence Test (Cattell, 1963), which evaluates fluid intelligence and problem-solving abilities. It consists of four subtests (Series, Classifications, Matrices, and Conditions) in which participants have to infer relationships between shapes and figures. In each subtest, they complete sequences of drawings by choosing among response options. The Series subtest has 13 sequences of drawings with six response options; participants had 3 min to complete as many problems as possible. The Classifications subtest has 14 series of five abstract shapes and figures, and participants have to identify the two that differ from the others; they had 4 min to complete this test. In the Matrices subtest, participants have to complete 13 matrices or patterns, choosing among six response options; they had 3 min to complete as many problems as possible. In the Conditions subtest, participants were presented with 10 series of geometric drawings and had to choose the one that met some specified condition from five response options; time was restricted to 150 s. The total score was calculated by adding the number of correct responses for each subtest, with a maximum score of 50.

2.2.2. Vocabulary and information tests

2.2.2.1. Mill Hill Vocabulary Test (Raven, 1983). To evaluate verbal abilities, participants completed the Synonyms section of the Mill Hill Vocabulary Test (Raven, 1983). They had to select synonyms for 35 words from a choice of six words. There was no time limit, and the score were the number of correct responses, with a maximum of 34 (one was given as an example).

2.2.2.2. WAIS III Information Test (Wechsler, 1997). General knowledge was assessed using the WAIS III, comprising 28 general knowledge

questions. The score is the sum of correct answers (one point for each correct response), with a maximum score of 28.

2.2.3. Assessment of physical exercise

Physical exercise was described as “a planned, structured and voluntary exercise as an activity in addition to the usual daily physical activities in order to improve or maintain physical fitness” (Chodzko-Zajko et al., 2009). In order to determine the frequency of practice of physical exercise, participants were asked to “Please indicate how many times per week you exercise voluntary (e.g. football, cycling, fitness, dance, running, etc.) outside of the physically daily living activities (e.g. gardening, housekeeping, walking your dog) during the last 12 months” on a five-point scale (0 = none, 1 = once a week, 2 = twice a week, 3 = 3 times a week, and 4 = at least 4 times a week).

2.2.4. Assessment of cognitively stimulating leisure activities

To assess the extent of participants' cognitively stimulating leisure activities, they were asked to indicate how often they had engaged in ten different leisure activities over the past 12 months (reading books, reading magazines, reading newspapers, playing music, going to the cinema, going to the theater, cultural outing (museum and travel), playing board games, playing word games and involvement in community activities). Similarly, to the assessment of physical exercise, the engagement to leisure activities was measured on a scale ranging from 0 to 4 that was adapted to the fact that leisure activities are less frequent than physical exercise (0 = never, 1 = once or twice a year, 2 = five to six times a year, 3 = several times a month, 4 = every week).

2.2.5. Procedure

At the beginning of the session, participants provided demographic and personal information and answered questions about their health (treatment and medical history). They then completed the Mill Hill Vocabulary Test (Raven, 1983) and the WAIS III Information Test (Wechsler, 1997). Older adults then completed the Mini-Mental State Examination (MMSE) (Folstein et al., 1975) in order to screen for cognitive dysfunction and/or preclinical dementia. All participants achieved scores over the cut-off of 27 points. Next, all the participants completed the questionnaires about leisure activities and physical exercise. Finally, they completed the EM task and the FI test.

3. Results

EM (score at free recall test) and FI (score at fluid intelligence test) performances of the general population are presented in Table 2. Statistical analyses were carried out using STATISTICA software (version 13).

First, in order to identify the effects of age and physical exercise, treated as continuous variables, and their interaction either on EM or on FI performances, we performed a General Linear Model ANCOVA-based analysis (GLM) with age and physical exercise entered as independent variables, and EM or FI as dependent variables. More precisely, these analyses were conducted with gender, educational level, general knowledge index, and leisure activity index partialled out (entered as co-variables in ANCOVA) to better examine the independent effects of age and physical exercise. The interaction in the ANCOVA between age and physical exercise will be used to test the hypothesis which stipulates that physical exercise would moderate the age-related effect on EM and FI with control for the co-variables listed above. In order to make the results as illustrative as possible, we made figures with four age groups

Table 2
EM and FI performances of the general population.

	Mean (SD)	Min-max
Free recall test (EM)	10,88 (2,56)	2–16
Fluid intelligence test (FI)	19,88 (6,92)	4–37

(20–39; 40–59; 60–69; 70–85) and two physical exercise groups (Low: less than twice a week; High: more than twice a week) (see Fig. 1 for EM and Fig. 2 for FI). The distribution of the weekly frequency into two groups (low vs. high) to less than 2 times and more than 2 times a week was made based on the analyses developed below.

Second, we aimed to determine from which age the effect of physical exercise becomes significant. To this end, we conducted additional ANCOVAs with age and physical exercise (continuous factors) on EM then FI performances (dependent variables) by adding age groups progressively as per the following (20–39 then 20–59 then 20–69 then 20–85).

Third, with the purpose of determining the exact frequency from which the effect of physical exercise becomes significant, ANCOVAs analyses with age and physical exercise factors on EM and FI performances have been conducted by first integrating only the subjects who exercise 0 and 1 time a week and then adding the higher frequencies gradually. In other words, we first included in the ANCOVA on EM and FI only subjects who exercise 0 and 1 times a week. Then, we included in addition to the subjects who practice from 0 to 1 time those who practice 2 times a week to test the effect of exercise between 0 and 2 times. Subsequently, we further included subjects who exercise 3 times to see the effect of exercise between 0 and 3 times per week and finally we also included the subjects who practice with a frequency of 4 times per week.

For EM, ANCOVA revealed a significant effect of age [$F(1,199) = 34.27$, $MSe = 3.70$, $\eta^2p = 0.15$, $p < .0001$] with a decrease in performance with advancing age (see Fig. 1). The analyses did not reveal a significant effect of physical exercise [$F(1,199) = 3.45$, $MSe = 3.70$, $\eta^2p = 0.01$, $p = .06$]. However, the results indicated a significant interaction between age and physical exercise for EM [$F(1,199) = 8.47$, $MSe = 3.70$, $\eta^2p = 0.04$, $p < .005$] confirming that the effect of physical exercise varies significantly as a function of age. Moreover, the interaction illustrated in Fig. 1 indicates a reduced effect of age in more physically active participants for EM. Additional analyses indicated that for EM, the effect of physical exercise was not significant when only participants aged from 20 to 39 years old were included in the analysis nor from 20 to 59 years old. The effect of physical exercise begins to be significant only when participants aged from 60 to 79 years were added in the analysis [$F(1,55) = 6.86$; $MSe = 3.19$; $\eta^2p = 0.11$; $p < .05$]. Thus, the effect of physical exercise begins to be significant on EM from the age of 60. Concerning determining the frequency from which the effect of physical exercise becomes significant on EM, the results indicated that the effect of physical exercise was not significant when including only the subjects who practice 0 or 1 time a week. This effect became significant with a weekly frequency of 2 times a week (i.e. including in addition to the subjects who practice 0 and 1 time a week, the subjects who practice 2 times a week) [$F(1,200) = 6.76$; $MSe = 3.84$; $\eta^2p = 0.003$; $p < .05$] and continues to be significant beyond this frequency (0, 1, 2 and 3 & 0, 1, 2, 3 and 4).

Concerning FI, ANCOVA showed a significant effect of age [$F(1,199) = 115.9$, $MSe = 17.38$, $\eta^2p = 0.037$, $p < .0001$] with a decrease in

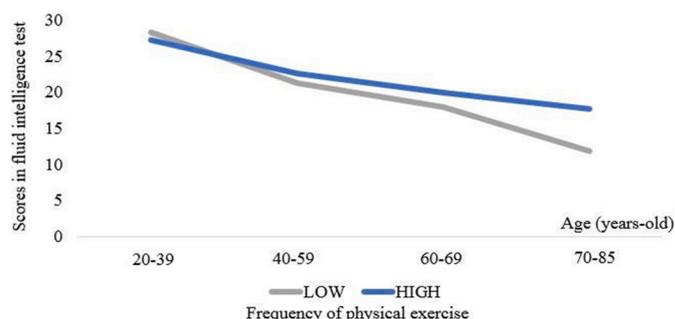


Fig. 2. Effect of physical exercise on fluid intelligence in function of age.

performance with advancing age and a significant effect of physical exercise [$F(1,199) = 4.82$, $MSe = 17.38$, $\eta^2p = 0.02$, $p < .05$] showing that subjects who exercise more frequently perform better than those who practice less or not at all (see Fig. 2). Then, concerning the optimal frequency from which the effect of physical exercise remains significant on FI, additional analyses demonstrate that the effect of physical exercise was not significant when only including participants with 0 and 1 a week frequency of practice. This effect became significant only when including in addition to the subjects who practice 0 and 1 time a week, the subjects who practice 2 times a week (0, 1 and 2 times a week) [$F(1,200) = 4.01$; $MSe = 18.11$, $\eta^2p = 0.02$, $p < .05$] and remains significant over this frequency (0, 1, 2 and 3 & 0, 1, 2, 3 and 4). Also, the main ANCOVA analysis showed a significant interaction between age and physical exercise for FI [$F(1,199) = 9.32$, $MSe = 17.38$, $\eta^2p = 0.044$, $p < .005$]. The additional analyses have shown that for FI the effect of physical exercise was not significant when participants aged from 20 to 39 years old were included in the analysis nor from 20 to 59 years old neither among 60–69 years old. The effect of physical exercise begins to be significant from the age of 70 and above [$F(1,52) = 12.43$, $MSe = 19.16$, $\eta^2p = 0.02$, $p < .0001$]. This result showed that the beneficial effect of physical exercise on IF capacities increases with age and is more observed in adults over 70 years of age with a reduced age-related decline in participants who exercise frequently. To sum, the significant interaction observed between age and physical-exercise variables for EM and FI suggests a reduced age-related effect as a function of highly physical exercise frequency (from twice a week for both functions).

4. Discussion

The present study examined whether the influence of age on EM and FI performance varies as a function of physical exercise, indexed by weekly frequency over the last 12 months, after statistical control for gender and potential reserve variables, namely educational level, general knowledge, and leisure activities. The results indicate a significant interaction between age and physical exercise when the other factors (gender, educational level, general knowledge, and cognitive leisure activity) were partialled out for EM and FI. The interaction suggests that the effect of age is reduced for physically active participants, which confirms the protective effect of physical exercise by considering a more important effect in older adults. The effect of physical activity can be observed from the age of 60 for EM and 70 for FI with a minimum frequency of 2 times per week for these two cognitive functions. Moreover, the interaction observed between age and physical exercise suggests that physical exercise acts as an independent moderator of the aging effect on EM and FI, as older adults who engaged in physical exercise more frequently appeared to be better protected against cognitive aging. Interestingly, in addition to confirming the moderating effect of frequent physical exercise, the results suggest a differential preservation profile for EM and FI, which seems more marked for EM (Salthouse, 2006; Tucker-Drob et al., 2009).

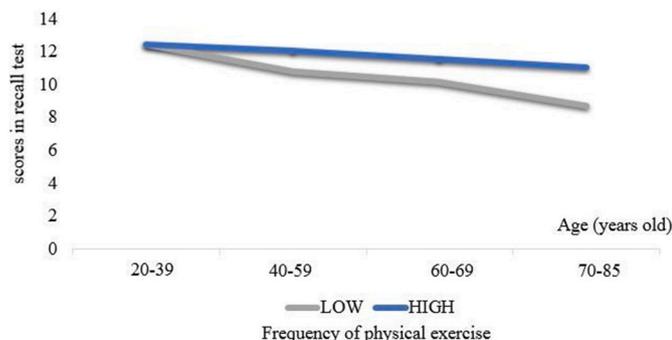


Fig. 1. Effect of physical exercise on episodic memory in function of age.

A classic pattern of aging was observed for EM and FI performance, confirming the age-related decline observed in previous studies (Crack & Jennings, 1992; Verhaeghen & Salthouse, 1997; Horn & Cattell, 1966; Salthouse, 1991). In the literature, the age-related decline in both cognitive abilities has been explained by the resource deficit hypothesis, involving notably a deficit of executive functions that play a significant role in EM and FI functioning (Angel et al., 2010; Ardiale & Lemaire, 2012; Barbey et al., 2012; Conway et al., 2002; Isingrini & Tacconat, 2008; Salthouse & Salthouse, 1992; Salthouse, 1993). Since studies suggest that executive functions are particularly sensitive to the beneficial effect of physical exercise (see for meta-analysis: Colcombe & Kramer, 2003; Kramer et al., 1999) it may be interesting to determine whether the beneficial effect of physical exercise on EM and FI may be mediated by the effect of physical exercise on executive functions. That is to say, physically active older subjects would have better executive functioning and therefore better FI and EM performances. It would therefore be interesting in future research to include executive functions measures in order to test this mediation hypothesis.

The original aspect of the present study examined changes across the adult lifespan and isolated statistically the effect of physical exercise from other reserve factors likely to influence age-related changes in EM and FI. The effect of physical exercise could be explained by various arguments present in the current literature which suggest from a behavioral point of view an improvement in strategies (e.g. André et al., 2018) and from a neuronal point of view greater volumes of different brain regions (frontal, occipital, entorhinal, and hippocampal regions) associated with a reduced risk of cognitive impairment (See for review Erickson & Kramer, 2009). Moreover, the practice of physical activity showed a significant effect on the maximum volume of oxygen in the body, particularly in brain structures (Jones et al., 2011; Whipp et al., 2005), on neuronal plasticity (Gyorkos et al., 2014; Revilla et al., 2014), and neurotrophic factors that regulate neuroprotective pathways (Vianney et al., 2013) (see for review Audiffren et al., 2011). In addition, it would be interesting in future research to explore brain aspects using imaging techniques that could indicate the brain mechanisms underlying the effects of physical exercise on cognitive functions. In fact, the Scaffolding Theory of Aging and Cognition (STAC) states that there is a compensatory scaffolding that entails the engagement of additional neural resources (network reorganization) providing support to preserve cognitive function against structural and functional decline (Park & Reuter-Lorenz, 2009). In addition, STAC-r modifiable model incorporates life-course variables that impact the structure and function of the aging brain. This model provides a dynamic between neurophysiological variables and compensatory neural processes that operate jointly to predict cognitive function over time (Reuter-Lorenz & Park, 2014).

After statistically controlling for gender, educational level, general knowledge, and leisure activities, we observed a significant interaction between age and physical exercise level which supports the hypothesis that physical exercise is a protective factor against cognitive decline independently of other reserve factors. This finding suggests that physical exercise could independently moderate age-related effects on EM and FI and therefore be considered as a reserve factor (Stern, 2002). The question of the optimal frequency of practice in order to moderate the effects of age especially during aging is of major importance but remains with no clear answer. In fact, analyses have shown in our study that whatever the nature of the physical exercise, practicing twice a week or more could moderate the effect of age on memory and fluid intelligence capacities. Aichberger et al. (2010) also reported that engagement in physical exercise more than once a week was associated with a lower rate of cognitive decline. Nevertheless, to concretely provide evidence-based recommendations of a specific frequency of physical exercise, it would be interesting to extend the present results with additional longitudinal intervention studies with precise measurements are needed (Herting & Keenan, 2017).

The age-related deficit in EM performance confirmed that physical exercise has a moderating effect on age-related changes in EM that

becomes significant for the elderly (from 60 years old). Regarding FI, the significant interaction between age and physical exercise variables indicated that the age-related effect was more marked when practicing less frequently a physical exercise and that this effect is mainly observed in adults over 70 years of age. In other words, these results confirm that the age-related decline in EM and FI performance is reduced in individuals, especially older adults, and that a physical exercise frequency of 2 times or more a week is needed. This beneficial effect of physical exercise on EM and FI increases with age, as it was observed less in the younger participants. This is in line with other studies that failed to show a benefit of physical exercise for younger adults on EM and FI (Bherer et al., 2005; Hayes et al., 2015; Hillman et al., 2004; Scisco et al., 2008; Van Boxtel et al., 1997; see for meta-analysis Etnier et al., 2006) but that did find a significant effect in older adults. It is difficult at this stage to give a definitive interpretation of this difference, but one possible explanation is that the brain and cognitive functioning of young adults is nearly optimal (Scisco et al., 2008). It would also be interesting to explore the effect of physical exercise across the lifespan, and not only for the last 12 months period, in order to determine whether the beneficial effect at an advanced age depends on life-long accumulation or can be achieved over a shorter time span. Subjective measures, such as those used in the present study, could be adapted to cover the entire life span and thus could examine the impact of physical exercise practiced over a longer period than one year. Other studies using a similar protocol showed that physical exercise may improve cognitive functions, including EM and FI especially in older adults (Clarkson-Smith & Hartley, 1989; Dregan & Gulliford, 2013; Dustman et al., 1990; Elsayed et al., 1980; for review see Albinet et al., 2008). However, self-report measures can often be biased by the tendency of respondents to overestimate the time spent on physical exercise (Sallis & Saelens, 2000), or by difficulty in recall, especially for older adults (Baranowski, 1988). However, in the present study, we used a simple, overall measure of weekly exercise over a period of one year, thus limiting the risk of this kind of bias.

Finally, a “selective improvement” effect of physical exercise has been reported in some studies, suggesting that the type of physical exercise (aerobic, resistance, balance, or stretching exercises) have selective cognitive effects (Kramer et al., 1999). It would thus be interesting to determine whether the improvement in cognitive abilities such as EM and FI is associated with a specific type or intensity of physical exercise in order to gain a clearer understanding of the effect of physical exercise on cognition during aging. Moreover, it would be interesting to examine the effect of other forms of everyday physical activities (e.g. gardening and walking). In summary, taking a cross-sectional lifespan approach and by controlling statistically for the main cognitive reserve factors (educational level, general knowledge and leisure activities) and gender, the present study confirmed the independent positive effect of physical exercise cognitive functioning, and showed that being physically active could moderate the age-related effects on EM and FI. It thus confirms that physical exercise can be a valuable way of optimizing episodic memory and fluid intelligence capacities, especially for older adults.

Declaration of competing interest

This manuscript has not been submitted to, nor is under review at, another journal or other publishing venue.

The authors have no affiliation with any organization with a direct or indirect financial interest in the subject matter discussed in the manuscript.

Acknowledgements

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

- Aichberger, M. C., Busch, M. A., Reischies, F. M., Ströhle, A., Heinz, A., & Rapp, M. A. (2010). Effect of physical inactivity on cognitive performance after 2.5 years of follow-up: Longitudinal results from the survey of health, ageing, and retirement (SHARE). *Geropsych: The Journal of gerontopsychology and geriatricPsychiatry*, 23(1), 7.
- Albinet, C., Fezzani, K., & Thon, B. (2008). Vieillesse, activité physique et cognition. *Movement Sport Sciences*, 1, 9–36.
- André, N., Ferrand, C., Albinet, C., & Audiffren, M. (2018). Cognitive strategies and physical activity in older adults: A discriminant analysis. *Journal of Aging Research*, 2018.
- Angel, L., & Isingrini, M. (2015). Le vieillissement neurocognitif : Entre pertes et compensation. *L'Année psychologique*, 115(2), 289–324.
- Angel, L., Fay, S., Bouazzaoui, B., & Isingrini, M. (2010). Individual differences in executive functioning modulate age effects on the ERP correlates of retrieval success. *Neuropsychologia*, 48(12), 3540–3553.
- Angevaeren, M., Aufdemkampe, G., Verhaar, H. J. J., Aleman, A., & Vanhees, L. (2008). Physical activity and enhanced fitness to improve cognitive function in older people without known cognitive impairment. *Cochrane database of systematic reviews*, 2.
- Ardiale, E., & Lemaire, P. (2012). Within-item strategy switching: An age comparative study in adults. *Psychology and Aging*, 27(4), 1138.
- Audiffren, M., André, N., & Albinet, C. (2011). Effets positifs de l'exercice physique chronique Sur les fonctions cognitives des seniors: Bilan et perspectives. *Revue de Neuropsychologie*, 3(4), 207–225.
- Baranowski, T. (1988). Validity and reliability of self report measures of physical activity: An information-processing perspective. *Research Quarterly for Exercise and Sport*, 59(4), 314–327.
- Barbey, A. K., Colom, R., Solomon, J., Krueger, F., Forbes, C., & Grafman, J. (2012). An integrative architecture for general intelligence and executive function revealed by lesion mapping. *Brain*, 135(4), 1154–1164.
- Bherer, L., Kramer, A. F., Peterson, M. S., Colcombe, S., Erickson, K., & Becic, E. (2005). Training effects on dual-task performance: Are there age-related differences in plasticity of attentional control? *Psychology and Aging*, 20(4), 695.
- Cattell, R. B. (1963). Theory of fluid and crystallized intelligence: A critical experiment. *Journal of Educational Psychology*, 54, 1–22.
- Chodzko-Zajko, W. J., Proctor, D. N., Singh, M. A. F., Minson, C. T., Nigg, C. R., Salem, G. J., & Skinner, J. S. (2009). Exercise and physical activity for older adults. *Medicine & Science in Sports & Exercise*, 41(7), 1510–1530.
- Christensen, H., Henderson, A. S., Griffiths, K., & Levings, C. (1997). Does ageing inevitably lead to declines in cognitive performance? A longitudinal study of elite academics. *Personality and Individual Differences*, 23(1), 67–78.
- Clarkson-Smith, L., & Hartley, A. A. (1989). Relationships between physical exercise and cognitive abilities in older adults. *Psychology and Aging*, 4(2), 183.
- Colcombe, S., & Kramer, A. F. (2003). Fitness effects on the cognitive function of older adults: A meta-analytic study. *Psychological Science*, 14(2), 125–130.
- Conway, A. R., Cowan, N., Bunting, M. F., Theriault, D. J., & Minkoff, S. R. (2002). A latent variable analysis of working memory capacity, short-term memory capacity, processing speed, and general fluid intelligence. *Intelligence*, 30(2), 163–183.
- Cox, E. P., O'Dwyer, N., Cook, R., Vetter, M., Cheng, H. L., Rooney, K., & O'Connor, H. (2016). Relationship between physical activity and cognitive function in apparently healthy young to middle-aged adults: A systematic review. *Journal of Science and Medicine in Sport*, 19(8), 616–628.
- Craick, F. I., & Jennings, J. M. (1992). Human memory. In F. I. M. Craik, & T. A. Salthouse (Eds.), *The handbook of aging and cognition* (pp. 51–110). Hillsdale, NJ: Erlbaum.
- De Frias, C. M., Dixon, R. A., & Strauss, E. (2006). Structure of four executive functioning tests in healthy older adults. *Neuropsychology*, 20(2), 206.
- Deltour, J. J. (1993). Echelle de vocabulaire Mill Hill. In J. C. de (Ed.), *Adaptation française et normes comparées du Mill Hill et du Standard Progressive Matrices (PM38). Manuel et Annexes. Braine le Château, Belgique : Application des Techniques Modernes*. Raven.
- Dregan, A., & Gulliford, M. C. (2013). Leisure-time physical activity over the life course and cognitive functioning in late mid-adult years: A cohort-based investigation. *Psychological Medicine*, 43(11), 2447.
- Dustman, R. E., Emmerson, R. Y., Ruhling, R. O., Shearer, D. E., Steinhaus, L. A., Johnson, S. C., Shigeoka, J. W., ... (1990). Age and fitness effects on EEG, ERPs, visual sensitivity, and cognition. *Neurobiology of Aging*, 11(3), 193–200.
- Elsayed, M., Ismail, A. H., & Young, R. J. (1980). Intellectual differences of adult men related to age and physical fitness before and after an exercise program. *Journal of Gerontology*, 35(3), 383–387.
- Erickson, K. I., & Kramer, A. F. (2009). Aerobic exercise effects on cognitive and neural plasticity in older adults. *British Journal of Sports Medicine*, 43(1), 22–24.
- Etnier, J. L., Nowell, P. M., Landers, D. M., & Sibley, B. A. (2006). A meta-regression to examine the relationship between aerobic fitness and cognitive performance. *Brain Research Reviews*, 52(1), 119–130.
- Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-mental state": A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research*, 12(3), 189–198.
- Ghetti, S., & Bunge, S. A. (2012). Neural changes underlying the development of episodic memory during middle childhood. *Developmental Cognitive Neuroscience*, 2(4), 381–395.
- Gombart, S., Fay, S., & Isingrini, M. (2018). Connaissances et contrôle exécutif: Deux facteurs de protection du vieillissement cognitif? *L'Année Psychologique*, 118(1), 59–92.
- Gur, R. C., Mozley, P. D., Resnick, S. M., Gottlieb, G. L., Kohn, M., Zimmerman, R., Berretta, D., ... (1991). Gender differences in age effect on brain atrophy measured by magnetic resonance imaging. *Proceedings of the National Academy of Sciences*, 88(7), 2845–2849.
- Gyorkos, A. M., McCullough, M. J., & Spitsbergen, J. M. (2014). Glial cell line-derived neurotrophic factor (GDNF) expression and NMJ plasticity in skeletal muscle following endurance exercise. *Neuroscience*, 257, 111–118.
- Hamer, M., Lavoie, K. L., & Bacon, S. L. (2014). Taking up physical activity in later life and healthy ageing: The English longitudinal study of ageing. *British journal of sports medicine*, 48(3), 239–243.
- Hatch, S. L., Jones, P. B., Kuh, D., Hardy, R., Wadsworth, M. E., & Richards, M. (2007). Childhood cognitive ability and adult mental health in the British 1946 birth cohort. *Social Science & Medicine*, 64(11), 2285–2296.
- Hayes, S. M., Allosco, M. L., Hayes, J. P., Cadden, M., Peterson, K. M., Allsup, K., Verfaellie, M., ... (2015). Physical activity is positively associated with episodic memory in aging. *Journal of the International Neuropsychological Society*, 21(10), 780.
- Hillman, C. H., Belopolsky, A. V., Snook, E. M., Kramer, A. F., & McAuley, E. (2004). Physical activity and executive control: Implications for increased cognitive health during older adulthood. *Research Quarterly for Exercise and Sport*, 75(2), 176–185.
- Horn, J. L., & Cattell, R. B. (1966). Refinement and test of the theory of fluid and crystallized general intelligences. *Journal of Educational Psychology*, 57(5), 253.
- Isingrini, M., & Taconnat, L. (2008). Mémoire épisodique, fonctionnement frontal et vieillissement. *Revue Neurologique*, 164, S91–S95.
- Isingrini, M., & Vazou, F. (1997). Relation between fluid intelligence and frontal lobe functioning in older adults. *The International Journal of Aging and Human Development*, 45(2), 99–109.
- Jeanin, A., & Pennequin, V. (2006). Explication du déclin du raisonnement inductif par le déficit exécutif lié à l'âge. *L'Année Psychologique*, 106(2), 213–233.
- Jones, A. M., Grassi, B., Christensen, P. M., Krustup, P., Bangsbo, J., & Poole, D. C. (2011). Slow component of VO2 kinetics: Mechanistic bases and practical applications. *Medicine and Science in Sports and Exercise*, 43(11), 2046–2062.
- Kramer, A. F., Hahn, S., Cohen, N. J., Banich, M. T., McAuley, E., Harrison, C. R., Colcombe, A., ... (1999). Ageing, fitness and neurocognitive function. *Nature*, 400(6743), 418–419.
- Kyllonen, P. C., & Christal, R. E. (1990). Reasoning ability is (little more than) working-memory capacity?! *Intelligence*, 14(4), 389–433.
- Labban, J. D., & Etnier, J. L. (2011). Effects of acute exercise on long-term memory. *Research Quarterly for Exercise and Sport*, 82(4), 712–721.
- Lindenberger, U., & Baltes, P. B. (1997). Intellectual functioning in old and very old age: Cross-sectional results from the Berlin aging study. *Psychology and Aging*, 12(3), 410.
- Loprinzi, P. D., & Kane, C. J. (2015). Exercise and cognitive function: A randomized controlled trial examining acute exercise and free-living physical activity and sedentary effects. *Mayo Clinic Proceedings*, 90(4), 450–460.
- Meinz, E. J., & Salthouse, T. A. (1998). Is age kinder to females than to males? *Psychonomic Bulletin & Review*, 5(1), 56–70.
- Musch, S., Wang, S. S., Hawkins, K., & Greame, C. (2017). The frequency and health benefits of physical activity for older adults. *Population Health Management*, 20(3), 199–207.
- Nanda, B., Balde, J., & Manjunatha, S. (2013). The acute effects of a single bout of moderate-intensity aerobic exercise on cognitive functions in healthy adult males. *Journal of Clinical and Diagnostic Research: JCDR*, 7(9), 1883.
- Newson, R. S., & Kemp, E. B. (2006). The nature of subjective cognitive complaints of older adults. *The International Journal of Aging and Human Development*, 63(2), 139–151.
- Nilsson, J., & Lövdén, M. (2018). Naming is not explaining: Future directions for the "cognitive reserve" and "brain maintenance" theories. *Alzheimer's Research & Therapy*, 10(1), 1–7.
- Old, S. R., & Naveh-Benjamin, M. (2008). Differential effects of age on item and associative measures of memory: a meta-analysis. *Psychology and aging*, 23(1), 104.
- Park, D. C., & Reuter-Lorenz, P. (2009). The adaptive brain: Aging and neurocognitive scaffolding. *Annual Review of Psychology*, 60, 173–196.
- Peig-Chiello, P., Perrig, W. J., Ehrsam, R., Staehelin, H. B., & Krings, F. (1998). The effects of resistance training on well-being and memory in elderly volunteers. *Age and Ageing*, 27(4), 469–475.
- Perrot, A., Gagnon, C., & Bertsch, J. (2009). Physical activity as a moderator of the relationship between aging and inductive reasoning. *Research Quarterly for Exercise and Sport*, 80(2), 393–397.
- Raven, J. C. (1983). Manual for Raven's progressive matrices and vocabulary scales. In *Standard progressive matrices*.
- Reuter-Lorenz, P. A., & Park, D. C. (2014). How does it STAC up? Revisiting the scaffolding theory of aging and cognition. *Neuropsychology Review*, 24(3), 355–370.
- Revilla, S., Suñol, C., García-Mesa, Y., Giménez-Llort, L., Sanfeliu, C., & Cristófol, R. (2014). Physical exercise improves synaptic dysfunction and recovers the loss of survival factors in 3xTg-AD mouse brain. *Neuropharmacology*, 81, 55–63.
- Richards, M., & Deary, I. J. (2005). A life course approach to cognitive reserve: A model for cognitive aging and development? *Annals of Neurology: Official Journal of the American Neurological Association and the Child Neurology Society*, 58(4), 617–622.
- Rouillard, M., Audiffren, M., Albinet, C., Ali Bahri, M., Garraux, G., & Collette, F. (2017). Contribution of four lifelong factors of cognitive reserve on late cognition in normal aging and Parkinson's disease. *Journal of Clinical and Experimental Neuropsychology*, 39(2), 142–162.
- Sallis, J. F., & Saelens, B. E. (2000). Assessment of physical activity by self-report: Status, limitations, and future directions. *Research Quarterly for Exercise and Sport*, 71(sup2), 1–14.
- Salthouse, T. A. (1991). Mediation of adult age differences in cognition by reductions in working memory and speed of processing. *Psychological Science*, 2(3), 179–183.
- Salthouse, T. A., & Salthouse, T. A. (1992). Reasoning and spatial abilities. In F. I. M. Craik (Ed.), *Handbook of aging and cognition* (pp. 167–211).

- Salthouse, T. A. (1993). Influence of working memory on adult age differences in matrix reasoning. *British Journal of Psychology*, 84, 171–199.
- Salthouse, T. A. (2006). Mental exercise and mental aging: Evaluating the validity of the “use it or lose it” hypothesis. *Perspectives on Psychological Science*, 1(1), 68–87.
- Salthouse, T. A. (2009). When does age-related cognitive decline begin? *Neurobiology of Aging*, 30(4), 507–514.
- Salthouse, T. A., Kausler, D. H., & Saults, J. S. (1990). Age, self-assessed health status, and cognition. *Journal of Gerontology*, 45(4), P156–P160.
- Scarmeas, N., & Stern, Y. (2003). Cognitive reserve and lifestyle. *Journal of Clinical and Experimental Neuropsychology*, 25(5), 625–633.
- Scisco, J. L., Leynes, P. A., & Kang, J. (2008). Cardiovascular fitness and executive control during task-switching: An ERP study. *International Journal of Psychophysiology*, 69(1), 52–60.
- Soggard, I., & Ni, R. (2018). Mediating age-related cognitive decline through lifestyle activities: A brief review of the effects of physical exercise and sports-playing on older adult cognition. *Acta Psychopathol*, 4(5), 22.
- Stern, Y. (2002). What is cognitive reserve? Theory and research application of the reserve concept. *Journal of the International Neuropsychological Society*, 8(3), 448–460.
- Stern, Y. (2009). Cognitive reserve. *Neuropsychologia*, 47(10), 2015–2028.
- Stones, M. J., & Kozma, A. (1988). Physical activity, age, and cognitive/motor performance. *Cognitive Development in Adulthood*, 273–321.
- Tucker-Drob, E. M., Johnson, K. E., & Jones, R. N. (2009). The cognitive reserve hypothesis: A longitudinal examination of age-associated declines in reasoning and processing speed. *Developmental Psychology*, 45(2), 431.
- Tulving, E. (1972). Episodic and semantic memory. *Organization of memory*, 1, 381–403.
- Van Boxtel, M. P., Paas, F. G., Houx, P. J., Adam, J. J., Teeken, J. C., & Jolles, J. (1997). Aerobic capacity and cognitive performance in a cross-sectional aging study. In *Medicine & Science in Sports & Exercise*.
- Van De Rest, O., van der Zwaluw, Tieland, M., Adam, J. J., Hiddink, G. J., ... de Groot. (2014). Effect of resistance-type exercise training with or without protein supplementation on cognitive functioning in frail and pre-frail elderly: secondary analysis of a randomized, double-blind, placebo-controlled trial. *Mechanisms of ageing and development*, 136, 85–93.
- Verhaeghen, P., & Salthouse, T. A. (1997). Meta-analyses of age-cognition relations in adulthood: Estimates of linear and nonlinear age effects and structural models. *Psychological Bulletin*, 122(3), 231.
- Vianney, J. M., McCullough, M. J., Gyorkos, A. M., & Spitsbergen, J. M. (2013). Exercise-dependent regulation of glial cell line-derived neurotrophic factor (GDNF) expression in skeletal muscle and its importance for the neuromuscular system. *Frontiers in Biology*, 8(1), 101–108.
- Voelcker-Rehage, C., & Niemann, C. (2013). Structural and functional brain changes related to different types of physical activity across the life span. *Neuroscience & Biobehavioral Reviews*, 37(9), 2268–2295.
- Herting, M. M., & Keenan, M. F. (2017). Exercise and the developing brain in children and adolescents. In R. R. Watson (Ed.), *1. Physical activity and the aging brain: Effects of exercise on neurological function* (pp. 13–19).
- Wang, H. X., Xu, W., & Pei, J. J. (2012). Leisure activities, cognition and dementia. *Biochimica et Biophysica Acta (BBA)-Molecular Basis of Disease*, 1822(3), 482–491.
- Wechsler, D. (1997). *WAIS-III Administration and scoring manual*. San Antonio, TX: The Psychological Association.
- West, R. L. (1996). An application of prefrontal cortex function theory to cognitive aging. *Psychological Bulletin*, 120(2), 272.
- Whipp, B. J., Ward, S. A., & Rossiter, H. B. (2005). Pulmonary O₂ uptake during exercise: Conflating muscular and cardiovascular responses. *Medicine & Science in Sports & Exercise*, 37(9), 1574–1585.
- Zelinski, E. M., Gilewski, M. J., & Schaie, K. W. (1993). Individual differences in cross-sectional and 3-year longitudinal memory performance across the adult life span. *Psychology and aging*, 8(2), 176–186. <https://doi.org/10.1037/0882-7974.8.2.176>