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Effects of Physical Exercise on Executive Functions: Going beyond Simply Moving to Moving with Thought

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Abstract

Studies of the cognitive benefits of physical activity need to move beyond simple aerobic activities that require little thought (treadmill running, riding a stationary bicycle, or rapid walking) and resistance training. Many studies have looked at this in older adults, and the evidence points strongly to those activities having little or no cognitive benefit, certainly little or no improvement to the executive functions that depend on prefrontal cortex. There is encouraging evidence for other types of physical activity improving executive functions; however they have received far less study.

Keywords

Physical exercise; Cognitive; flexibility; Executive functions

Introduction

To review the evidence on the benefits of physical activity for executive functions (EFs), it is necessary first to find all the studies that examined this and to exclude all studies whose experimental designs prohibit drawing a conclusion about whether the activity benefited EFs or not. For example, all purely correlationl studies need to be excluded. Those studies compare the EFs of persons who happen to have engaged in Activity A versus the EFs of others who happen to have engaged in Activity B or at least not in Activity A. Factors which caused people to pick Activity A or not might account for any differences in EFs found; we have no way of knowing if the activity itself caused any benefit found. Second, studies with no comparison group (e.g., studies that looked only participants in Activity A) must be excluded because there is no way to tell if improvements might have been found even if participants had not done that activity. Third, I have excluded all studies that looked only at an acute effect right after one bout of exercise because I do not know what those results imply about effects that last more than 24 hours from an exercise program or regimen.

Finally, because I am interested specifically in EFs, only studies that included at least one EF outcome measure, broadly defined, are included here. The core EFs consist of (1) *inhibitory control, including selective attention*: thinking before we act (i.e., giving

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considered responses rather than impulsive ones), resisting temptations, resisting distractions, and staying focused; (2) *working memory*: holding information in mind and mentally working with it, such as mentally exploring relations among ideas and facts, updating your thinking or planning, translating instructions into action plans, or mentally doing a mathematical calculation; and (3) *cognitive flexibility*: 'thinking outside the box,' being able to adjust to changed demands or priorities, take advantage of sudden, unexpected opportunities, or overcome sudden, unexpected problems [1,2]. From those core EFs, higher-order EFs of reasoning, planning, and creative problem-solving are built [1,3]. These 4 criteria yielded the 15 studies included in this review.

Six studies have examined EF benefits from aerobic activity versus an active control group. All six were in older adults (most subjects being >60 years). Four of those six studies (67%) found no EF benefits at all from aerobic exercise [4-7]. Similarly, two meta-analyses that included 11 and 17 randomized control trials respectively found minimal or no EF benefits from aerobic activity [8, 9].

Five studies have examined EF benefits from resistance training. Again, all were in older adults. For three of those studies, resistance training was the active control condition, rather than the activity of primary interest; in none of those three studies was any EF benefit observed from resistance training. In the two studies where resistance training was the activity of interest and stretching/toning was the active control, a few EF benefits were found for resistance training. Better spatial working memory was found by Cassilhas [10]. More improvement, though no better post-test scores, on the Stroop and Flanker tasks than controls was found by Liu-Ambrose et al 11,12]. Neither study found improvements in verbal working memory.

Contrast the disappointing results for aerobic exercise and resistance training with the very encouraging results for traditional martial arts [13]. Those randomly assigned to TaeKwonDo showed more improvement and better post-test scores than those randomly assigned to physical exercise on *all* dimensions of EFs studied (e.g., cognitive [focused vs. distractible] and affective [persevere vs. quit] and emotion regulation). This was found in multiple contexts and on multiple measures. Also worth following up is Manjunath and Telles [14] finding that those randomly assigned to yoga (which included relaxation and awareness training in addition to exercises) improved more, and performed better at post-test, on the Tower of London EF task than their peers assigned to physical exercise. (Unfortunately there was only one outcome measure.)

The martial arts and yoga studies were done in children, not older adults. Were better results found because of the age of participants or because of differences between these activities and simple aerobic exercise or resistance training? It is difficult to know for sure. Only two studies that meet the criteria above have looked at possible EF benefits from simple aerobic exercise in children (in one of those two studies it was simple aerobic exercise plus resistance training[15]. Tuckman and Hinkle [16] found better post-test performance (they did not look at change) on one of their three EF measures, the most difficult one, in children who did aerobic running versus standard physical education. Kamijo et al. (2011) [15] found a small EF benefit but that was due to the control group getting worse on the very easiest

condition. These two studies suggest that simple aerobic exercise or resistance training may be no more beneficial for the EFs of children than it is for older adults. Alas there are no studies of effects on EFs from traditional martial arts or yoga in older adults, or adults of any age for that matter.

The two studies in older adults that found some EF benefits from simple aerobic exercise [17, 18] had younger subjects than the other four studies. In Dustman et al. [17], the age range of subjects was 55-70 and their mean age was 60 years. The mean age of subjects in Kramer et al. [18] was 62 years (no range given). The mean age of participants in the four studies that found no EF benefit from simple aerobic exercise was 66-70 years; none included participants<60 years and all included participants>70 years. Perhaps after the late 60's, EFs can no longer benefit from aerobic exercise. However, Williams and Lord [19] found EF benefits from a program that included aerobic exercise, resistance training, and eye-hand and eye-foot coordination in participants whose mean age was **72 years**. Perhaps the inclusion of activities targeting coordination was critical to seeing the EF benefits.

Davis et al. [20] had children do aerobic games where they had to think (e.g., basketball and soccer). They found that the group randomly assigned to 40-minute sessions (43 hours total) showed EF improvements while the group randomly assigned to 20-minute sessions (22 hours total) did not, though both groups performed comparably on the physical fitness outcome measure (treadmill endurance). After reviewing the literature, Kramer and Erickson (2007) [21] came to a conclusion quite consistent with what Davis et al. [20] found: There is "little evidence of a significant relationship between fitness change and cognitive change". Could it be that it was the cognitive components of the exercise in the Davis et al.[20] study that accounted for the EF benefit, and that spending more time doing activities that trained and challenged EFs in the course of playing the games accounted for why the high-dose group showed EF benefits? (For computerized cognitive training, it certainly appears to be the case that the more time spent training and challenging EFs, the better the EF results [22-24].

Best concluded in his review that "cognitively-engaging exercise appears to have a stronger effect than non-[cognitively]-engaging exercise on children's executive function[s]." I fully agree. I would like to extend that in several ways. First, I predict that will be found to be true at all ages, not just in children. Two, I predict that improving bimanual coordination and eye-hand coordination, and working on activities that require frequently crossing the midline and/or rhythmic movement, might be particularly valuable. Researchers need to start looking at more interesting activities than running in place and need to systematically examine what aspects of those more interesting activities appear to be the critical elements for improving EFs[25-28].

EFs, and the prefrontal cortex on which they depend, are the first to suffer and suffer more than any other brain region or mental abilities if you are sad, stressed, lonely, not getting enough sleep, or not physically[1,29]. Any of those factors would work against seeing an EF benefit from an intervention or that EF benefit lasting. Conversely, we all display better EFs when we are happy, calm, well-rested, physically fit, and feel socially supported [1,29]. Any program that enhances these things that support EFs and/or reduces things that impair EFs

(like feeling alone) while also directly requiring, training, and challenging EFs should, I think, be best at improving EFs [30, 31].

We need to have people do things that they absolutely love, that bring them great joy and pride and build their self-confidence, and things that make them feel less alone and more a part of a larger community working on something that all participants value – in addition to improving physical fitness and motor skills and directly training and challenging EFs. That could be a sports activity, dancing (especially where everyone dances not only with their partner but with everyone else in the group, as in the Cuban-style of salsa [Rueda] and in New England-style contradance), a traditional martial art, drumming circle [32, 33], or social circus (which provides many activities to choose from including juggling, tight-rope walking, unicycle riding, pyramid building, clowning, and acrobatics).

Only one study thus far that meets the criteria for inclusion in this review has examined the possible EF benefits of TaeKwonDo or aerobic exercise + resistance training + eye-hand and eye-foot coordination. Clearly more studies of these are needed and at different ages. Other types of traditional martial arts (like aikido or qigong) should also be investigated. Only two studies have looked at a sports activity, and in those studies either children did a little of this and a little of that or they did soccer only twice a week, for only 35 minutes each time, for only 8 weeks [34]. More studies are needed of different sports and with participants committed to one another as team-mates. Studies should look at the possible EF benefits of dance, band, drumming, circus, and other activities. Only two studies have looked at possible cognitive benefits of simple aerobic exercise in children. More studies are needed. Research on why aerobic activities might benefit EFs has focused on variables like increased blood flow and oxygen to the brain and increased BDNF in the brain; no one has looked at whether the mechanism of action might be by improving mood or sleep, which vigorous activity has been shown to do [35-37]. No study meriting inclusion in this review has looked at whether benefits last even as long as a month, much less how long they last. No study meriting inclusion here has looked at whether, or for how long, participants continue to do the activity they did for a study after the study ended. No one has looked at the possible EF benefits of simple aerobic exercise or resistance training in young children (3-6 years of age). No one has looked at the possible EF benefits for young children of physical activities that not only improve fitness but also demand and improve diverse motor and EF skills. I predict that the later (movement activities that improve physical fitness and also train diverse motor and EF skills) will be the most effective in improving the EFs of young children. Until the many holes in the research literature begin to be filled it will be difficult to draw firm conclusions but I put my money on activities that improve physical fitness but also (a) train and challenge diverse motor and EF skills, (b) bring joy, pride, and self-confidence, and (c) provide a sense of social belonging (e.g., group or team membership).

References

1. Diamond A. Executive functions. Annu Rev Psychol. 2013; 64:135–168. [PubMed: 23020641]
2. Davidson MC, Amso D, Anderson LC, Diamond A. Development of cognitive control and executive functions from 4 to 13 years: evidence from manipulations of memory, inhibition, and task switching. Neuropsychologia. 2006; 44:2037–2078. [PubMed: 16580701]

3. Logue SF, Gould TJ. The neural and genetic basis of executive function: Attention, cognitive flexibility, and response inhibition. Pharmacol Biochem Behav. 2014; 123:45–54. [PubMed: 23978501]

4. Blumenthal JA, Emery CF, Madden DJ, George LK, Coleman RE, Riddle MW, et al. Cardiovascular and behavioral effects of aerobic exercise training in healthy older men and women. J Gerontol. 1989; 44:M147–157. [PubMed: 2768768]

5. Fabre C, Chamari K, Mucci P, Massé-Biron J, Préfaut C. Improvement of cognitive function by mental and/or individualized aerobic training in healthy elderly subjects. Int J Sports Med. 2002; 23:415–421. [PubMed: 12215960]

6. Moul JL, Goldman B, Warren B. Physical activity and cognitive performance in the older population. Journal of Aging & Physical Activity. 1995; 3:135–145.

7. Smiley-Oyen AL, Lowry K, Francois SJ, Kohut ML, Ekkekakis P. Exercise, fitness, and neurocognitive function in older adults: The “selective improvement” and “cardiovascular fitness” hypotheses. Ann Behav Med. 2008; 36:280–291. [PubMed: 18825471]

8. Angevaren M, Aufdemkampe G, Verhaar HJ, Aleman A, Vanhees L. Physical activity and enhanced fitness to improve cognitive function in older people without known cognitive impairment. Cochrane Database of Systematic Reviews. 2008; 3:1–70.

9. Smith PJ, Blumenthal JA, Hoffman BM, Cooper H, Strauman TA, Welsh-Bohmer K, et al. Aerobic exercise and neurocognitive performance: A meta-analytic review of randomized controlled trials. Psychosomatic medicine. 2010; 72:239–252. [PubMed: 20223924]

10. Cassilhas RC, Viana VA, Grassmann V, Santos RT, Santos RF, Tufik S, et al. The impact of resistance exercise on the cognitive function of the elderly. Med Sci Sports Exerc. 2007; 39:1401–1407. [PubMed: 17762374]

11. Liu-Ambrose T, Nagamatsu LS, Graf P, Beattie BL, Ashe MC, Handy TC. Resistance training and executive functions: a 12-month randomized controlled trial. Arch Intern Med. 2010; 170:170–178. [PubMed: 20101012]

12. Liu-Ambrose T, Nagamatsu LS, Voss MW, Khan KM, Handy TC. Resistance training and functional plasticity of the aging brain: a 12-month randomized controlled trial. Neurobiol Aging. 2012; 33:1690–1698. [PubMed: 21741129]

13. Lakes KD, Hoyt WT. Promoting self-regulation through school-based martial arts training. Journal of Applied Developmental Psychology. 2004; 25:283–302.

14. Manjunath NK, Telles S. Improved performance in the Tower of London test following yoga. Indian J Physiol Pharmacol. 2001; 45:351–354. [PubMed: 11881575]

15. Kamijo K, Pontifex MB, O'Leary KC, Scudder MR, Wu CT, Castelli DM, et al. The effects of an afterschool physical activity program on working memory in preadolescent children. Dev Sci. 2011; 14:1046–1058. [PubMed: 21884320]

16. Tuckman BW, Hinkle JS. An experimental study of the physical and psychological effects of aerobic exercise on schoolchildren. Health Psychol. 1986; 5:197–207. [PubMed: 3743529]

17. Dustman RE, Ruhling RO, Russell EM, Shearer DE, Bonekat HW, Shigeoka JW, et al. Aerobic exercise training and improved neuropsychological function of older individuals. Neurobiology of Aging. 1984; 5:35–42. [PubMed: 6738784]

18. Kramer AF, Hahn S, Cohen NJ, Banich MT, McAuley E, Harrison CR, Chason J. Ageing, fitness and neurocognitive function. Nature. 1999; 400:418–419. [PubMed: 10440369]

19. Williams P, Lord SR. Effects of group exercise on cognitive functioning and mood in older women. Aust N Z J Public Health. 1997; 21:45–52. [PubMed: 9141729]

20. Davis CL, Tomporowski PD, McDowell JE, Austin BP, Miller PH, Yanasak NE, et al. Exercise improves executive functions and achievement and alters brain activation in overweight children: A randomized, controlled trial. Health Psychology. 2011; 30:91–98. [PubMed: 21299297]

21. Kramer AF, Erickson KI. Capitalizing on cortical plasticity: influence of physical activity on cognition and brain function. Trends Cogn Sci. 2007; 11:342–348. [PubMed: 17629545]

22. Basak C, Boot WR, Voss MW, Kramer AF. Can training in a real-time strategy video game attenuate cognitive decline in older adults? Psychol Aging. 2008; 23:765–777. [PubMed: 19140648]

23. Diamond, A.; Ling, D. Fundamental questions surrounding efforts to improve executive functions (including working memory). In: Bunting, M.; LNovicking, J.; Dougherty, M.; Engle, RW., editors. An integrative approach to cognitive and working memory training: Perspectives from psychology, neuroscience, and human development. New York, NY: Oxford University Press; in press

24. Jaeggi SM, Buschkuehl M, Jonides J, Perrig WJ. Improving fluid intelligence with training on working memory. Proc Natl Acad Sci U S A. 2008; 105:6829–6833. [PubMed: 18443283]

25. Crova C, Struzzolino I, Marchetti R, Masci I, Vannozzi G, Forte R, et al. Cognitively challenging physical activity benefits executive function in overweight children. J Sports Sci. 2014; 32:201–211. [PubMed: 24015968]

26. Forte R, Boreham CA, Leite JC, De Vito G, Brennan L, Gibney ER, et al. Enhancing cognitive functioning in the elderly: Multicomponent vs resistance training. Clinical Interventions in Aging. 8:19–27. [PubMed: 23341738] Pesce C. Shifting the focus from quantitative to qualitative exercise characteristics in exercise and cognition research. J Sport Exerc Psychol. 2012; 34:766–786. [PubMed: 23204358]

27. Tomporowski, PD.; McCullick, BA.; Pesce, C. Enhancing children's cognition with physical activity games. Champaign, IL: Human Kinetics; in press

28. Diamond A. Want to Optimize Executive Functions and Academic Outcomes?: Simple, Just Nourish the Human Spirit. Minn Symp Child Psychol. 2014; 37:205–232. [PubMed: 25360055]

29. Diamond A. Activities and Programs That Improve Children's Executive Functions. Curr Dir Psychol Sci. 2012; 21:335–341. [PubMed: 25328287]

30. Ling, D.; Kelly, MK.; Diamond, A. Human-animal interaction and the development of cognitive control (executive functions). In: Freund, L.; McCune, S.; McCardle, P.; Esposito, L.; Griffin, JA., editors. Social neuroscience of human-animal interaction. New York, NY: American Psychological Association Press; in press

31. Ho P, Tsao JC, Bloch L, Zeltzer LK. The impact of group drumming on social-emotional behavior in low-income children. Evid Based Complement Alternat Med. 2011; 2011:250708. [PubMed: 21660091]

32. Metzler-Baddeley C, Cantera J, Coulthard E, Rosser A, Jones DK, Baddeley RJ. Improved executive function and callosal white matter microstructure after rhythm exercise in Huntington's Disease. J Huntingtons Dis. 2014; 3:278–283.

33. Chang YK, Tsai YJ, Chen TT, Hung TM. The impacts of coordinative exercise on executive function in kindergarten children: an ERP study. Exp Brain Res. 2013; 225:187–196. [PubMed: 23239198]

34. Loprinzi PD, Cardinal BJ. Association between objectively-measured physical activity and sleep, NHANES 2005–2006. Mental Health and Physical Activity. 2011; 4:65–69.

35. Penedo FJ, Dahn JR. Exercise and well-being: a review of mental and physical health benefits associated with physical activity. Curr Opin Psychiatry. 2005; 18:189–193. [PubMed: 16639173]

36. Williamson D, Dewey A, Steinberg H. Mood change through physical exercise in nine- to ten-year-old children. Percept Mot Skills. 2001; 93:311–316. [PubMed: 11693702]

37. Best JR. Effects of physical activity on children's executive function: Contributions of experimental research on aerobic exercise. Dev Rev. 2010; 30:331–351. [PubMed: 21818169]