frontiers | Frontiers in Cognition

TYPE Specialty Grand Challenge
PUBLISHED 18 October 2022
DOI 10.3389/fcogn.2022.1009713

Check for updates

OPEN ACCESS

EDITED BY
Valentina Parma,
Monell Chemical Senses Center,
United States

REVIEWED BY
Phillip Tomporowski,
University of Georgia, United States

*CORRESPONDENCE
Petra Jansen
petra.jansen@ur.de

SPECIALTY SECTION
This article was submitted to
Cognition and Movement,
a section of the journal
Frontiers in Cognition

RECEIVED 02 August 2022
ACCEPTED 21 September 2022
PUBLISHED 18 October 2022

CITATION
Jansen P (2022) Grand challenges in cognition and movement.
Front. Cognit. 1:1009713.
doi: 10.3389/fcogn.2022.1009713

Grand challenges in cognition and movement

Petra Jansen*

Faculty of Human Science, University of Regensburg, Regensburg, Germany

KEYWORDS

central nervous system, motor learning and control, motor skills, motor process, cognitive process

Introduction

The relation between cognition and movement is often highlighted and taken for granted, especially in popular science. However, this relationship is not as straightforward as it appears. One first reason for this might be the imprecise definition of the concepts of cognition and movement across the studies. The word cognition comes from the Latin word "cognoscere," which means something like "discover, know, learn;" the word movement is from the Latin word "movere", which means to move. Cognition includes, among others, the processes of perception, attention, thinking, problem-solving, memory, mental imagery, and language processing (Eysenck and Keane, 2020). As described in (Lewthwaite and Wulf, 2010), "Movement is a product of the events and processes of the mind, brain, and body, as well as a reflection of diverse influences, from the physical, social and cultural environment to the body's structure and function." From the broad term movement, the concepts of motor control, motor learning, and physical activity are distinguishable. Motor control describes the production of purposeful movement initiated by the central nervous system, CNS (Latash et al., 2010), motor learning, the changing of a person's motor skills (Wulf, 2012), and physical activity, any bodily movement that requires energy expenditure (Caspersen et al., 1985).

In my view, significant challenges in the research area on cognition and movement are:

1. Further development of a theoretical framework, including the role of the brain.
2. Investigating the relation of cognition and movement over the life span.
3. Creating training tools for enhancing motor and cognitive processes.

Further development of a theoretical framework, including the role of the brain

Different approaches are required for further development of a theoretical framework, as it is the elaboration on embodiment cognition theory (Wilson and Golonka, 2013), dual-tasks theories (e.g., Tomporowski and Qazi, 2020) or the importance of skill-acquisition (Tomporowski and Pesce, 2019). Embodied cognition theories describe the interaction between cognition, perception, and movement. Several taxonomies (e.g., Six-View) exist (Raab and Raab, 2022).

For example, the grounded-cognition taxonomy can differentiate the three theory groups of common coding, internal model, and simulation theories. The three approaches differ according to the conceptual tools they use. They further operate on different levels and interfaces between domains of action cognition (Gentsch et al., 2016). The performance decline in dual-task conditions when two continuous tasks must be executed simultaneously can be explained in resource- or stage accounts or within the theory of event coding (Hommel, 2020). Skill-acquisition theory emphasizes that the largest cognitive benefit could be retrieved by the allocation of mental resources during the skill-learning process (Tomporowski and Pesce, 2019). This hints that not only exercise but also for example performance arts can benefit cognition.

A further promising approach is to investigate the role of the brain concerning cognition and movement in more detail (Jost and Jansen, 2022). Using new methods, like functional near-infrared spectroscopy, will allow further insight into the brain activity during the concurrent execution of a motor and cognitive task. The reticular-activating hypofrontality model of acute exercise can explain both the facilitating and detrimental effects of exercise during cognitive tasks (Dietrich and Audiffren, 2011). It assumes that physical activity severely strains the limited information-processing capacity. Nevertheless, due to increased activity of catecholamines, procedural or "implicit" tasks tend to be facilitated. In contrast, executive or "explicit" tasks are impaired because exercise affects, for example, the prefrontal cortex, which is also relevant for executive functions (Dietrich and Audiffren, 2011).

Physical activity or movement can be seen as a model for health neuroscience (Stillman and Erickson, 2018). In most studies, the brain can not only be seen as the outcome while investigating movement interventions on brain processes. It can also be a mediator or a predictor (Stillman and Erickson, 2018). The brain as a mediator was challenged by a review (Erickson et al., 2014) demonstrating that parts of gray matter volume mediate the relationship between physical activity and cognitive function. However, it is still possible that the change in brain structure and cognitive abilities are independent of each other (Diamond and Ling, 2019a). A third possibility is that specific brain characteristics predict engagement in physical activity. There is a need to investigate those neural circumstances in depth, considering the crosstalk between muscles and the brain (Pedersen, 2019) and the use of biomarkers (Hillman et al., 2017). Additionally, investigating individual differences due to environmental circumstances and possible gene differences (Aasdahl et al., 2021) must be integrated into those theories as this integration has been missing until now.

The presentation of the different theoretical approaches (and these are only some) shows that the biggest challenge is working on a common theoretical framework for the relation between cognition and movement. The different aspects of cognition and movement (plus their interaction) and the role of the brain must be considered. A first approach would be to relate theories from other domains within the research topic without losing depth: For example, one might want to ask if there is a relation between dual-tasks theories and the reticular-activating hypofrontality model of acute exercise. A central question would be how we encourage more abstract and concrete theories that mention changes in different brain regions or the changing in brain-related mechanisms. However, even though brain imaging studies are important, their value for explaining cognitive processes besides structural aspects must be discussed.

Investigating the relation of cognition and movement over the life span

In randomized controlled trials, the evidence of exercise on cognition depends on the age and the mechanism investigated (Stillman et al., 2020). Stillman et al. mention three different levels of mechanism: Level 1 points to cellular and molecular signaling pathways. There is an increase in the brain-derived neurotrophic factor (BDNF) in children older than 6 years, young-middle, and older adults. There seems to be also an increase in the insulin-like growth factor (IGF)-1 in older adults, even though studies exist that did not show an increase (Stein et al., 2018). Level 2 includes the changes in brain structure and function. According to Stillman et al., there is a change in white matter and brain function in children between 6 and 13 years old and a change in hippocampal volume in adolescents. In older adults, hippocampal and cortical volume, white matter, and brain structure change. In level 3, psychosocial effects, like improving mood through physical activity, are described, which have a salutary impact on the brain and cognition. There is evidence of an improvement in mood up from 14 years old. In older adults, physical activity also affects sleep. On all three levels, studies with very young children are missing.

On a behavioral level, the relation between motor abilities and executive functions (EF, working memory, inhibition, and cognitive flexibility, Miyake et al., 2000) is pronounced. A meta-analysis confirmed the small acute effect of aerobic exercise on executive functions. When the reaction time is considered, children before adolescence and older adults benefit most (Ludyga et al., 2016). Nevertheless, aerobic exercise and resistance training interventions seemed to be the least effective ways to improve executive functions (Diamond and Ling, 2019a). The evidence is not as straightforward as widely assumed in any case. However, the different methodological approaches and the quality of the interventions seemed to be very important for the different results (Vazou et al., 2019). The importance of the methodological approach is another hint at the fragile relationship between movement and cognition.

Executive functions are not the only cognitive domain investigated concerning movement. One of the other cognitive domains is spatial cognition (Voyer and Jansen, 2017). In 9-month-old infants, manual rotation and crawling experience help to build an internal spatial representation of an object (Kelch et al., 2021). One component of spatial cognition, mental rotation, could be trained by physical activity programs in school-aged children (Pietsch et al., 2017) and adults (Jansen et al., 2009). Furthermore, balance training improves a total spatial cognition score (composed of an orienting and perspective-taking test, a figure orientation, and a mirror image test) in older adults (Rogge et al., 2017). Because different spatial tests are used, the results could not be directly related to the results with younger children. Also, the physical activity interventions differ.

As mentioned above, studies focused mainly on the relationship between movement and visual-spatial and executive functional processes. Studies on long-term memory, learning, and academic achievement are rare. However, executive functions and visual-spatial processes can be seen as more basic cognitive functions related to higher functions; for example, executive functions are related to academic achievement (Best et al., 2011). To summarize, studies regarding cognition and movement over the lifespan leave more questions than answers. This drawback could be overcome using comparable interventions and outcome measurements and planning longitudinal studies.

Further research will investigate the underlying cellular, molecular, and psychosocial mechanisms in different age groups for the effects of movement on cognition (Stillman et al., 2020). Furthermore, the methodological differences between the various studies must be overcome. Besides those suggestions, a more holistic approach might be valuable also because, for example, childhood development is complex, and discipline-related research does not cover its whole complexity. In this sense, Stodden et al. (2021) propose “exploration” as a principal component of any intervention.

Creating training tools for enhancing motor and cognitive processes

Due to the abovementioned issue that the relation between cognition and movement is not entirely understood in different age groups, it is not easy to develop the appropriate (motor) training tools. For example, Diamond and Ling (2019b) predict that activities that will most successfully improve executive functions (EF) must include elements that challenge EF in new and different ways and are meaningful to the own person. Furthermore, they should have an emotional involvement. A person who believes in their effectiveness should guide them, and the intervention must provide joy while reducing stress. Diamond and Ling (2019b) see these points in real-world (physical) activities, which must last longer to see beneficial effects. This point of view differs from some physical activity investigations that only focus on executive function, ignoring influential emotional and social factors. The importance of social and emotional factors claimed by Diamond and Ling (2019b) can be seen in line with the third level of evidence by Stillman et al. (2020). Some support for this comes from intervention studies with older people (Rieker et al., 2022), demonstrating that performing interactive training like exergames (a combination of exercise and video games with a fun factor) leads to significant gains in executive functions. Furthermore, subjective cognitive effort should be considered, too (Jost et al., 2022).

Another critical research focus should concentrate on developing movement training for cognition for specific subgroups. These subgroups might be, for example, patients with attention- deficit hyperactivity disorder (ADHD; Ziereis and Jansen, 2015), Parkinson’s disease (Dahmen-Zimmer and Jansen, 2017), or cancer, where cognitive decline can develop through chemotherapy (Ahles et al., 2012). Next to the beneficial effect on the general cognitive decline in aging (Erickson et al., 2022), patients with mild cognitive decline (Lautenschlager et al., 2019) and dementia (e.g., de Almeida et al., 2020) benefit from physical activity. For each of the subgroups, it must be evaluated which cognitive ability can be strengthened most by which type of movement. This evaluation should also be accompanied by further theoretical development.

The development of the appropriate motor training for different cognitive abilities in different subgroups is a grand challenge dependent on the theoretical advances in this field. However, the effectiveness of those motor training must be compared with other interventions like musical training (Bigand and Tillmann, 2022) or meditation (Sumantry and Stewart, 2021), which also have beneficial training effects on some cognitive abilities. Individual preferences for one of them shall be considered.

Concluding remarks

It seems to be clear that the relation between movement and cognition is far from being understood. One reason for this is undoubtedly the broad definition of movement and cognition: Movement ranges from single motor tasks (like finger tapping) to complex movements that also put a cognitive strain on the person, such as in some sports. Cognition ranges from low-level sensory tasks (e.g., visual search) to complex ones, such as problem-solving or creativity. The investigation of cognition cannot be entirely isolated from the movement because a motor reaction (pressing a key in a cognitive experiment) is often necessary. To close the research gap, a wide range of scientific methods, from experimental psychology, brain imaging, electrophysiology, eye tracking, virtual reality, biomechanical measurements, neuropharmacology, and genetic analysis, are needed.

Nevertheless, it is not enough to complete this grand challenge using different methods. Most importantly, research groups from other areas must work together to complete well-powered studies, developing the research agenda from different points of view but using the same methodological approaches in different labs worldwide. Each researcher (but not only close to the field of cognition and movement) should commit not only to open science practice but also to the necessity of cooperation instead of competition to enhance the research. Due to the replication crisis in psychology, researchers are sensitive to this. However, still, studies are underpowered (Brysbaert, 2019). Experiments with more power due to cooperation will stimulate theoretical development.

Author contributions

The author confirms being the sole contributor of this work and has approved it for publication.

Acknowledgments

The author is thankful for the critical reading of Philipp Hofmann, Dr. Leonardo Jost, Dr. Martina Rahe, and Ronja Rundberg. Furthermore, the author is very grateful for the helpful suggestions and thoughts of Prof. Dr. Phillip Tomporowski.

Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

Aasdahl, L., Nilsen, T. I. L., Meisingset, I., Nordstoga, A. L., Evensen, K. A. I., Paulsen, J., et al. (2021). Genetic variants related to physical activity or sedentary behaviour: a systematic review. *Int. J. Behav. Nutr. Phys. Act.* 18, 15. doi: 10.1186/s12966-020-01077-5

Ahles, T. A., Root, J. C., and Ryan, E. L. (2012). Cancer- and cancer treatment-associated cognitive change: an update on the state of the science. *J. Clin. Oncol.* 30, 3675–3686. doi: 10.1200/JCO.2012.43.0116

Best, J. R., Miller, P. H., and Naglieri, J. A. (2011). Relations between executive function and academic achievement from ages 5 to 17 in a large, representative national sample. *J. Individ. Differ.* 21, 327–336. doi: 10.1016/j.lindif.2011.01.007

Bigand, E., and Tillmann, B. (2022). Near and far transfer: is music special? *Mem. Cogn.* 50, 339–347. doi: 10.3758/s13421-021-01226-6

Brysbaert, M. (2019). How many participants do we have to include in properly powered experiments? A tutorial of power analysis with reference tables. *J. Cogn.* 2, 16. doi: 10.5334/joc.72

Caspersen, C. J., Powell, K. E., and Christenson, G. M. (1985). Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. *Public Health Rep.* 100, 126–131.

Dahmen-Zimmer, K., and Jansen, P. (2017). Karate and dance training to improve balance and stabilize mood in patients with Parkinson's disease: a feasibility study. *Front. Med.* 4, 237. doi: 10.3389/fmed.2017.00237

de Almeida, S. I., Gomes da Silva, M., and Marques, A. S. P. D. (2020). Home-based physical activity programs for people with dementia: systematic review and meta-analysis. *Gerontologist* 60, 600–608. doi: 10.1093/geront/gnz176

Diamond, A., and Ling, D. S. (2019a). Aerobic-exercise and resistance-training interventions have been among the least effective ways to improve executive functions of any method tried thus far. *Dev. Cogn. Neurosci.* 37, 100572. doi: 10.1016/j.dcn.2018.05.001

Diamond, A., and Ling, D. S. (2019b). "Review on the evidence on, and fundamental questions about, efforts to improve executive functions, including working memory," in *Cognitive and Working Memory Training: Perspectives from Psychology, Neuroscience, and Human Development*, eds J. M. Novick, M. F. Bunting, M. R. Dougherty, and R. W. Engle (New York, NY: Oxford University Press), 145-431. doi: 10.1093/oso/9780199974467.003.0008

Dietrich, A., and Audiffren, M. (2011). The reticular-activating hypofrontality (RAH) model of acute exercise. *Neurosc. Biobehav. Rev.* 35, 1305–1325. doi: 10.1016/j.neubiorev.2011.02.001

Erickson, K. I., Leckie, R. L., and Weinstein, A. M. (2014). Physical activity, fitness, and gray matter volume. *Neurobiol. Aging* 35(Suppl.2), S20–S28. doi: 10.1016/j.neurobiolaging.2014.03.034

Erickson, K. I., Shannon, D., Donofry, S. D., Sewell, K. R., Brown, B. M., and Stillman, C. M. (2022). Cognitive aging and the promise of physical activity. *Annu. Rev. Clin. Psychol.* 18, 417–442. doi: 10.1146/annurev-clinpsy-072720-014213

Eysenck, M. W., and Keane, M. T. (2020). *Cognitive Psychology: A Student's Handbook, 8th Edn*. London: Psychology Press Ltd. doi: 10.4324/9781351058513

Gentsch, A., Weber, A., Synofzik, M., Vosgerau, G., and Schuetz-Bosbach, S. (2016). Towards a common framework of grounded action cognition: relating motor control, perception and cognition. *Cognition.* 146, 81–89. doi: 10.1016/j.cognition.2015.09.010

Hillman, C. H., Erickson, K. I., and Hatfield, B. D. (2017). Run for your life! Childhood physical activity effects on brain and cognition. *Kinesiol. Rev.* 6, 12–21. doi: 10.1123/kr.2016-0034

Hommel, B. (2020). Dual-task performance: theoretical analysis and an event-coding account. *J. Cogn.* 3, 29. doi: 10.5334/joc.114

Jansen, P., Titze, C., and Heil, M. (2009). The influence of juggling on mental rotation performance. *Int. J. Sport Psychol.* 40, 351–359.

Jost, L., and Jansen, P. (2022). "Neurowissenschaftliche Sichtweise zur Bedeutung der körperlichen Aktivität für kognitive Prozesse und das Gehirn," in *Kognition und Motorik*, eds S. Klatt and B. Strauß (Göttingen: Hogrefe), 17–30.

Jost, L., Weishäupl, A., and Jansen, P. (2022). Interactions between simultaneous aerobic exercise and mental rotation. *Curr. Psychol.* 2022, 6. doi: 10.1007/s12144-021-01785-6

Kelch, A., Schwarzer, G., Gehb, G., and Jovanovic, B. (2021). How 9-month-old crawling infants profit from visual-manual rotations in a mental rotation task. *Infant. Behav. Dev*. 65, 101642. doi: 10.1016/j.infbeh.2021.101642

Latash, M. L., Levin, M. F., Scholz, J. P., and Schöner, G. (2010). Motor control theories and their applications. *Medicina* 46, 382–392. doi: 10.3390/medicina46060054

Lautenschlager, N. T., Cox, K. L., and Ellis, K. A. (2019). Physical activity for cognitive health: what advice can we give to older adults with subjective cognitive decline and mild cognitive impairment? *Dialogues Clin. Neurosci*. 21, 61–68. doi: 10.31887/DCNS.2019.21.1/nlautenschlager

Lewthwaite, R., and Wulf, G. (2010). Grand challenge for movement science and sport psychology: embracing the social-cognitive–affective–motor nature of motor behavior. *Front. Psychol*. 1, 42. doi: 10.3389/fpsyg.2010.00042

Ludyga, S., Gerber, M., Brand, S., Holsboer-Trachsler, E., and Pühse, U. (2016). Acute effects of moderate aerobic exercise on specific aspects of executive function in different age and fitness groups: a meta-analysis. *Psychophysiology* 53, 1611–1626. doi: 10.1111/psyp.12736

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., and Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "Frontal Lobe" tasks: a latent variable analysis. *Cogn. Psychol*. 41, 49–100. doi: 10.1006/cogp.1999.0734

Pedersen, B. K. (2019). Physical activity and muscle-brain crosstalk. *Nat. Rev. Endocrinol*. 15, 383–392. doi: 10.1038/s41574-019-0174-x

Pietsch, S., Böttcher, C., and Jansen, P. (2017). Cognitive motor coordination training improves mental rotation performance in primary school-aged children. *Mind Brain Educ*. 4, 176–180. doi: 10.1111/mbe.12154

Raab, M., and Raab, M. (2022). "Embodied cognition: Zusammenspiel von wahrnehmungsbezogenen und motorischen Prozessen," in *Kognition und Motorik*, eds S. Klatt and B. Strauß (Göttingen: Hogrefe), 88–102.

Rieker, J. A., Reales, J. M., Muiños, M., and Ballesteros, S. (2022). The effects of combined cognitive-physical interventions on cognitive functioning in healthy older adults: a systematic review and multilevel meta-analysis. *Front. Hum. Neurosci*. 16, 838968. doi: 10.3389/fnhum.2022.838968

Rogge, A. K., Röder, B., Zech, A., Nagel, V., Hollander, K., Braumann, K. M., et al. (2017). Balance training improves memory and spatial cognition in healthy adults. *Sci. Rep*. 7, 5661. doi: 10.1038/s41598-017-06071-9

Stein, A. M., Silva, T. M. V., Coelho, F. G. M., Arantes, F. J., Costa, J. L. R., Teodoro, E., et al. (2018). Physical exercise, IGF-1 and cognition: a systematic review of experimental studies in the elderly. *Dement. Neuropsychol.* 12, 114–122. doi: 10.1590/1980-57642018dn12-020003

Stillman, C. M., and Erickson, K. I. (2018). Physical activity as a model for health neuroscience. *Ann. N. Y. Acad. Sci*. 1428, 103–111. doi: 10.1111/nyas.13669

Stillman, C. M., Esteban-Cornejo, I., Brown, B., Bender, C. M., and Erickson, K. I. (2020). Effects of exercise on brain and cognition across age groups and health states. *Trends Neurosci*. 43, 533–543. doi: 10.1016/j.tins.2020.04.010

Stodden, D. F., Lakes, K. D., Cote, J., Aadland, E., Benzing, V., Brian, A., et al. (2021). Exploration: an overarching focus for holistic development. *Braz. J. Mot. Behav.* 15, 301–320. doi: 10.20338/bjmb.v15i5.254

Sumantry, D., and Stewart, K. E. (2021). Meditation, mindfulness, and attention: a meta-analysis. *Mindfulness* 12, 1332–1349. doi: 10.1007/s12671-021-01593-w

Tomporowski, P. D., and Pesce, C. (2019). Exercise, sports, and performance arts benefit cognition *via* a common process. *Psychol. Bull*. 145, 929–951. doi: 10.1037/bul0000200

Tomporowski, P. D., and Qazi, A. S. (2020). Cognitive-Motor dual task interference effects on declarative memory: a theory-based review. *Front. Psychol.* 11, 1015. doi: 10.3389/fpsyg.2020.01015

Vazou, S., Pesce, C., Lakes, K., and Smiley-Oyen, A. (2019). More than one road leads to Rome: a narrative review and meta-analysis of physical activity intervention effects on cognition in youth. *Int. J. Sport Exerc. Psychol*. 17, 153–178. doi: 10.1080/1612197X.2016.1223423

Voyer, D., and Jansen, P. (2017). Motor expertise and performance in spatial tasks: a meta-analysis. *Hum. Mov. Sci*. 54, 110–124. doi: 10.1016/j.humov.2017.04.004

Wilson, A. D., and Golonka, S. (2013). Embodied cognition is not what you think it is. *Front. Psychol*. 4, 58. doi: 10.3389/fpsyg.2013.00058

Wulf, G. (2012). "Motor learning," in *Encyclopedia of the Sciences of Learning*, ed N. M. Seel (Boston: Springer), 2348–2350. doi: 10.1007/978-1-4419-1428-6_869

Ziereis, S., and Jansen, P. (2015). Effects of physical activity on executive functions and motor performance in children with ADHD. *Res. Dev. Disabil*. 38, 181–191. doi: 10.1016/j.ridd.2014.12.005