REVIEW ARTICLE

The effects of cognitive and physical training on cognitive performance

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Objective: To provide a brief overview of the literature evaluating the individual and combined effects of cognitive and physical (exercise) training on cognitive function.

Design and Methods: An overview review approach was employed.

Results: Cognitive and physical training, and their combination, can improve various cognitive outcomes (e.g., memory) in several adult populations (e.g., healthy older adults, older adults with mild cognitive impairment). These effects, however, are influenced by several factors, such as the setting in which the training occurs (e.g., supervised or home-based), the type of combined training (e.g., physical-cognitive, motor-cognitive, multi-domain), and the type of comparison/control group utilized.

Conclusions: Combining cognitive and physical exercise together in a training program may yield improvements in cognitive function.

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Key words: cognition ■ mental stimulation ■ physical activity

THE EFFECTS OF COGNITIVE AND PHYSICAL TRAINING ON COGNITIVE PERFORMANCE

Throughout life, people are faced with many challenging tasks (e.g., remembering past information, remembering to execute an intention in the future, inhibiting goal-irrelevant information) that require complex cognitive processes. Thus, identification of ways to optimize and preserve cognitive function is of critical importance.

The study of cognition is vast, including investigations focused on how cognition is influenced from intrapersonal, interpersonal, and social/environmental factors. The present paper, written as a brief overview,[1] takes a focused approach in evaluating the individual and combined effects of two specific intrapersonal-related factors on cognitive function.[2] Specifically, this overview evaluates the individual and combined effects of cognitive training and physical exercise (training) on cognitive performance. Of specific interest is whether these two types of training (cognitive and physical) have an additive effect on cognition that is greater than their individual effects.

COGNITIVE TRAINING ON COGNITIVE PERFORMANCE

People, particularly those without pathological cognitive impairment, have the ability to learn new tasks/information. Of general interest, however, is whether cognitive training can result in a transfer effect to other tasks involving cognitive operations, including near-transfer (e.g., a task in the same domain) or far-transfer (e.g., a task in a different domain) tasks. Transfer-of-training studies often involve repeated engagement in a mental task that targets specific or multiple cognitive processes (e.g., attention, memory). Select examples include playing certain video games (e.g., Big Brain Academy via Nintendo Wii),[3] engaging in reading tasks (e.g., newspapers and magazine articles on various topics),[4] memory training (e.g., taught mnemonic strategies for remembering words),[5] reasoning training (e.g., taught strategies to identify patterns),[6] and speed-of-processing training (e.g., completing complex speed tasks on a computer).[6] In addition to these types of cognitive training interventions, some interventions, although fewer in number, have focused on general mental stimulation training;[7] these include, for example, taking an acting class, a computer course, or guided computer use. Control conditions often include educational arms, no contact controls, and shame controls (e.g., lower difficulty level of the cognitive training task). Notably, there is an obvious overlap in some of the cognitive training, mental stimulation, and control conditions. Some mental stimulation interventions are not included in reviews on cognitive interventions or some consider cognitive training and mental stimulation as one, ultimately making it difficult to determine the effects of these

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interventions on cognition.

The delivery of these conditions varies, including home-based training, supervised training, and occurring in individual versus group-based settings. Further, training programs vary in dose, including, for example, 5-48 hours of cognitive training. These types of training programs are compared to each other (and a control) and often evaluated on performance measures related to the task (e.g., video game performance measures, knowledge tests from the reading material), and importantly, on transfer tasks. The focus here will be on transfer task performance.

In a meta-analysis among healthy older adults,[8] the effect of cognitive training on overall cognitive function (i.e., considering performance on all cognitive outcomes – not isolating domain-specific cognitive outcomes) was small (g = .18), albeit statistically significant. Multi-domain cognitive training (e.g., targeting multiple cognitive domains) was greatest for improving overall cognition, but improvements were also observed for other types of training (e.g., speed-of-processing, working memory). Meta-regression analyses demonstrated larger cognitive training effects on overall cognition for supervised versus home-based training (also supported by other meta-analyses[9]). Session length and total duration of training were not associated with the overall cognitive effect from cognitive training; other meta-analytic work, however, demonstrates that training more than three times per week may be counterproductive.[9] Another meta-analysis among older healthy adults also showed improvements of cognitive training on various cognitive outcomes, such as memory recall;[7] these effects have not always been extended to executive function.[9] Cognitive training most reliably produced transfer effects within the same cognitive domain (also supported by other reviews[10]), although several training studies have demonstrated transfer to untrained cognitive domains. Factors that predicted a far-transfer effect included using adaptive (e.g., adjustments to the training are made based on performance) and repetitive training sessions as well as longer training sessions. Although a specific quantitative analysis was not conducted, they also reported some beneficial effects of mental stimulation interventions on various cognitive outcomes, such as memory and executive function.

In a meta-analysis focused on adults with major depressive disorder,[11] cognitive training was effective in improving overall cognition (g = .35); improvements were also observed for various cognitive domains, including executive function (g = .37), processing speed (g = .35), and verbal memory (g = .56), but not for working memory or verbal learning. There was limited evidence of a far-transfer effect, possibly a result of the limited studies evaluating the far-transfer effects of cognitive training.

Beneficial effects of cognitive training have also been observed among those with mild cognitive impairment. Meta-analytic work shows a statistically significant small effect (g = .23) of cognitive training in improving overall cognition;[12] similar results were observed for other cognitive outcomes, including episodic memory (g = .30) and working memory (g = .39), but not executive function. These findings are generally supported by other related meta-analyses in this population;[13, 14] opposing results, however, have been observed.[10, 15]

PHYSICAL TRAINING ON COGNITIVE PERFORMANCE

In addition to cognitive training, physical training can improve cognitive function. Physical training, within this section, refers to repeated bouts of whole-body movement (e.g., aerobic or resistance exercise) during leisure time that results in energy expenditure above resting levels. Meta-analytic work demonstrates that physical training among healthy older adults can improve various cognitive parameters, including executive function (d = 0.27) and memory (d = 0.24), but not overall cognition.[16] Among those with cognitive impairment, physical training has been shown to improve overall cognition (d = 0.47) and executive function (d = 0.24), but not memory.[16] In this vulnerable population, shorter exercise session duration and greater exercise frequency predicted higher effect sizes.

Among adults older than 50 years, a meta-analysis showed that physical training improved cognition (SMD = 0.29), for both those with (SMD = 0.28) and without (SMD = 0.36) mild cognitive impairment.[17] Physical training did not improve overall cognition, but improved various subdomains, including attention, executive function, episodic memory, and working memory. Moderation analyses demonstrated that all modes of exercise (aerobic, resistance, multicomponent training, Tai chi), with the exception of yoga, improved cognition. Further, greater benefits in cognition were observed among exercise programs involving medium duration (45-60 min) sessions and moderate- and vigorous-intensity exercise (not light-intensity). Importantly, the type of control group played an important role, as physical training only improved cognition when it was compared to a non-contact or education control, but was not effective in improving cognition when compared to an active control group, such as stretching or a social group comparison.

Additionally, as published by the 2018 Physical Activity Advisory Committee,[18] there is a moderate strength of evidence that long-term moderate-to-vigorous physical training interventions can improve brain structure, function, and cognition in older adults; strong strength of evidence that physical training can reduce the risk of cognitive impairment in older adults; moderate strength of evidence that physical training can improve cognition in adults with dementia; and moderate strength of evidence that physical training can improve cognition in individuals with other clinical disorders (e.g., ADHD, schizophrenia, Parkinson's, stroke) that are associated with impaired cognition.

COMBINED EFFECTS OF COGNITIVE AND PHYSICAL TRAINING ON COGNITIVE PERFORMANCE

Combined training interventions focus on incorporating both cognitive and physical training together. This can occur in a sequential fashion, e.g., first perform a bout of exercise and then complete a cognitive task while seated. Alternatively, combined training programs may employ a simultaneous approach, including "*thinking while moving*" (e.g., exercising while concurrently doing an arithmetic task) or a "*moving while thinking*" (e.g., walking while completing a navigational task; involves incorporating cognitive processes into a complex motor task) approach.[19] Additionally, combined training programs may include three unique types, namely physical-cognitive training, motor-cognitive training, and multi-domain training.[19] Physical-cognitive training involves combining aerobic/resistance exercise with cognitive training; motor-cognitive training involves motor skill training with cognitive training (e.g., with the simultaneous approach, completing a visual search task while concurrently completing a balance task; completing a verbal task (counting) while concurrently performing a driving simulation task); and multi-domain training consists of an integration of aerobic/resistance exercise, complex motor skills, and cognitive engagement through customized training situations (e.g., alternating between walking/resistance exercises and balance exercises while concurrently completing a cognitive task, such as recalling pre-selected words).

Rahe et al.[20] randomized participants (50-85 years) into one of three groups, including Cognitive Training (CT), Cognitive + Physical Training (CPT), and CPT + Counseling (CPT+C). All three groups completed seven weeks of training, including two sessions per week for 90 minutes per session. The CT group completed a multi-domain cognitive training program, involving training to improve memory, attention, and executive function. They also completed other mental stimulation activities, such as board games, watching educational lectures, and completing various cognitively-stimulating homework assignments. The CPT group was similar to the CT group except that the first 20 minutes of the session was dedicated to physical movement, including activities targeting strength, flexibility, coordination, and endurance. Lastly, the CPT+C group was similar to the CPT group but involved additional mental stimulation and motivational engagement; during the first and last week of training, participants received physical activity counseling (e.g., how to set goals) that was centered around motivational interviewing techniques. Results demonstrated that all three groups showed pre-post improvements in various cognitive parameters (e.g., memory and executive function). Notably, however, CPT was not superior to CT, but CPT+C was superior to CPT for improving verbal fluency. Similar results were obtained in their subsequent paper reporting results for a 1-year follow-up period.[21] No control group, however, was included in the design of this experiment.

This no control group limitation was addressed in a study by Bherer et al.[22] Not only did they include a control group, but they implemented active control groups for both the cognitive and physical training groups to better isolate the active ingredient in both the cognitive and physical training interventions. The intervention involved 12-weeks of training (2 days/week for physical training and 1/day week for cognitive training; each session lasted 60 minutes), with participants randomized into one of four groups: cognitive training + aerobic/resistance exercise (COG+/AER+), computer lessons + aerobic/resistance exercise (COG-/AER+), cognitive training + stretching (COG+/AER-), and computer lessons + stretching (COG-/AER-). Thus, the computer lessons and stretching arms, respectively, served as the active control groups for cognitive training and physical training. The outcome measure was a computerized dual-task involving performing two visual discrimination tasks separately and concurrently. The COG+ group involved training on a similar dual-task assessment. Results demonstrated that the COG+/AER+ group improved response accuracy on one of the cognitive outcomes (task-set cost), which involves maintaining different response alternatives in memory, reflective of working memory. Notably, COG+ alone or AER+ alone did not improve performance on this outcome (task-set cost), demonstrating a synergistic effect of cognitive training and physical training on cognition.

These findings are in support of results from review papers. In a systematic review, Lauenroth et al.[23] evaluated 20 articles that evaluated the effects of combined cognitive and physical training – either concurrently (dual task) or subsequently – when compared to cognitive/exercise training alone on cognitive performance. Among the 20 studies, 16 involved cardiovascular exercise, 10 involved resistance exercise, balance tasks in 9, and flexibility exercises in 7. Regarding cognitive training, 9 studies trained attention, 15 executive function/working memory, 5 episodic memory/learning, 4 perception, and 3 speed-of-information processing. Of the 20 evaluated studies, 18 showed improvements in cognitive performance in the combined intervention group. These improvements were generally restricted to the trained cognitive functions, as opposed to observing far-transfer effects. Further, 12 of the 13 studies that implemented cognitive and physical training concurrently demonstrated improvements in cognition, whereas 5 of the 6 studies following a subsequent approach showed improvements in cognition. Thus, both approaches may have merit in improving cognition. The authors of this review also concluded that both approaches (concurrent or subsequent) may be superior in improving cognition when compared to cognitive or physical training alone. However, a quantitative analysis of this would help address any potential uncertainties of this effect.

A meta-analysis by Sun et al.[24] also evaluated the effects of combined cognitive and physical training on cognition, but they restricted their population to those demonstrating subjective cognitive decline. Combined training, when compared to control, was not effective in improving subjective memory function. An overall objectively-determined cognitive function variable was created by combining the scores from the different objectively-evaluated cognitive outcomes. Results showed that combined training, compared to control, improved objectively-evaluated cognitive performance (SMD = 0.12); this effect was very similar to exercise only when compared to control (SMD = 0.13), suggesting that the combined effects may not be greater than exercise alone.

In a comprehensive review, Torre and Temprado[19] metaanalyzed the combined effects of cognitive training and physical training on cognition. Care was taken in considering different types of combined training, including physical-cognitive training, motor-cognitive training, and multi-domain training. When comparing physical-cognitive training to control, there was consistent evidence that physical-cognitive training improved cognition, occurring for both simultaneous and sequential training programs. In contrast, there were mixed findings of a beneficial effect of physical-cognitive training when compared to physical training alone or when compared to cognitive training alone. When comparing motor-cognitive training to control, three out of four studies demonstrated improvements in at least one cognitive outcome. Although limited in investigation, research findings from the evaluated studies also supported superior cognitive benefits for motor-cognitive training when compared to motor alone or cognitive training only. For multi-domain training versus control, two out of three studies demonstrated greater cognitive performance for combined training; similar results occurred when comparing multi-domain training to physical training alone. Limited work, to date, has compared multi-domain training to cognitive training alone.

CONCLUSION AND RECOMMENDATIONS

Presently, there is evidence to suggest that cognitive training alone and exercise training alone can improve various cognitive outcomes, with such effect occurring among diverse adult populations. These effects may be influenced by a multitude of factors, such as the setting in which the training occurs (e.g., supervised v home-based) and the comparison group employed (e.g., non-contact group, active control). Combined training (cognitive and exercise) has also demonstrated evidence of enhancing cognition, suggesting a potential additive effect in improving cognition, but this may be influenced by several notable factors, such as the employed control group and type of combined training program (e.g., physical-cognitive, motor-cognitive, multi-domain).

A notable point of discussion in the reviewed articles was the lack of detail and reporting of treatment fidelity parameters, such as adherence to the protocol. This information should be carefully documented and reported in future work on this topic. Further, for both cognitive and physical training programs, additional details on the characteristics of the interventions (e.g., description and progression of the protocols) will help aid in future replication and comparability efforts.

Future work should also carefully consider the control group comparison in an effort to better isolate the key ingredient of the training program. Care should also be taken in designing studies that rigorously compare and differentiate mental stimulation activities from cognitive training activities. This will help determine whether it is simply the engagement of cognitive operations, or rather, employment of specific cognitive processes, that is needed to improve cognition. Relatedly, although current work suggests greater near-transfer effects of cognitive training, future work should continue to investigate near- and far-transfer effects, including when evaluating the effects of combined (cognitive and physical) training on cognition. Evaluating far-transfer effects should not be limited to cognitive outcomes, but also consider functional parameters and everyday behaviors.[25] Such work would also benefit by evaluating the sustainability of the observed effects (e.g., include long-term follow-up assessments), consider comparing natural exercises that incorporate multi-domain stimulations (e.g., Tai Chi, Dance), and explore potential mechanisms through which individual and combined training may have on cognition.[26] It would also be worthwhile for future work to not only evaluate the effects of combined cognitive and physical training on general cognitive function, but evaluate whether such effects influence specific cognitive processes that can aid in sport-specific cognitive function, and in turn, enhanced sport performance.[27]

Disclosures. None

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