Intrinsic motivation magnifies the effects of physical activity on cognitive health

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Abstract

Objective. Among its health benefits, physical activity improves cognitive health, but the strength of this association remains heterogeneous across studies. While previous research focused on structural factors of physical activity as potential moderating factors (e.g., duration, type), we aimed to examine whether the type of motivation (i.e., intrinsic versus extrinsic forms of motivation) could moderate the strength of the association between physical activity and cognitive health.

Methods. Participants were 512 Canadian students (72% female and a mean age = 20 ± 5 years). Seven days after assessing their intrinsic and more extrinsic motivations toward physical activity, moderate-to-vigorous physical activity and perceived cognitive health were measured by questionnaire. Linear regression models were used to examine the moderating effect of motivation on the association between physical activity and cognitive health.

Results. Intrinsic motivation moderated the association between moderate-to-vigorous physical activity and self-reported cognitive health (β = .12, 95CI = .04; .20, p = .004). As hypothesized, simple slope analyses showed that the association between moderate-to-vigorous physical and cognitive health was positive when intrinsic motivation was high (at sample mean + 1SD, β = .14, 95CI = .03; .25, p = .013), but not significant when intrinsic motivation was low (at sample mean - 1SD, β = -.09, 95CI = -.24; .06, p = .220). However, the moderating effect of extrinsic forms motivation was not significant (*ps*. > .071).

Conclusion. In addition to structural aspects of physical activity, it is important to consider motivation toward physical activity when examining its effect on cognitive health.

Keywords: cognition, exercise, motivation, health, moderation.

Intrinsic motivation magnifies the effects of physical activity on cognitive health

Engaging in regular physical activity has a myriad of health benefits (e.g., Warburton, 2006) and among its important benefits are those for cognitive health (Dupuy et al., 2024; Singh et al., 2025) – here defined in reference to optimal cognitive abilities (Zou et al., 2024). Engaging in this health behavior predicts a lower risk of dementia (Iso-Markku et al., 2022), as well as it favors the maintenance of cognitive function across aging (Cheval et al., 2021; Hamer et al., 2018). For example, a Mendelian Randomization (MR) study has recently supported the beneficial causal role of physical activity on cognitive function (Cheval et al., 2023).

Although previous research has collectively demonstrated the potential importance of physical activity as a modifiable lifestyle factor for cognitive health, it should also be noted that the strength of the effects varies considerably between studies (Singh et al., 2025). Such heterogeneous findings have encouraged researchers to better identify when physical activity provides the greatest cognitive benefits. By focusing on the structural aspects of physical activity, including its frequency, intensity, type, and duration, several candidate moderating variables have been identified. For example, a meta-analysis found that coordinative exercise was among the most promising types of physical activity for improving cognitive health (e.g., Ludyga et al., 2020). Although this focus on structural factors provides useful information for physical activity recommendations, it neglects more experiential considerations, such as the reasons that drive a person to engage in physical activity, and that may yet play a pivotal role in explaining the association between physical activity and cognitive health. The present study focuses on an overlooked potential moderating factor: peoples' intrinsic motivation toward physical activity.

The self-determination theory (SDT) distinguishes between behaviors that are done for intrinsic and for more extrinsic motives (Ryan & Deci, 2017). Behaviors that are done because they are inherently pleasurable and satisfying in themselves reflect intrinsic forms of motivation. In contrast, extrinsic forms of motivation reflect behaviors that are pursued the consequences to which it leads and not for what it provides in itself. Extrinsic motivation encompasses more or less self-determined motives, ranging from integrated motivation (because they reflect one's core values), identified motivation (because they are personally important), introjected motivation (because of internal pressures, such as guilt or shame), and external motivation (because of external pressures, including external rewards or punishments). There is a wealth of evidence that a high intrinsic motivation is associated with a higher long-term engagement in physical activity (Teixeira et al., 2012), and promotes the development of physical activity habits (Maltagliati et al., 2021, 2023).

In addition to promoting engagement in physical activity, emerging evidence suggests that intrinsic motivation may also reinforce the health benefits of this behavior. For example, in the mental health domain, individuals who reported positive affective responses while exercising – responses frequently associated with intrinsic motivation – had more positive outcomes afterward, such as higher self-esteem or well-being (Furzer et al., 2021; White et al., 2018). A recent consensus statement emphasized that "*to optimize the mental health benefits of physical activity, activity selection should be guided by factors associated with adherence and enjoyment as opposed to any specific type*" (Vella et al., 2023). Following the same line of reasoning, intrinsic motivation could also moderate the association between physical activity and cognitive health. As stated by Diamond et al., (2016, *p*. 38), "*there's evidence that any benefit of physical activity for cognition may be proportional to how much joy the physical activity brings*".

Although speculative, several mechanisms could support the potential moderating effect of intrinsic motivation on the dose-response between physical activity and cognitive health. For example, at the neurophysiological level, the beneficial effects of physical activity on brain health are expected to rely on neurotransmitter signaling, including endogenous opiods (e.g., endorphins) or endocannabinoid (eCB) signaling, among other pathways (Hill et al., 2010). For example, the secretion of anandamide – one of the most studied eCBs – is correlated with the affective responses during moderate-intensity exercise (Raichlen et al., 2012). As such and although associations are likely bidirectional, a high intrinsic motivation could stimulate the secretion of endocannabinoid, which would in turn reinforce the cognitive benefits of physical activity. Animal models suggest that eCBs are a key mechanism in the links between exercise, spatial memory, and hippocampal neurogenesis, suggesting overlapping pathways between (intrinsic) rewards and cognition in response to physical activity (Ferreira-Vieira et al., 2014). Similarly, a review suggested that exercise-induced dopamine release – which is dependent on the pleasure experienced during exercise – may be involved in the acute PA-cognition link (Hou et al., 2024). Dopamine also appears to be a key regulator of the short-term improvement in cognitive functions following acute physical exercise, as shown by a study using PET imaging, which demonstrated that the improvement in reaction times during a Go-NoGo task was correlated with dopamine release during exercise (Ando et al., 2024). At the behavioral level, intrinsic motivation has been shown to robustly predict how much effort individuals are willing to invest in learning new skills, their readiness to cooperate and take up new challenges, or to find creative solutions when facing complex problems (Ryan & Deci, 2017). Holding a strong intrinsic motivation could thus promote the engagement in more cognitively demanding and physical activities. Yet, these so-called mindful types of physical activity are ultimately expected to generate higher cognitive benefits (Diamond & Ling, 2016; but see also Hillman et al., 2019). However, despite both theoretical and indirect empirical data consistent with a role of intrinsic motivation in enhancing the cognitive benefits of physical activity, to the best of our knowledge, the moderating effect of intrinsic motivation on the association between physical activity and cognitive health has never been directly tested.

The present research

The aim of the current study was to examine whether intrinsic motivation moderates the association between physical activity and self-reported cognitive health. We expected that the association between physical activity and self-reported cognitive health would be stronger for a high (vs. low) intrinsic motivation. Additionally, to better highlight the specific mechanistic contribution of intrinsic motivation, we explored whether other types of motivation (i.e., integrated, identified, introjected and external) significantly moderated the association between physical activity and cognitive health.

Methods

Procedure and participants

Participants were undergraduate students recruited from the research participation pool at a Canadian university in exchange for partial course credits. Participants all reported sufficient English language proficiency. All participants followed the procedure online and were asked to complete the study on a computer in a quiet environment. They first completed an initial ~15-minute questionnaire assessing, among other variables, their type of motivation toward physical activity. Seven days later, they were invited to complete a second questionnaire, in which they self-reported their physical activity levels over the past week, and rated their cognitive health. This seven-day period was selected in relation to evidence showing that cognitive performance can be influenced by physical activity levels, even on narrow timeframe (Hakun et al., 2025). The study was approved by the Research Ethics Board of the University of [blind for review].

In total, 522 English-speaking participants provided complete answers on the variables of interest at both time points. Ten participants who reported implausible levels of physical activity (i.e., > 25 hours of moderate-to-vigorous physical activity per week) were excluded. Thus, 512 participants were included in the present analyses, with 72% of participants identifying themselves as female and a mean age = 20 ± 5 years (Table 1).

Measures

Type of motivation: At the first timepoint, intrinsic motivation and other types of motivation toward physical activity were assessed using two items (Sheldon & Elliot, 1998). Participants were asked to rate the extent to which statements reflected their motivation to engage in moderate-to-vigorous physical activity during leisure time. Answers were given on a Likert scale ranging from 1 (Not true for me) to 5 (Very true for me). For intrinsic motivation, two items were used: 'I participate in physical activity because it's fun' and 'I find physical activity a pleasurable activity'. Scores on the two items were averaged to compute a score of intrinsic motivation (α = .90). For more extrinsic motivation, two items covered four forms of regulation: integrated motivation (e.g., 'I consider physical activity a fundamental part of who I am'), identified motivation (e.g. 'I value the benefits of participating in physical activity'), introjected motivation (e.g., 'I feel ashamed when I miss a physical activity session') and external motivation (e.g., 'I participate in physical activity because other people say I should'). For each type of extrinsic motivation, scores were averaged to create a score of integrated (α = .78), identified (α = .81), introjected (α = .83), and external motivation (α = .78).

Level of physical activity: Seven days after completing the first questionnaire, participants' level of physical activity was measured using a modified version of the International Physical Activity Questionnaire (Craig et al., 2003). Participants were asked to report the amount of time (in hours and minutes) they spent in moderate physical activity, vigorous physical activity, walking and sitting during their leisure time over the past seven days. Unlike the original tool in which both weekly frequency of physical activity and time spent practicing physical activity are reported, participants were here however not asked to report the number of days spent per week in each of these activity categories. This version of the questionnaire has been used in previous studies (Cheval, Sivaramakrishnan, et al., 2020). Time spent in moderate-to-vigorous physical activity was considered as the main variable of interest.

Current self-reported cognitive health: Seven days after completing the first questionnaire, participants rated their cognitive health over the last seven days using six items from the Patient-Reported Outcomes Measurement Information System (PROMIS) (Lai et al., 2014). The six items covered different aspects of cognitive functioning : 'My memory has been as good as usual'; 'I have been able to concentrate'; 'My thinking has been as fast as usual'; 'I have been able to keep track of what I am doing, even if I am interrupted'; 'I have been able to think clearly without extra effort'. Participants answered on a Likert scale ranging from 1 (Not at all) to 5 (Very much). Other studies showed that this scale was associated with other measures of cognitive performance and cognitive decline among older adults (Howland et al., 2017). In the present study, internal consistency was good, with Cronbach's α = .91.

Statistical analyses

Main analyses

To examine the potential moderating effect of intrinsic motivation toward physical activity on the association between physical activity and cognitive health, a first linear regression model was performed. This model included an interactive term between moderate-to-vigorous physical activity and intrinsic motivation. If the interaction term was significant, simple slope analyses were then performed to decompose the interaction. To estimate the threshold of intrinsic motivation above which the association between moderate-to-vigorous physical activity and cognitive health becomes significant, we performed region of significance analyses using the Johnson-Neyman method (Bauer & Curran, 2005). A second set of models were computed using each type of motivation as moderating variable. Statistical assumptions associated with linear regressions (i.e., normality of the residuals, linearity, multicollinearity, and undue influence) were checked for all the models.

Secondary analyses

In a first set of additional analyses, the same models were further adjusted for participants' gender and age. Because of the small number of participants who did not identify as "Female" of "Male" (n = 10), only participants who identified themselves as "Female" or "Male" were included in the analyses, resulting in a sample of 502 participants. In a second model, only participants who reported 30 minutes of moderate-to-vigorous physical activity were included (N = 416), as the interactive effects of intrinsic motivation on the association between physical activity and cognitive health may only emerge above a minimal level of physical activity. In a third set of additional analyses, the same models were re-run with moderate and vigorous physical activity being distinctly specified as independent variables. Finally, to account for the non-normal distribution of physical activity and intrinsic motivation, we evaluated a series of power-law transformations using the Box-Cox method to approximate a normal distribution (Box & Cox, 1964; Osborne, 2010). The transformed variables were used in a final set model of models.

All analyses were performed using the R software (version 4.4). Scripts and data are available at the following link: https://zenodo.org/records/15088567

Results

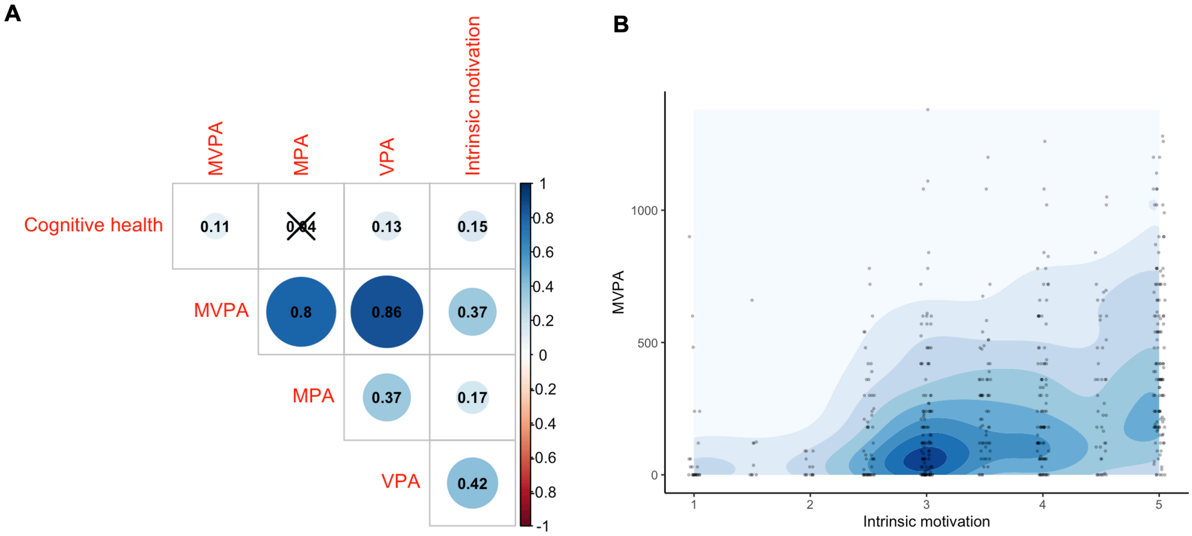
Descriptive statistics are reported in Table 1. Participants reported a mean of 295 ± 298 minutes of moderate-to-vigorous physical activity per week. The mean score for intrinsic motivation was of 3.6 ± 1.1 on the Likert scale ranging from 1 to 5. Their self-reported cognitive health was of 3.6 ± 0.9 on the Likert scale ranging from 1 to 5. Bivariate correlations are shown in Figure 1. Notably, we observed significant small-to-medium-sized correlations between moderate-to-vigorous physical activity and cognitive health (r = 0.11), intrinsic motivation and cognitive health (r = 0.15); intrinsic motivation and moderate-to-vigorous physical activity (r = 0.37). Moreover, the correlation between vigorous physical activity and cognitive health was significant (r = 0.13), but not between moderate physical activity and cognitive health (r = 0.04).

Table 1. Demographic information and descriptive statistics.

	Mean (SD)	Range
Demographic information		
Sex (N, % of women)		
Female	352 (69%)	–
Male	150 (29%)	–
Prefer not to disclose	2 (< 1%)	–
These options do not apply	8 (2%)	–
Age	20 (5)	18; 52
Faculty or school		
Social Sciences	107 (21%)	–
Health Sciences	144 (28%)	–
School of Management	66 (13%)	–
Sciences	104 (20%)	–
Arts	75(14%)	–
Engineering	16 (3%)	–
Law	2 (<1%)	–
Descriptive statistics		
Self-reported cognitive health	3.4 (0.9)	1; 5
Intrinsic motivation	3.6 (1.1)	1; 5
Moderate-to-vigorous PA (in min)	294 (292)	0; 1380
Moderate PA (in min)	142 (162)	0; 1200
Vigorous PA (in min)	153 (191)	0; 900

Notes. SD: standard-deviation; PA: physical activity.

Figure 1. Bivariate correlation table (A) and two-dimensional density plot for intrinsic motivation and physical activity) (B).



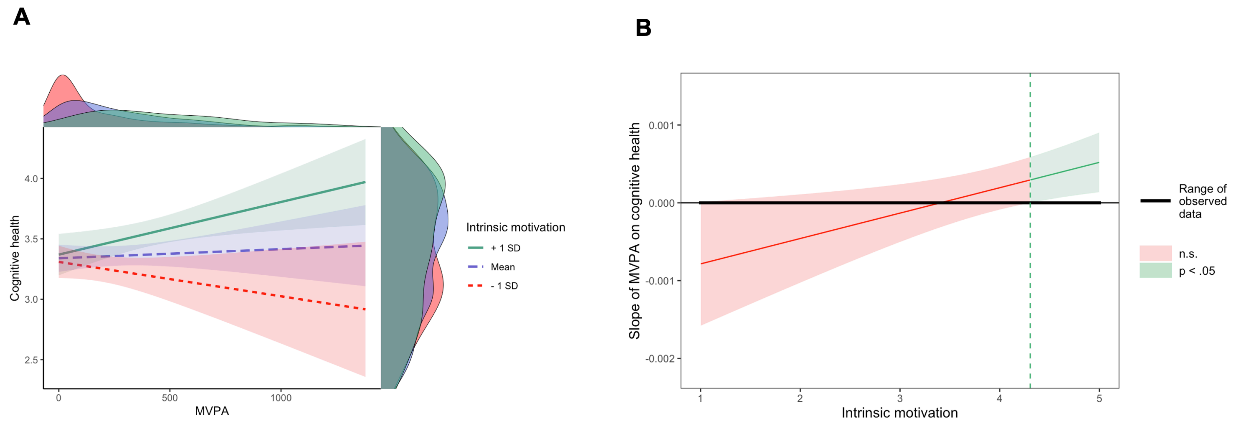
Note. MVPA: moderate-to-vigorous physical activity, MPA: moderate physical activity; VPA: vigorous physical activity. For Figure A, all correlations are significant, with $p < .05$, with the exception of cells that are marked by a cross ($p > .05$). For Figure B, in the two-dimensional density, different density ranges of the data are displayed, with darker color corresponding to a greater density of observations in the data.

Main analyses

In the first linear regression model, the interaction term between intrinsic motivation and moderate-to-vigorous physical activity was significant, suggesting that intrinsic motivation moderated the association between physical activity and self-reported cognitive health (β = .12, 95CI = .03; .21, *p* = .011). As hypothesized, simple slope analyses showed that the association between moderate-to-vigorous physical activity and cognitive health was significant and positive when intrinsic motivation was high (i.e., at sample mean + 1SD, corresponding to 4.7 on the five-point Likert scale, β = .14, 95CI = .03; .25, *p* = .013), but non-significant when intrinsic motivation was moderate (i.e., at the sample mean, corresponding to 3.6 on the five-point Likert scale, β = .03, 95CI = -.07; .12, *p* = .612) or low (i.e., at sample mean - 1SD, corresponding to 2.5 on the five-point Likert scale, β = -.09, 95CI = -.24; .06, *p* = .220) (Figure 3A). Johnson-Neyman analyses further showed that the association between moderate-to-vigorous physical activity and cognitive health was significant when intrinsic motivation was above ~4.3 on the Likert scale ranging from 1 to 5 (i.e., mean scaled sample score + 0.61SD, corresponding to 32% of the sample) and non-significant below this threshold (Figure 3B).

In the second set of linear regression models, the interactive terms between other types of motivation and moderate-to-vigorous physical activity were however not significant suggesting that neither integrated, identified, introjected, nor external motivation did significantly moderate the association between physical activity and self-reported cognitive health (*ps.* > .071).

Figure 3. Simple slopes for the association between moderate-to-vigorous physical activity and intrinsic motivation on self-reported cognitive health (A) and region of significance of the association between moderate-to-vigorous physical activity on self-reported cognitive health, depending on intrinsic motivation (B).



Notes. MVPA: Moderate-to-vigorous physical activity; SD: standard-deviation. Density plots by level of intrinsic motivation are displayed for moderate-to-vigorous physical activity (on top) and cognitive health (on the right). To ease interpretation of the results, raw (i.e., unscaled) variables were used to create the figures.

Additional analyses

In additional models, after further adjustment for age and sex in the first set of additional models, the interactive term between intrinsic motivation and moderate-to-vigorous physical activity on cognitive health remained significant (Table S1). In the second set of models, when including participants who reported at least 30 minutes of physical activity (N = 416), the interactive term between intrinsic motivation and moderate-to-vigorous physical activity on cognitive health was significant, consistent with the main analyses (Table S2). In the third set of additional models, consistent with the main analyses, when moderate physical activity was used as the independent variable, its interactive term with intrinsic motivation was significant on cognitive health (Table S3). However, when vigorous physical activity was used as the independent variable, its interactive term with intrinsic motivation was non-significant (Table S4). Finally, consistent with the main analyses, the interactive term between power-law transformed moderate-to-vigorous physical activity and power-law transformed intrinsic motivation was significant on cognitive health (Table S4).

Discussion

Main findings

This study examines the moderating effect of intrinsic motivation on the association between self-reported physical activity and perceived cognitive health in young adults. It overall supports the idea that the quality of the experience associated with physical activity may be an important moderator to consider when investigating its cognitive benefits.

Comparison with previous studies

A recent line of research has recently suggested that, in addition to promoting long-term engagement in physical activity, intrinsic motivation may indeed also reinforce the benefits of this behavior on health (Furzer et al., 2021; White et al., 2018). For example, in the mental domain, adolescents who engaged in active travel for autonomous reasons reported better affective wellbeing than those who engaged in active travel for more controlled reasons. Consistent with these findings, our study provides the first evidence that intrinsic motivation strengthens the relationship between self-reported physical activity and perceived cognitive health in young adults. Notably, we found that this association became significant only when participants reported a very high intrinsic motivation (i.e., above 4.3 on a Likert scale ranging from 1 to 5). The non-significant moderating effect of other types of extrinsic motivation (i.e., integrated, identified, introjected and external motivation) further reinforces the specific role that intrinsic motivation could play in altering the physical activity-cognition association. While this result even suggests that the improvement of cognitive health through exercising may be dependent on having a high level of intrinsic motivation, this finding should however be interpreted with caution as we cannot show causal relationships using observational data. Our findings are thus consistent with those observed in the mental health domain, and suggest that intrinsic motivation could promote better cognitive health not only by enhancing engagement in healthy behaviors – such as physical activity – but also because, once engaged in these behaviors, intrinsic motivation reinforces the health benefits of these behaviors. Future experimental research is needed to examine these two pathways through which intrinsic motivation could promote better health: how it promotes a sustained engagement in healthy behaviors (i.e., mediating pathway) and how, once engaged in these behaviors, it magnifies their benefits (i.e., moderating pathway) (Maltagliati et al., 2022).

Our findings also complement previous literature that has mostly focused on structural moderators (e.g., type, frequency, duration) of the physical activity-cognition association (Ludyga et al., 2020). Based on our current results and indirect evidence, we postulate that intrinsic motivation may represent an active ingredient underlying the effects of some structural aspects of physical activity on cognitive health. For example, exercising in natural settings has been found to enhance the benefits of physical activity on cognition (Boere et al., 2023). As physical activity in natural environments is also associated with more positive affective states (Kinnafick & Thøgersen-Ntoumani, 2014), it is possible that intrinsic motivation could drive the benefits of nature-based physical activity on cognition. Interestingly , we observed that intrinsic motivation significantly moderated the association between moderate physical activity and cognitive health, but not the association between moderate physical activity and cognitive health vigorous physical activity and cognitive health. Given the conflicting results on the differential effects of moderate and vigorous physical activity on brain (e.g., de Pais et al., 2024), as well as on the affective responses they trigger (Ekkekakis et al., 2005), the use of accelerometer-based measures of physical activity is needed to examine disentangle whether the intensity of physical activity interacts with the motivation underlying these specific forms of movement-based behaviors to predict cognitive health. Overall, further work is needed to provide empirical support for our assumptions and, ultimately, to allow an-depth overview of the associations between structural factors of physical activity, motivation and cognitive health.

Potential underlying mechanisms

The moderating effect of intrinsic motivation on the association between physical activity and cognitive health may be driven by several mechanistic pathways. At the neurophysiological level, engaging in physical activity for intrinsic reasons may for example enhance the biological responses triggered by exercise-induced signaling (e.g., eCB, dopamine) that are known to play a key role in cognitive health (e.g., neurogenesis, synaptic neuroplasticity, regulation of inflammatory processes) (Hill et al., 2010; Hou et al., 2024). Notably, beyond playing this crucial role in central fatigue processes and in effort regulation (McMorris et al., 2018), dopamine may also be involved in driving the relationship between exercise and cognition, as its release during physical activity explains the short-term improvement in cognitive functions observed after exercise cessation (Ando et al, 2024). Additionally, evidence suggests that intrinsically motivated exploratory are phylogenetically ancient tendencies that are subserved by dopaminergic systems (Di Domenico & Ryan, 2017; Knab & Lightfoot, 2010) – providing indirect support to this interplay between intrinsic motivation, dopamine and exercise-induced cognitive improvements. At the behavioral level, the strength of the association of physical activity with cognition may also be enhanced because intrinsic motivation involves engaging in more cognitively demanding types of physical activity. Indeed, cognitive engagement, defined as the level of cognitive effort exerted to master complex (motor) skills, may depend on people's intrinsic motivation toward physical activity (Wulf & Lewthwaite, 2016). It has precisely been shown that cognitively demanding tasks ultimately lead to greater cognitive benefits. Future experimental research is warranted to shed further light on these mechanisms.

Strengths and limitations

Among the strengths of this study are its large sample size, its two-timepoint design, and the consistency of the results across sensitivity analyses. However, the study has at least four limitations. First, we used a self-reported measure of physical activity, which may not accurately assess actual levels of physical activity (Prince et al., 2008), especially when it comes to dissociate moderate from vigorous intensities. Second, our results may be conflated by the reliance on a self-reported measure of perceived cognitive health over a narrow timeframe, which had not been validated among young and non-clinical participants (Lai et al., 2014). Future studies should rely on a formal in-depth assessment of cognitive health that combines questionnaires, standardized tests, and neurophysiological measures. In the same perspective, it could be interesting to examine whether observed associations differ across domains of cognition (e.g., executive functions vs memory). Third, the study design prevents to establish any causal associations between our variables. Notably, should be noted that a good cognitive health may be a prerequisite for engaging in physical activity (Cheval, Orsholits, et al., 2020). Disentangling the potential bidirectional links between cognitive health, physical activity and motivation may be a promising challenge for future experimental research. Fourth, the data were obtained from a cohort of young, healthy, physically active (i.e., they self-reported an average of 295 minutes of moderate-to-vigorous physical activity per week), and well-educated individuals. Therefore, the generalizability of the conclusions to other samples (e.g., older adults) needs to be confirmed.

Conclusion

Our findings support the hypothesis that intrinsic motivation moderates the association between physical activity and cognitive health. Alongside with structural factors of physical activity, this study highlights the need to consider more qualitative, experiential aspects of physical activity when examining its association with cognitive health. Ultimately, these findings may pave the way for future guidance on how to maximize the benefits of physical activity for cognitive health.

References

Ando, S., Fujimoto, T., Sudo, M., Watanuki, S., Hiraoka, K., Takeda, K., Takagi, Y., Kitajima, D., Mochizuki, K., Matsuura, K., Katagiri, Y., Nasir, F. M., Lin, Y., Fujibayashi, M., Costello, J. T., McMorris, T., Ishikawa, Y., Funaki, Y., Furumoto, S., … Tashiro, M. (2024). The neuromodulatory role of dopamine in improved reaction time by acute cardiovascular exercise. *The Journal of Physiology*, *602*(3), 461–484. https://doi.org/10.1113/JP285173

Boere, K., Lloyd, K., Binsted, G., & Krigolson, O. E. (2023). Exercising is good for the brain but exercising outside is potentially better. *Scientific Reports*, *13*(1), 1140. https://doi.org/10.1038/s41598-022-26093-2

Cheval, B., Csajbók, Z., Formánek, T., Sieber, S., Boisgontier, M. P., Cullati, S., & Cermakova, P. (2021). Association between physical-activity trajectories and cognitive decline in adults 50 years of age or older. *Epidemiology and Psychiatric Sciences*, *30*, e79. https://doi.org/10.1017/S2045796021000688

Cheval, B., Darrous, L., Choi, K. W., Klimentidis, Y. C., Raichlen, D. A., Alexander, G. E., Cullati, S., Kutalik, Z., & Boisgontier, M. P. (2023). Genetic insights into the causal relationship between physical activity and cognitive functioning. *Scientific Reports*, *13*(1), 5310. https://doi.org/10.1038/s41598-023-32150-1

Cheval, B., Orsholits, D., Sieber, S., Courvoisier, D., Cullati, S., & Boisgontier, M. P. (2020). Relationship between decline in cognitive resources and physical activity. *Health Psychology*, *39*(6), 519–528. https://doi.org/10.1037/hea0000857

Cheval, B., Sivaramakrishnan, H., Maltagliati, S., Fessler, L., Forestier, C., Sarrazin, P., Orsholits, D., Chalabaev, A., Sander, D., Ntoumanis, N., & Boisgontier, M. P. (2020). Relationships between changes in self-reported physical activity, sedentary behaviour and health during the coronavirus (COVID-19) pandemic in France and Switzerland. *Journal of Sports Sciences*, 1–6. https://doi.org/10.1080/02640414.2020.1841396

Craig, C. L., Marshall, A. L., Sjöström, M., Bauman, A. E., Booth, M. L., Ainsworth, B. E., Pratt, M., Ekelund, U. L. F., Yngve, A., & Sallis, J. F. (2003). International physical activity questionnaire: 12-country reliability and validity. *Medicine & Science in Sports & Exercise*, *35*(8), 1381–1395.

de Pais, I. M. N. M., Rabelo, W. L., Ferreira, N. V., Ferri, C. P., Suemoto, C. K., & Gomes Gonçalves, N. (2024). Association of Moderate and Vigorous Physical Activity With Cognitive Performance. *Alzheimer Disease & Associated Disorders*, *38*(3), 249–256. https://doi.org/10.1097/WAD.0000000000000637

Di Domenico, S. I., & Ryan, R. M. (2017). The Emerging Neuroscience of Intrinsic Motivation: A New Frontier in Self-Determination Research. *Frontiers in Human Neuroscience*, *11*. https://doi.org/10.3389/fnhum.2017.00145

Diamond, A., & Ling, D. S. (2016). Conclusions about interventions, programs, and approaches for improving executive functions that appear justified and those that, despite much hype, do not. *Developmental Cognitive Neuroscience*, *18*, 34–48. https://doi.org/10.1016/j.dcn.2015.11.005

Dupuy, O., Ludyga, S., Ortega, F. B., Hillman, C. H., Erickson, K. I., Herold, F., Kamijo, K., Wang, C.-H., Morris, T. P., Brown, B., Esteban-Cornejo, I., Solis-Urra, P., Bosquet, L., Gerber, M., Mekari, S., Berryman, N., Bherer, L., Rattray, B., Liu-Ambrose, T., … Cheval, B. (2024). Do not underestimate the cognitive benefits of exercise. *Nature Human Behaviour*, *8*(8), 1460–1463. https://doi.org/10.1038/s41562-024-01949-x

Ekkekakis, P., Hall, E. E., & Petruzzello, S. J. (2005). Some like It Vigorous: Measuring Individual Differences in the Preference for and Tolerance of Exercise Intensity. *Journal of Sport and Exercise Psychology*, *27*(3), 350–374. https://doi.org/10.1123/jsep.27.3.350

Ferreira-Vieira, T. H., Bastos, C. P., Pereira, G. S., Moreira, F. A., & Massensini, A. R. (2014). A role for the endocannabinoid system in exercise-induced spatial memory enhancement in mice. *Hippocampus*, *24*(1), 79–88. https://doi.org/10.1002/hipo.22206

Furzer, B., Rebar, A., Dimmock, J. A., More, A., Thornton, A. L., Wright, K., Colthart, A., & Jackson, B. (2021). Exercise is medicine… when you enjoy it: Exercise enjoyment, relapse prevention efficacy, and health outcomes for youth within a drug and alcohol treatment service. *Psychology of Sport and Exercise*, *52*, 101800. https://doi.org/10.1016/j.psychsport.2020.101800

Hakun, J. G., Benson, L., Qiu, T., Elbich, D. B., Katz, M., Shaw, P. A., Sliwinski, M. J., & Mossavar-Rahmani, Y. (2025). Cognitive Health Benefits of Everyday Physical Activity in a Diverse Sample of Middle-Aged Adults. *Annals of Behavioral Medicine*, *59*(1). https://doi.org/10.1093/abm/kaae059

Hamer, M., Muniz Terrera, G., & Demakakos, P. (2018). Physical activity and trajectories in cognitive function: English Longitudinal Study of Ageing. *Journal of Epidemiology and Community Health*, *72*(6), 477–483. https://doi.org/10.1136/jech-2017-210228

Hill, M. N., Titterness, A. K., Morrish, A. C., Carrier, E. J., Lee, T. T. -Y., Gil-Mohapel, J., Gorzalka, B. B., Hillard, C. J., & Christie, B. R. (2010). Endogenous cannabinoid signaling is required for voluntary exercise-induced enhancement of progenitor cell proliferation in the hippocampus. *Hippocampus*, *20*(4), 513–523. https://doi.org/10.1002/hipo.20647

Hillman, C. H., McAuley, E., Erickson, K. I., Liu-Ambrose, T., & Kramer, A. F. (2019). On mindful and mindless physical activity and executive function: A response to Diamond and Ling (2016). *Developmental Cognitive Neuroscience*, *37*, 100529. https://doi.org/10.1016/j.dcn.2018.01.006

Hou, M., Herold, F., Zhang, Z., Ando, S., Cheval, B., Ludyga, S., Erickson, K. I., Hillman, C. H., Yu, Q., Liu-Ambrose, T., Kuang, J., Kramer, A. F., Chen, Y., Costello, J. T., Chen, C., Dupuy, O., Pindus, D. M., McMorris, T., Stiernman, L., & Zou, L. (2024). Human dopaminergic system in the exercise-cognition link. *Trends in Molecular Medicine*, *30*(8), 708–712. https://doi.org/10.1016/j.molmed.2024.04.011

Howland, M., Tatsuoka, C., Smyth, K. A., & Sajatovic, M. (2017). Evaluating PROMIS(®) applied cognition items in a sample of older adults at risk for cognitive decline. *Psychiatry Research*, *247*, 39–42. https://doi.org/10.1016/j.psychres.2016.10.072

Iso-Markku, P., Kujala, U. M., Knittle, K., Polet, J., Vuoksimaa, E., & Waller, K. (2022). Physical activity as a protective factor for dementia and Alzheimer's disease: systematic review, meta-analysis and quality assessment of cohort and case–control studies. *British Journal of Sports Medicine*, *56*(12), 701–709. https://doi.org/10.1136/bjsports-2021-104981

Kinnafick, F.-E., & Thøgersen-Ntoumani, C. (2014). The effect of the physical environment and levels of activity on affective states. *Journal of Environmental Psychology*, *38*, 241–251. https://doi.org/10.1016/j.jenvp.2014.02.007

Knab, A. M., & Lightfoot, J. T. (2010). Does the difference between physically active and couch potato lie in the dopamine system? *International Journal of Biological Sciences*, 133–150. https://doi.org/10.7150/ijbs.6.133

Lai, J.-S., Wagner, L. I., Jacobsen, P. B., & Cella, D. (2014). Self-reported cognitive concerns and abilities: two sides of one coin? *Psycho-Oncology*, *23*(10), 1133–1141. https://doi.org/10.1002/pon.3522

Ludyga, S., Gerber, M., Pühse, U., Looser, V. N., & Kamijo, K. (2020). Systematic review and meta-analysis investigating moderators of long-term effects of exercise on cognition in healthy individuals. *Nature Human Behaviour*, *4*(6), 603–612. https://doi.org/10.1038/s41562-020-0851-8

Maltagliati, S., Rebar, A., Fessler, L., Forestier, C., Sarrazin, P., Chalabaev, A., Sander, D., Sivaramakrishnan, H., Orsholits, D., Boisgontier, M. P., Ntoumanis, N., Gardner, B., &

Cheval, B. (2021). Evolution of physical activity habits after a context change: The case of COVID-19 lockdown. *British Journal of Health Psychology*, bjhp.12524. https://doi.org/10.1111/bjhp.12524

Maltagliati, S., Sarrazin, P., Fessler, L., Lebreton, M., & Cheval, B. (2022). Why people should run after positive affective experiences instead of health benefits. *Journal of Sport and Health Science*. https://doi.org/10.1016/j.jshs.2022.10.005

Maltagliati, S., Sarrazin, P., Isoard-Gautheur, S., Pelletier, L., Rocchi, M., & Cheval, B. (2023). Automaticity mediates the association between action planning and physical activity, especially when autonomous motivation is high. *Psychology & Health*, 1–17. https://doi.org/10.1080/08870446.2023.2188886

McMorris, T., Barwood, M., & Corbett, J. (2018). Central fatigue theory and endurance exercise: Toward an interoceptive model. *Neuroscience & Biobehavioral Reviews*, *93*, 93–107. https://doi.org/10.1016/j.neubiorev.2018.03.024

Raichlen, D. A., Foster, A. D., Gerdeman, G. L., Seillier, A., & Giuffrida, A. (2012). Wired to run: exercise-induced endocannabinoid signaling in humans and cursorial mammals with implications for the 'runner's high.' *Journal of Experimental Biology*, *215*(8), 1331–1336. https://doi.org/10.1242/jeb.063677

Ryan, R., & Deci, E. (2017a). *Self-determination theory. Basic psychological needs in motivation, development and wellness* (G. Press, Ed.).

Ryan, R., & Deci, E. (2017b). *Self-determination theory. Basic psychological needs in motivation, development and wellness* (G. Press, Ed.).

Sheldon, K. M., & Elliot, A. J. (1998). Not all Personal Goals are Personal: Comparing Autonomous and Controlled Reasons for Goals as Predictors of Effort and Attainment. *Personality and Social Psychology Bulletin*, *24*(5), 546–557. https://doi.org/10.1177/0146167298245010

Singh, B., Bennett, H., Miatke, A., Dumuid, D., Curtis, R., Ferguson, T., Brinsley, J., Szeto, K., Petersen, J. M., Gough, C., Eglitis, E., Simpson, C. E., Ekegren, C. L., Smith, A. E., Erickson, K. I., & Maher, C. (2025). Effectiveness of exercise for improving cognition, memory and executive function: a systematic umbrella review and meta-meta-analysis. *British Journal of Sports Medicine*, bjsports-2024-108589. https://doi.org/10.1136/bjsports-2024-108589

Teixeira, P. J., Carraça, E. V, Markland, D., Silva, M. N., & Ryan, R. M. (2012). Exercise, physical activity, and self-determination theory: A systematic review. *International Journal of Behavioral Nutrition and Physical Activity*, *9*(1), 78. https://doi.org/10.1186/1479-5868-9-78

Vella, S. A., Aidman, E., Teychenne, M., Smith, J. J., Swann, C., Rosenbaum, S., White, R. L., & Lubans, D. R. (2023). Optimising the effects of physical activity on mental health and wellbeing: A joint consensus statement from Sports Medicine Australia and the Australian Psychological Society. *Journal of Science and Medicine in Sport*, *26*(2), 132–139. https://doi.org/10.1016/j.jsams.2023.01.001

Warburton, D. E. R. (2006). Health benefits of physical activity: the evidence. *Canadian Medical Association Journal*, *174*(6), 801–809. https://doi.org/10.1503/cmaj.051351

White, R. L., Parker, P. D., Lubans, D. R., MacMillan, F., Olson, R., Astell-Burt, T., & Lonsdale, C. (2018). Domain-specific physical activity and affective wellbeing among adolescents: an observational study of the moderating roles of autonomous and controlled motivation. *International Journal of Behavioral Nutrition and Physical Activity*, *15*(1), 87. https://doi.org/10.1186/s12966-018-0722-0

Wulf, G., & Lewthwaite, R. (2016). Optimizing performance through intrinsic motivation and attention for learning: The OPTIMAL theory of motor learning. *Psychonomic Bulletin & Review*, *23*(5), 1382–1414. https://doi.org/10.3758/s13423-015-0999-9

Zou, L., Herold, F., Cheval, B., Wheeler, M. J., Pindus, D. M., Erickson, K. I., Raichlen, D. A., Alexander, G. E., Müller, N. G., Dunstan, D. W., Kramer, A. F., Hillman, C. H., Hallgren, M., Ekelund, U., Maltagliati, S., & Owen, N. (2024). Sedentary behavior and lifespan brain health. *Trends in Cognitive Sciences*. https://doi.org/10.1016/j.tics.2024.02.003