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Research Article

A Comparison of the Effect of Physical Activity and Cognitive Training on Dual-Task Performance in Older Adults

Tudor Vrinceanu, MA,[1,2] Caroll-Ann Blanchette, MSc,[1,2] Brittany Intzandt, MSc,[2,3] Maxime Lussier, PhD,[4,5] Kristell Pothier, PhD,[4,6] Thien Tuong Minh VU, MD,[1,7] Anil Nigam, MD,[1,2] Laurent Bosquet, PhD,[8,9] Antony D. Karelis, PhD,[4,10] Karen Z. H. Li, PhD,[11,12] Nicolas Berryman, PhD,[4,10] and Louis Bherer, PhD[1,2,*]

[1]Department of Medicine, University of Montréal, Montréal, Quebec, Canada. [2]Research Centre, Montreal Heart Institute, Montréal, Quebec, Canada. [3]School of Graduate Studies, Concordia University, Montreal, Quebec, Canada. [4]Research Centre, Institut Universitaire de Gériatrie de Montréal, Montréal, Quebec, Canada. [5]Rehabilitation Science, Faculty of Medicine, University of Montréal, Montréal, Quebec, Canada. [6]EA 2114, Psychologie des Âges de la Vie et Adaptation, University of Tours, Tours, France. [7]Research Centre, Centre hospitalier de l'Université de Montréal, Montréal, Quebec, Canada. [8]Laboratoire MOVE (EA6314), Université de Poitiers, Faculté des sciences du sport, Poitiers, France. [9]Ecole de kinésiologie et des sciences de l'activité physique, Faculté de médecine, Université de Montréal, Montreal, Quebec, Canada. [10]Département des Sciences de l'Activité Physique, Université du Québec à Montréal, Montréal, Quebec, Canada. [11]PERFORM Centre, Concordia University, Montréal, Quebec, Canada. [12]Department of Psychology, Concordia University, Montreal, Quebec, Canada.

*Address correspondence to: Louis Bherer, PhD, Centre de Recherche, Institut de Cardiologie de Montréal, 5000 Belanger, Montréal, QC H1T 1C8, Canada. E-mail: louis.bherer@umontreal.ca

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Abstract

Objectives: Studies suggest that cognitive training and physical activity can improve age-related deficits in dual-task performances. However, both of these interventions have never been compared in the same study. This article investigates the improvement in dual-task performance in 2 types of exercise training groups and a cognitive training group and explores if there are specific dual-task components that are more sensitive or more likely to improve following each type of training.
Methods: Seventy-eight healthy inactive participants older than the age of 60 ($M = 69.98$, $SD = 5.56$) were randomized to one of three 12-week training programs: aerobic training (AET) = 26, gross motor abilities (GMA) = 27, and cognition (COG) = 25. Before and after the training program, the participants underwent physical fitness tests, and cognitive evaluations involving a computerized cognitive dual task. The AET consisted of high- and low-intensity aerobic training, the GMA of full-body exercises focusing on agility, balance, coordination, and stretching, and the COG of tablet-based exercises focusing on executive functions.
Results: Repeated-measures analysis of variance on reaction time data revealed a group × time interaction ($F_{(2,75)} = 11.91$, $p < .01$) with COG having the greatest improvement, followed by a significant improvement in the GMA group. Secondary analysis revealed the COG to also improve the intraindividual variability in reaction time ($F_{(1,24)} = 8.62$, $p < .01$), while the GMA improved the dual-task cost ($F_{(1,26)} = 12.74$, $p < .01$).
Discussion: The results show that physical and cognitive training can help enhance dual-task performance by improving different aspects of the task, suggesting that different mechanisms are in play.

Keywords: Cognitive aging, Cognitive training, Dual-tasking, Physical training

Worldwide the proportion of seniors is increasing quickly. By 2050, one out of every six individuals will be older than 65 years of age, while the proportion of people aged 80 and older is expected to triple (United Nations, 2019). Aging is associated with cognitive changes (Zanto & Gazzaley, 2019), including declines in executive functions, a set of mechanisms that modulate the functioning of a variety of subprocesses, and the dynamics of cognition (Miyake et al., 2000; Verhaeghen, 2011). Executive functions are the most sensitive to change throughout the normal aging process, preceding memory declines by up to 3 years, and functional decline by up to 6 years (Carlson et al., 2009; Johnson et al., 2007).

A consequence of decline in executive control and speed of processing is a reduced ability to accomplish two tasks simultaneously. Because dual-tasking plays a fundamental role in the independent functioning of older adults (Martyr & Clare, 2012), declines in this domain could have serious impacts. A meta-analysis has found dual-task reaction time (RT) to be consistently slower in older adults and showed that the RT cost associated with performing two simultaneous tasks cannot be fully accounted for by age-related cognitive slowing, supporting the notion that there is a specific deficit in dual-task ability with aging (Verhaeghen et al., 2003). The present dual task (DT) involves discriminating between two sets of images by pressing the corresponding button with the correct hand. While there are multiple different paradigms for dual-tasking in the literature, the present study used a simplified one to better isolate, and study-specific DT components (RT, DT cost, task-set cost, intraindividual variability; please see the *Assessments* section for a detailed description of all DT components) known to be affected in aging (Fraser & Bherer, 2013). Age-related deficits in dual-task cost can be observed in simple conditions when performing basic discrimination tasks. By comparing the tasks performed in a single condition to a condition in which both tasks have to be performed concurrently, past studies have reported that older adults tend to show larger dual-task effects (Bherer et al., 2005). This has been particularly evident in tasks requiring two motor responses (Hartley & Little, 1999), like in the present study. Studies have also shown an increased intraindividual variability in RT compared with younger adults, suggesting greater response inconsistency (Bherer et al., 2006; Brydges et al., 2020). This decline of performance in dual-task conditions observed in older adults is most likely multidetermined (Verhaeghen et al., 2003). It can be caused by a potential impairment in the basic cognitive mechanisms involved, a lower ability to dedicate resources to each task, but also a change in the cognitive strategy with which older adults approach dual-task conditions (Bialystok & Craik, 2006; Braver et al., 2008; Fraser & Bherer, 2013). However, studies suggest that dual-task performances can be improved in older adults through cognitive and physical training.

Computerized cognitive training (COG) has shown to improve dual-task ability in older adults (Bherer et al., 2005, 2008; Karbach & Verhaeghen, 2014; Li et al., 2010; Lussier et al., 2012, 2015). Notably, Chiu et al. (2018) in a double-blind randomized controlled trial trained 31 older adults 3 times per week—30 min per session—for 8 weeks to an executive functions program (focused on switching, working memory, and inhibition). Results showed significantly improved task switching and working memory. Other programs of similar length and structure training dual-tasking, either alone or in combination with working memory, have also shown a general improvement in dual-task performances on a similar DT to the one used in the present study (Bherer et al., 2005, 2008; Kramer et al., 1995; Lussier et al., 2012, 2015, 2017). In addition to improved processing speed, these studies were able to show improvements in dual-task cost performance, suggesting that it affected the ability to perform two simultaneous tasks. Intraindividual variability has also been shown to improve following COG in different studies training dual-tasking or even general cognitive abilities (Bherer et al., 2006; Brydges et al., 2020; Könen & Karbach, 2015). The cognitive training program used in this study focused on training executive functions based on the Miyake model that identified inhibition, switching, working memory, and dual-tasking as core functions (Miyake et al., 2000). The training included component-specific and variable priority training, designed to maximize learning, and decrease dual-task cost. Adaptive training, where the difficulty and/or stimuli change over time, helps counteract the automation of cognitive processes and stimulates plasticity (Düzel et al., 2010; Kim et al., 2017). Feedback, on the other hand, allows participants to adapt their responses based on the demands of the task and ensures progression and understanding (Lussier et al., 2015). When it is continuous and progressive, feedback can also keep the participant motivated because it allows them to quantify their improvement as training progresses (Strobach & Karbach, 2016). All these aspects, with the changes in demand and the presentation of several stimuli, also contribute to the generalization of learning.

Physical training programs have also demonstrated some benefits on cognitive abilities, including memory, attention, processing speed, and executive functions (Bherer et al., 2013; Kramer & Erickson, 2007; Smith et al., 2010), including dual-tasking (Colcombe & Kramer, 2003). Most often those studies used aerobic training (AET), but emerging studies have highlighted the cognitive benefit of other types of exercises like resistance training (Liu-Ambrose et al., 2012) and gross motor abilities (GMA) training (Berryman et al., 2014). More precisely, Berryman et al. (2014) showed that even 8 weeks of GMA (including stretching, relaxation, locomotion, coordination, juggling, and balance exercises) was able to improve inhibition scores in a random number generation task. This improvement has been recorded while performing the cognitive task alone as well as during a walking dual task. The authors argue that the GMA resulted in cognitive benefits as a result of the exercises used, which required the use of coordination and perceptual adaptations. Those results are promising, suggesting that the cognitive benefit of physical training is not limited to aerobic fitness.

Specifically to dual-tasking, the evidence is scarce, suggesting only a potential benefit of AET (Bherer et al., 2019, 2020; Hawkins et al., 1992; Madden et al., 1989). Although Madden et al. (1989) did not find an improvement in RT in a dual-task paradigm following AET, Hawkins et al. (1992) showed faster RT while performing a dual task. Moreover, Bherer et al. (2019) showed that AET can also improve the task-set cost in older adults. Other studies show higher aerobic fitness to be associated with lower intraindividual variability, while physical training did not have an impact on this variable (Bielak & Brydges, 2019; Raine et al., 2018). Even though the results in those studies are mixed, they show a potential link between physical training and dual-task performance which might be dependent on the content and the duration of the training program.

Although the evidence suggests that all three training groups have the capacity to improve dual-tasking abilities, it is still unclear how those programs compare against each other. In addition, it is not clear if the benefits of physical training are comparable between AET and GMA. Thus, this study aims to investigate if the three training groups can improve dual-task performance, and if there are specific dual-task components that are more sensitive or more likely to improve following each type of training. Although all groups are expected to show some form of improvement, it is hypothesized that the COG will show the largest improvement across all parameters, while the GMA group is expected to improve more than the AET in dual-task performances.

Method

Participants

A total of 133 participants from the community provided their informed consent before starting the study. Table 1 documents participants' demographic characteristics. Participants were eligible if were older than the age of 60, were nonsmokers, and consumed less than two standard drinks of alcohol per day. Participants were not eligible if they had followed a structured exercising program of 150 min/week or more in the last year (including home exercising), had contraindications to perform physical activity, had limited mobility, a surgery involving general anesthetic in the previous year, were diagnosed with any orthopedic, neurological, cardiovascular, or respiratory problems within the last 6 months, were diagnosed or suspected to have dementia (a Mini-Mental State Examination score <26; Folstein et al., 1975), had an unstable chronic condition in the past 6 months (new diagnosis or a change in disease presentation or medication), or if they started a hormone therapy program in the past year. Thirty participants were ineligible or dropped out before starting the training program, followed by 17 participants who dropped out during the training period. There was no difference in the demographic parameters between the individuals who dropped out and those who finished the study. Eight participants, who made up the pilot cohort, were excluded from the analysis due to changes to the protocol related to the order of the tests administered. The final sample was comprised of 78 participants (AET: 26; COG: 25; GMA: 27). Supplementary Figure 1 shows the sample flowchart.

Procedure

Following a phone interview, participants were invited to four pretraining appointments over 2 weeks. The eligibility of the participants was evaluated during a medical exam by a geriatrician and a neuropsychological exam with a neuropsychologist (or a trained and supervised psychology student). An experimental tablet-based dual task was also administered on the last appointment. The mobility of the participants was assessed with a 10-m walking test, and their cardiorespiratory fitness was measured with a VO_2

Table 1. Baseline Descriptive Values (Means or Percentage, and Standard Deviations)

Characteristic	All samples, *N* = 78	AET, *n* = 26	GMA, *n* = 27	COG, *n* = 25	*F* or χ^2	*p*
Age	69.98 (5.56)	69.28 (4.85)	70.21 (5.86)	70.46 (6.07)	*F* = 0.32	.73
Education (years)	16.05 (3.62)	16.35 (3.82)	16.26 (3.73)	15.50 (3.37)	*F* = 0.41	.66
Attendance (%)	91.99 (5.46)	92.73 (4.79)	90.84 (6.10)	92.44 (5.41)	*F* = 0.92	.40
Female (%)	65.4	73.1	74.1	48.0	χ^2 = 4.92	.09
BMI (kg/m^2)	26.10 (4.32)	26.46 (4.60)	25.25 (3.62)	26.63 (4.74)	*F* = 0.80	.46
MoCA[a]	26.33 (2.51)	26.88 (2.30)	26.15 (2.46)	25.96 (2.76)	*F* = 1.08	.34
MMSE[a]	28.49 (1.16)	28.92 (.89)	28.26 (1.29)	28.28 (1.17)	*F* = 2.90	.06
GDS[b] (range)	5.09 (5.66)	3.31 (3.97)	5.74 (5.03)	6.24 (7.33)	*F* = 2.04	.14
Walking speed 10 m (m/s)	1.38 (.18)	1.43 (.22)	1.34 (.13)	1.37 (.18)	*F* = 1.48	.23
VO_2 peak (mL/kg/min)	20.70 (5.87)	21.58 (6.43)	20.26 (5.32)	20.25 (5.95)	*F* = 0.43	.65

Note: AET = aerobic training; GMA = gross motor abilities; COG = cognition; BMI = body mass index; MoCA = Montreal Cognitive Assessment; MMSE = Mini-Mental State Examination; GDS = Geriatric Depression Scale.

[a] Higher scores indicate better performance, range: 0–30.

[b] Higher scores are maladaptive, range: 0–30.

peak test completed on a cycle ergometer. The physical tests and trainings were supervised by a kinesiologist. Please see Pothier et al., (2021) for a more detailed overview of the protocol.

Assessments

VO$_2$ peak

A maximal graded test was performed on a cycle ergometer (Lode, CORIVAL). Participants were equipped with an electrocardiogram and wore a mask to measure the gas exchange. Participants began at a predefined load and were required to maintain a pedaling rate of 60–80 revolutions per minute. The test was deemed complete if the kinesiologist observed physiological signs and symptoms reflecting inability to continue. VO$_2$ peak was defined as the highest relative volume of oxygen consumed over a 30-s interval measured in mL/kg/min. A detailed description of this assessment can be found in the work of Pothier et al. (2021).

10-m walking test

Usual gait speed was assessed using a 10-m walking test in which participants had to walk in a straight line at their usual pace for 10 m.

Dual-task paradigm

This consisted of performing two visual discrimination tasks either separately or at the same time (Lussier et al., 2020). Participants were instructed to identify stimuli presented on the screen by pressing the corresponding button/s as quickly as possible while making as few errors as possible (RT in ms and percentage of accuracy were recorded). The task was administered on an Apple iPad Air 2 tablet. Participants performed this task seated at a desk in a quiet room, and the position of the tablet relative to the participant was standardized and remained the same for all. Each task involved three different stimuli (drawings of animals or planets) presented for 3 s in the center of the screen. The dual-task paradigm involved three different trial types: single-pure (SP), single-mixed (SM), and dual-mixed (DM) trials. In the SP trials, participants had to answer to one stimulus of a single task set (e.g., participants were presented with one stimulus associated with the left hand alone—animals, followed by a separate block where one stimulus associated with the right hand was presented—planets). In the SM trials, participants were presented and responded to one stimulus of either task set (e.g., one stimulus was presented, each trial at random, sometimes from the set associated with the left hand, sometimes from the set associated with the right hand). Finally, in the DM trials, participants were presented simultaneously with two stimuli, one from each task set (e.g., right and left hands), and they had to answer to both. The participants were asked to respond without prioritizing one hand over the other. Overall, there were 60 SP trials answered (30/each hand), 66 SM trials (33/each hand), and 51 DM trials. The participants started by answering 10 SP trials, followed by SM trials and finally DM trials. After reaching the first DM trials, the task alternated mostly between SM and DM trials with 10 more SP trials halfway and 10 SP trials at the end. Overall, the task lasted roughly 15 min. Each trial lasted 3 s, whether answered or not. Unanswered trials and wrong responses were labeled as incorrect and were removed from RT means (Supplementary Table 1 details the accuracy data).

In order to better understand the cognitive mechanisms involved in dual-task performance, two costs were calculated from the RT data: task-set cost (SM/SP) and dual-task cost (DM/SM) (Bherer et al., 2019). This approach of calculating the costs is more conservative than a simple subtraction because it takes into account each individual's response time in the previous block and therefore is less affected by general slowing (similar to a percentage change vs. a subtraction change). Therefore, this gives more weight to the findings reported in this study. The *task-set cost* reflects the ability to maintain different response alternatives in working memory and preparing to respond to one stimulus while controlling for the speed of executing one task. Finally, the *dual-task cost* reflects the delay in RT required to perform two tasks simultaneously. *Intraindividual variability* was also extracted, which measures the variability of RT between all trials of the same type for each participant (Bherer et al., 2006). This value was calculated as the standard deviation of RT divided by the mean RT of a given type of trial (SP, SM, and DM) and reflects RT response consistency (Bherer et al., 2006).

Psychological constructs known to affect cognitive abilities in aging were also measured in order to rule out their potential impact. Depressive symptoms were assessed using the Geriatric Depression Scale (Yesavage et al., 1982), and anxiety levels were measured using the State/Trait Anxiety Inventory (Julian, 2011).

Interventions

Following the pretraining assessments, all participants were randomly assigned to one of the three training programs: AET, GMA, or COG. The randomization was done using a randomly generated list created at the beginning of the study by the project manager where groups were matched for age, sex, and mobility level. All training programs were held in groups of three to six individuals, were supervised by an expert, and took place 3 times a week for approximately 60 min each time for 12 weeks. The physical training programs were individually tailored to each participant's abilities, and the trainer offered progress feedback and encouragement throughout the training. Immediately after the end of the training program, the same tests that were used during pretesting were readministered in the same order over the course of 2 weeks. The structure of all three training programs has been determined based on previous studies (Berryman et al., 2014; Lussier et al., 2015, 2017).

Although past cognitive trainings have been shown to be successful in even shorter programs, the present study used a similar length and structure in all three training programs, to have a comparable exposure across all three groups.

Aerobic training

The AET program was completed on a recumbent bicycle (LifeFitness; Kinequip, St-Hubert, QB) and was designed to increase the aerobic fitness. The program consisted of a high-intensity interval training (HIIT) component and a continuous component which were done on separate days alternating one at a time. The maximal aerobic power (MAP) was determined during the VO_2 peak at pretesting. Every training session started and ended with a 10-min biking session at 50% of the MAP. The target cadence was between 60 and 80 RPM. The continuous component of AET lasted 20 min at 65% of the MAP. The HIIT was comprised of two blocks of 5 min each with a 2-min break in between blocks, alternating every 15 s between 100% and 60% of the MAP. In order to ensure a progression in training loads, every 4 weeks, all power values (during the HIIT and the continuous component) were increased by 5%.

Motor functions training

The GMA was designed to improve walking abilities, based on the program described by Berryman et al. (2014). Each session started and ended with a 10-min walking exercise on a treadmill at a slow speed gradually increasing up to 3 mph. The remainder of the session was comprised of exercises designed to improve mobility, balance, agility, lower-body coordination, and hand–eye coordination; for example, throwing a ball at a target, following an obstacle course, one leg balance, balancing on a stability ball, stationary bodyweight exercises, and walking sideways. In order to increase the difficulty of the GMA, a combination of those exercises was performed at the same time (i.e., one leg balance while throwing a ball at a target). The session concluded with a full-body stretching period for the remaining time.

Cognitive training

The COG was designed to improve executive functions with a focus on switching, inhibition, and working memory. Each session was done in groups of three to six participants in a room with cubicles. Three tasks were done at each training session—dual task, modified Stroop, and N-Back, for an approximate duration of 20 min each. During all training tasks, feedback based on participants' accuracy was provided. A performance bar located at the bottom of the screen displayed comments ranging from "WELL DONE" to "INCREDIBLE!!!!!" and was reset when an incorrect answer was given. The button also flashed green when a correct answer was given or red when it was incorrect. Finally, at the end of each completed session, a graph combining errors and RT showed the individual progress of the participant.

The dual-task training sessions were similar to the dual-task assessment task. The instructions were the same; however, in order to increase the level of difficulty, participants were instructed to prioritize one hand over the other after two training sessions. An additional feedback on speed was also provided for each hand individually. The stimuli used for training were alternating between fruits and vehicles and letters and numbers.

For the N-Back task, the participants had to answer if a presented stimulus was the same or different than the one presented one position (1-back), two positions (2-back), or three positions (3-back) before. Stimuli were presented visually and audibly every 3 s. During the first month, only 1- and 2-back were presented, from the second month the 3-back was added and the third month consisted of only 2- and 3-back. The stimuli used alternated between letters and images between training sessions. Participants were instructed to focus on the accuracy of their response rather than the speed at which they answered.

Finally, the modified Stroop task included four conditions: reading, naming, inhibition, and switching. During the reading condition, letters were presented in small groups corresponding to a bigger identically formed letter (e.g., multiple "H" arranged to form a big "H"). The participant had to press the corresponding letter. In the naming condition, asterisks were presented in the same layout found in the reading condition (e.g., asterisks arranged to form the letter "H"). The participants had to report which letter was presented. In the inhibition condition, letters were presented in small groups, but were incompatible with the bigger formed letter (e.g., multiple "H" arranged to form the letter "F"). The participants were asked to identify the bigger formed letter. Finally, during the switching condition, a white border surrounded the stimuli meaning the participants had to report the identity of the small letter instead of the bigger formed letter. The stimuli used alternated between letters or symbols (e.g., small bars forming a larger plus sign for the inhibition block) between training sessions.

Statistical Approach

All analyses were performed using IBM SPSS v.24.0 for Windows (IBM, Inc., Chicago, IL). Normality of data distribution was checked using the kurtosis and skewness of all variables, and outliers were winsorized at 2 *SD*. All reported p values are two-tailed. The significance level was set to .05, and a Bonferroni correction was applied for all post hoc tests. All tablet data (RT, accuracy, intraindividual variability) were averaged for both hands. The primary analysis consisted of a repeated-measures analysis of variance (ANOVA) with group (AET, GMA, and COG) as the between-subject factor, time (pre vs. post) and trial type (SP, SM, DM) as the within-subject factors on the dependent variables (RT, accuracy, intraindividual variability). Secondary analyses involved repeated-measures ANOVAs with group as between-subject factor and time as within-subject factor on the two dual-task costs variables (task-set cost and dual-task cost) and on the VO_2 peak data.

Results

The baseline characteristics (Table 1) showed no group differences. The sample was relatively fit in terms of mobility (10-m walk test usual gait: 1.36 m/s) and highly educated. Following the training, the VO_2 peak improved only in the AET group (group × time interaction: $F_{(2,75)} = 7.13$, $p < .01$, $\eta^2_p = 0.16$), with the AET improving from 21.58 (±6.43) to 23.51 (±7.23) mL/kg/min, $F_{(1,25)} = 9.18$, $p < .00$, $\eta^2_p = 0.27$.

Dual-Task Performances

The repeated ANOVA on RT data (Figure 1) revealed a significant improvement through time, ($F_{(1,75)} = 45.93$, $p < .01$, $\eta^2_p = 0.38$). However, this effect was characterized by a Time × Group interaction ($F_{(2,75)} = 11.91$, $p < .01$, $\eta^2_p = 0.24$). Post hoc tests showed RT to improve only in the COG group (149 ms, $F_{(1,24)} = 44.25$, $p < .01$, $\eta^2_p = 0.65$) and the GMA group (57 ms, $F_{(1,26)} = 14.24$, $p < .01$, $\eta^2_p = 0.35$), while the change in the AET group was not significant.

The repeated ANOVA also revealed a Time × Trial type interaction ($F_{(2,150)} = 21.48$, $p < .01$, $\eta^2_p = 0.22$). Repeated contrast indicated that RT improved significantly in the dual-mixed trials ($F_{(1,75)} = 27.15$, $p < .01$, $\eta^2_p = 0.26$). Interestingly, this improvement was not characterized by a Time × Trial type × Group interaction, therefore indicating that the improvement in RT seen in the dual-mixed trials was present in all groups.

Dual-Task Costs

The repeated ANOVA (Figure 2) revealed a significant time improvement ($F_{(1,75)} = 5.19$, $p < .05$, $\eta^2_p = 0.07$) and a Time × Group interaction ($F_{(2,75)} = 4.39$, $p < .05$, $\eta^2_p = 0.11$) on the dual-task cost. Post hocs revealed only the GMA group had a significant decrease in dual-task cost ($F_{(1,26)} = 12.74$, $p < .01$, $\eta^2_p = 0.33$), while the AET group ($F_{(1,25)} = 3.22$, $p = .09$, $\eta^2_p = 0.11$) and the COG group ($F_{(1,24)} = 1.21$, $p = .28$, $\eta^2_p = 0.05$) showed no significant change. No significant differences were observed on the task-set cost.

Dual-Task Intraindividual Variability Results

The repeated ANOVA performed on intraindividual variability (Figure 3) revealed a significant time improvement ($F_{(1,75)} = 5.19$, $p < .05$, $\eta^2_p = 0.07$) and a Time × Group interaction ($F_{(2,75)} = 4.39$, $p < .05$, $\eta^2_p = 0.11$). Post hoc analyses showed a significant decrease in intraindividual variability in the COG group only ($F_{(1,24)} = 8.62$, $p < .01$, $\eta^2_p = 0.26$), and nonsignificant changes in the GMA group ($F_{(1,26)} = 3.05$, $p = .09$, $\eta^2_p = 0.11$) and the AET group ($p = .99$, $\eta^2_p = 0.00$). As the two exercise groups seem to improve differently, we also checked for any potential group differences posttraining. The post hoc group analysis on the posttraining data revealed only the COG group to be different than the AET group ($p < .01$), while the GMA

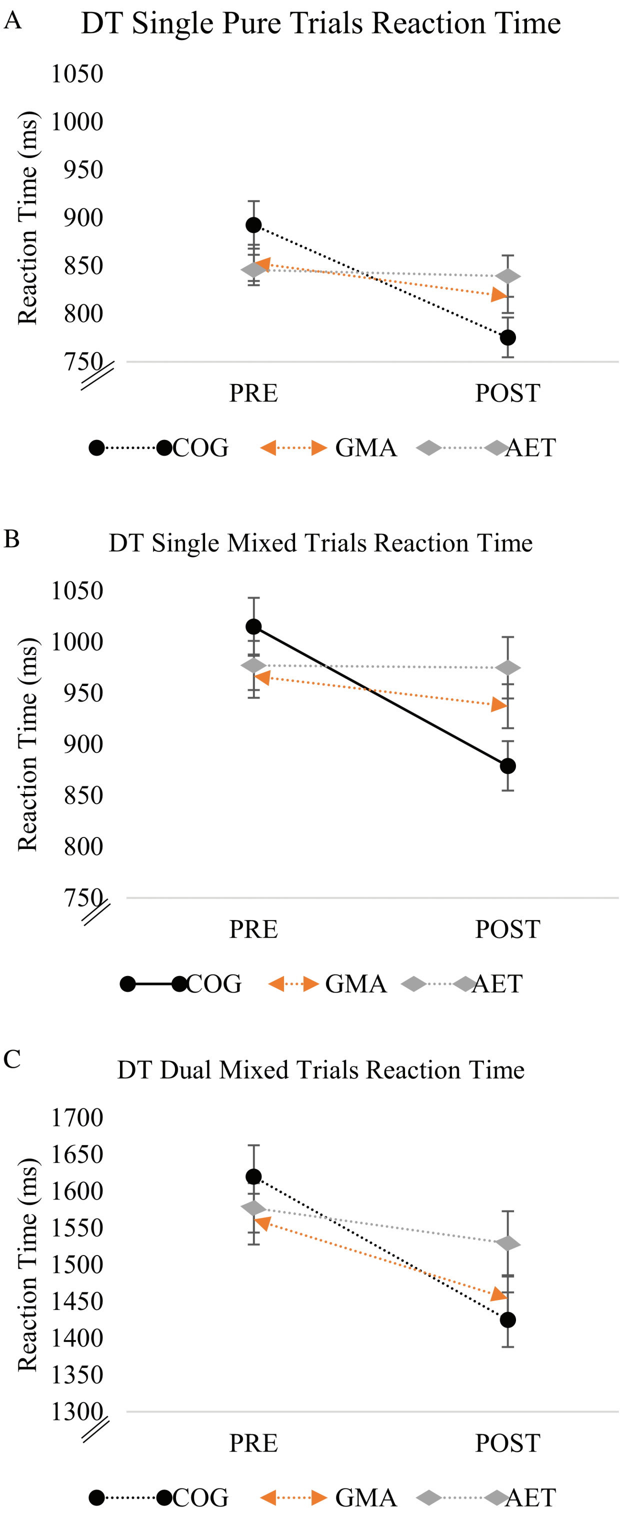

Figure 1. Change in DT reaction time across all blocks. Graphs showing means and standard error. AET = aerobic training; GMA = gross motor abilities; COG = cognition; DT = dual task. Full color version is available within the online issue.

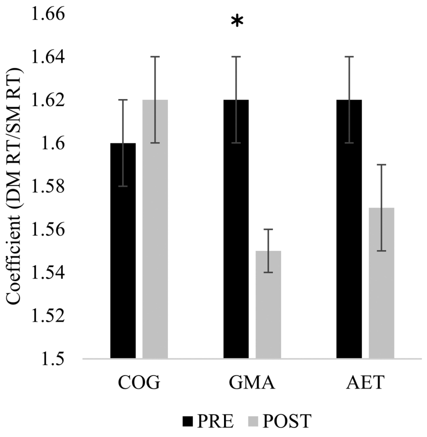

Figure 2. Bar graph illustrating the post hoc analysis of the change in dual-task cost (means and standard errors). AET = aerobic training; GMA = gross motor abilities; COG = cognition; SM = single-mixed; DM = dual-mixed; RT = reaction time; * = $p < .01$.

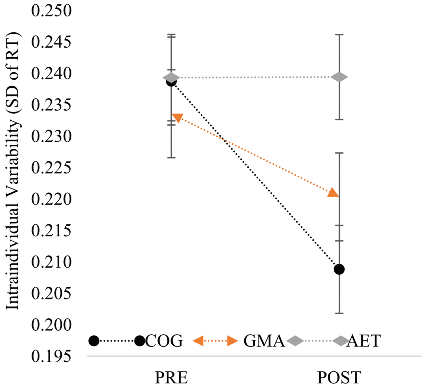

Figure 3. Change in intraindividual variability. AET = aerobic training; GMA = gross motor abilities; COG = cognition; RT = reaction time. Full color version is available within the online issue.

group was not statistically different than either of the other two groups.

Dual-Task Accuracy Results

There was no significant time effect or Time × Group interaction ($p > .05$) on the accuracy data. This is consistent with previous findings showing high accuracy rates on this tablet task (Lussier et al., 2020). Please see Supplementary Table 1 for all DT data.

Discussion

The goal was to compare the effects of two physical training programs relative to a COG program on a cognitive dual task. The results showed RT to improve only in the COG and GMA groups with the highest improvement in the COG group. The RT improvement was also observed to be the highest in the dual-mixed blocks suggesting a potential dual-task cost improvement across all groups. However, further analyses looking at the dual-task cost showed only the GMA group to improve while the AET group was approaching significance. The COG group was the only one to improve the intraindividual variability index. These results suggest that both physical and cognitive training programs can lead to improved performance in dual task, but they affect different aspects of it. In fact, COG led to large improvements in many aspects of the dual task, including a reduced response variability, while GMA seems to lead to larger benefits in improving task-coordination ability. Although only theoretically hypothesized in the past (Ludyga et al., 2020; Netz, 2019), the present study is the first to bring direct evidence to the separate cognitive mechanisms through which different types of training programs affect dual-tasking abilities.

In accordance with previous research (Forte et al., 2013; Gothe et al., 2019; Rehfeld et al., 2017; Wayne et al., 2014), this study shows that GMA has higher cognitive benefits on the dual task than AET. Netz (2019) has suggested that GMA and AET can improve cognition through different mechanisms. The author suggests that physical training programs relying on motor training can improve cognition directly through its cognitive demands and those improvements tend to be task-specific. This means that cognitive tasks that rely on similar cognitive abilities to those trained are likely to show higher improvements. On the other hand, AET would improve cognitive abilities through the benefits following improved cardiovascular fitness, and this cognitive improvement tends to be more global. Effectively, this improved cardiovascular capacity helps the efficiency of the transport of oxygen and nutrients to the brain (Ainslie et al., 2008; Vogiatzis et al., 2011). As a result, changes like increased oxygenated blood flow, neurogenesis, and angiogenesis improve the brain structure and function, which can result in a generalized improvement in cognitive abilities (Brown et al., 2010; Colcombe et al., 2003). In the present study, this differentiation is supported by the specific high dual-task cost improvement observed following the GMA, and the general improvement in RT (although only trending significance) observed in the AET group. The nonsignificant change in RT cost observed in the AET group here does not mean that aerobic exercise cannot improve dual-tasking, as this has been previously shown using a similar dual task (Bherer et al., 2019, 2020). This discrepancy might actually suggest that differences in training intensity or volume might play a role in facilitating the cognitive benefit of dual-tasking and should be further investigated. Furthermore, age seems to also play a role in how AET-induced cardiorespiratory fitness improvements result in better dual-task performance (Bherer et al., 2019) and should be taken into account in the future.

The improvement on the dual task seen in the GMA group could be attributed to the higher cognitive load associated with this type of training compared to AET. The GMA program trained coordination skills and sometimes physical dual-tasking and therefore improved those abilities. More specifically, in the present study, the GMA group improved dual-task cost, which could be explained by the superior improvement in RT in the dual-mixed block rather than the single-pure or single-mixed blocks. This is as a result of the higher demand during the dual-mixed block on switching and coordination skills which were trained as part of the GMA program. The type of dual task that was performed by those participants involved tasks like keeping their balance on one leg while throwing a ball at a target, upper body exercises while balancing on a stability ball, or navigating an obstacle course while holding different items. Even though the tablet dual task is different, the training could have resulted in the generalization of some skills that could have transferred.

Despite the cognitive benefit observed from physical training, COG is the most efficient type of training at improving overall dual-task performance through RT and intraindividual variability. This is expected because the COG used a similar task as part of the training (although with different stimuli, instructions, and feedback). Although not extensively investigated, improvements in intraindividual variability have been recorded following only some forms of interventions (Brydges et al., 2020). Consistent with our results, studies have shown intraindividual variability to be less sensitive following general exercise interventions, but showed improvements following interventions that train attention abilities (Bielak & Brydges, 2019; Brydges et al., 2020). The current results also suggest that COG might be superior at improving the general "cognitive processing" that takes place while performing the dual task, because the improvement in RT is consistent across all trials. The lack of improvement in any of the two costs following the COG in the current study might be due to the way it was calculated. Some studies show cost improvements by subtracting the average RT between the different blocks (Bherer et al., 2005). If the dual-task cost was to be calculated the same way, the current article would reveal a similar improvement in dual-task cost across all groups. This can be observed through the time effect of the repeated contrasts post hoc of the primary analysis. However, some studies show improvements in the dual-task cost calculated as a ratio of the RT (DM RT/SM RT) and suggest that this might be more informative as it is taking into account the change in RT relative to the change in the previous block (Bherer et al., 2019). Indeed, the approach in the present study is more conservative and brings further support to these results. In the current study, the RT improvement following COG was large across all three trials (SP, SM, and DM; which potentially reflects a "floor" effect), and this resulted in a small dual-task cost.

Although the presence of near versus far transfer is still debated in the cognitive training literature, the improvements observed in this study can, to some extent, be explained through transfer. More specifically, the DT improvements observed in the GMA group could reflect far transfer, potentially because this group trained some abilities that are also involved in the DT (i.e., switching, coordination). At the same time, the stimuli used and the task performed were significantly different both perceptually and conceptually (in training vs. testing) which makes this improvement likely to be qualified as far transfer (Barnett & Ceci, 2002). On the other hand, the improvements observed in the COG group could reflect near transfer because the training included a similar task with common specific mechanisms. Although practice effects are also likely to play a role in the cognitive improvements recorded across this study, its impact is considered small because the two physical training groups that had an equal exposure to the DT show a different pattern of improvements.

Moreover, a recent study was able to show that a program using both cognitive and physical training was able to improve the dual-task accuracy task-set cost more than cognitive or physical training alone (Bherer et al., 2020). Similar to the present results, the authors also showed that COG alone was able to improve RT performance, while AET did not have a significant impact on the dual task. This raises questions on other potential mediating variables or the dose effect of AET.

The present study highlights specific dual-task components that can be improved depending on the training modality, which could be used in the future to better test the efficacy of combined training programs. However, it is unclear how the improvements observed in this study would translate to more complex DT paradigms (i.e., following an obstacle course while performing a cognitive task). The currently used DT requires discriminating between two visual tasks and giving a motor response. Dual tasks with two motor inputs are more difficult for older adults and more likely to express age-related differences in performance (Hartley & Little, 1999). As a result, it is unclear how the performance observed on the current task might compare to the performance on other DT. In fact, a study suggests that there could be limited cross-modality transfer effects that can be expected following DT training with this task (Lussier et al., 2012). In other words, the improvement in dual-task performance might not generalize as much to a context requiring another response modality or involving other factors that might affect DT performance. Although the advantage of using this simple DT allows us to identify how the three training types affect specific core components involved in dual-tasking in aging, future studies should try to replicate those results with other more complex DT paradigms.

The results of the present study could be limited by a few factors. First, the relatively small sample size could have affected the results. Second, the simple nature of the DT used in the study helped inform on mechanisms involved in dual-tasking, but this might limit the generalizability of the findings to more complex real-world situations. Future studies could try to replicate the mechanism highlighted above in more ecologically valid paradigms. Finally, the difference in social interactions inherent in each training program is virtually impossible to fully control for when comparing a cognitive training program with a physical training program, and this could have affected to a certain extent the results.

Conclusions

Across all dual-task components, the COG training had the highest improvements, while the GMA training showed superior cognitive benefits than the AET. Specifically, the study shows that COG improves RT the most in a consistent manner, and it might be the best way of improving DT abilities. The results also bring support to the use of lower-intensity motor physical training programs as an effective method to boost cognitive abilities in aging. This is relevant because certain older adults might not be able to follow an intense aerobic program, in which case other types of physical activities could be used to boost cognitive abilities in aging. However, because all programs are likely to improve cognitive abilities through specific mechanisms, a combination of different types of physical exercises, as well as supplementing with cognitive training, might be ideal. However, evidence for this is still limited and should be further investigated.

The current results also highlight the importance of using multiple parameters when investigating cognitive performance on computerized tasks. This allows the capture of different processes or mechanisms that can be improved through different interventions. Future studies are encouraged to employ similar approaches especially when investigating the cognitive benefits of different interventions in older adults using other ecologically valid DT paradigms.

Supplementary Material

Supplementary data are available at *The Journals of Gerontology, Series B: Psychological Sciences and Social Sciences* online.

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Conflict of Interest

None to declare.

Data Availability

This study was not preregistered. Data, analytic methods, and study materials can be made available upon request.

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