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A Comparison of Physical Exercise and Cognitive Training Interventions to Improve Determinants of Functional Mobility in Healthy Older Adults

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ABSTRACT

Objectives: Mobility is a complex but crucial clinical outcome in older adults. Past observational studies have highlighted that cardiorespiratory fitness (CRF), energy cost of walking (ECW), and cognitive switching abilities are associated with mobility performance, making these key determinants of mobility intervention targets to enhance mobility in older adults. The objective of this study was to compare, in the same design, the impact of three training methods - each known to improve either CRF, ECW, or cognitive switching abilities - on mobility in healthy older adults.

Methods: Seventy-eight participants (69.28 ± 4.85 yo) were randomly assigned to one of three twelve-week interventions: Aerobic Exercise (AE; $n=26$), Gross Motor Abilities (GMA; $n=27$), or Cognitive (COG; $n=25$) training. Each intervention was designed to improve one of the three key determinants of mobility (CRF, ECW, and cognitive switching). Primary outcomes (usual gait speed, and TUG performance) and the three mobility determinants were measured before and after the intervention.

Results: Repeated-measures ANOVAs showed a time effect for TUG performance ($F_{(1,75)}=14.92$, $p<.001$): all groups equally improved after the intervention ($\Delta_{TUG_{post-pre}}$, in seconds, with 95% CI: AE = $-.44$ [$-.81$ to $-.08$]; GMA= $-.60$ [-1.10 to $-.10$]; COG= $-.33$ [$-.71$ to $.05$]). No significant between group differences were observed. CRF was improved in the AE group only (Hedges' $G=.27$, small effect), ECW and cognitive switching improved the most in the GMA (Hedges' $G= -.78$, moderate effect) and COG groups (Hedges' $G=-1.93$, large effect) respectively. Smaller improvements in ECW were observed following AE and COG trainings (Hedges' G : AE= $-.39$, COG= $-.36$, both small effects) as well as in cognitive switching following AE and GMA training (Hedges' G : AE= $-.42$, GMA= $-.21$, both small effects).

Discussion: This study provides further support to the notion that multiple interventional approaches (aerobic, gross motor exercise, or cognitive training) can be employed to improve functional mobility in older adults, giving them, and professionals, more options to promote healthy ageing.

Keywords: Aerobic training; Gross Motor Abilities; Computerized cognitive training; Timed-Up and Go Test; Cognitive switching abilities.

INTRODUCTION

Mobility, defined as the ability to move within the environment (Webber et al., 2010), is a crucial clinical outcome in older adults. While usual gait speed, a marker for walking performance, is positively associated with functional status and overall health in aging (Middleton et al., 2015), the Timed-Up and Go (TUG) also represents a pertinent test to monitor older adults' mobility (Podsiadlo et al., 1991). It consists of everyday common motor tasks: to stand up from a chair, to walk three meters, to turn and to sit back on the chair. Individuals with slower TUG performances tend to have an increased risk of incident disability within two years (Donoghue et al., 2014), an increased risk of adverse cardiovascular outcomes (Chun et al., 2019), and an increased risk of all-cause mortality (Bergland et al., 2017). Preventing mobility declines should be a priority as this could delay disability and result in slower disease progression in older adults.

Although mobility is definitely a complex construct, observational studies have highlighted three key determinants of gait speed and TUG performance. *Cardiorespiratory fitness* (CRF), reflecting how efficient the circulatory and respiratory systems are at providing oxygen from the ambient air to the working muscles, is a strong predictor of multiple health outcomes as it integrates many physiological systems (e.g., cardiovascular, muscular, respiratory; see Ross et al., 2016). Higher levels of CRF are associated with faster walking and TUG performances (Berryman et al., 2013). *The energy cost of walking* (ECW), defined as the energy needed to walk through a given distance (Malatesta et al., 2003), is also associated with both gait speed and TUG performances (Berryman et al., 2013; Schrack et al., 2013). In a longitudinal study with a sample of 457 participants aged 40 and older, those with an elevated ECW were at higher risk of developing slow gait speed (Schrack et al., 2016). Along with

physical capacities, walking also requires cognitive abilities, in particular executive functions, to adequately navigate in the surrounding environment (Yogev-Seliman et al., 2008). Interestingly, lower TUG performances seem to be significantly associated with lower executive, and especially *cognitive switching* abilities, in healthy older adults (Langeard et al., 2019), highlighting the involvement of cognition in walking and mobility.

In line with the World Health Organization's recommendations on healthy ageing that emphasize the importance of prevention over treatment, intervention to enhance mobility could have an important impact on older adults' overall quality of life (WHO, 2015). In order to optimize such intervention, it is essential to focus on key determinants of performance, and CRF, ECW as well as cognitive switching appear as great intervention targets. A few past intervention studies have shown that different approaches can be used to improve determinants of walking identified earlier; an aerobic training intervention can lead to improved CRF (Henderson et al., 2017), a gross motor skills intervention to enhanced ECW (Berryman et al., 2014), and a cognitive training focusing on executive functions have led to faster gait speed in older adults (Pothier et al., 2018). However, the effects of these three types of intervention have never been compared in the same intervention study.

Thus, the objective of this original study was to compare, in the same study design, the impact of three training methods (i.e., aerobic exercise, gross motor abilities and computerized cognitive training) known to improve key determinants associated with mobility in older adults (i.e., CRF, ECW and cognitive switching). It was hypothesized that all three interventions would improve both gait speed and TUG performances. Furthermore, it was expected that the improvement in mobility within each training group would be associated with the improvement in the relevant specific variable (i.e., CRF, ECW and cognitive switching).

METHODS

Study design

This is a randomized, parallel assignment, open label intervention study with a three-arm design. After a medical visit performed by a geriatrician and collection of demographic and clinical data, participants were invited to three pre-intervention visits evaluating physical and cognitive outcomes. Participants were then randomized to one of the following three training protocols: Aerobic (AE), Gross Motor Abilities (GMA) or Cognitive (COG) program (see Supplementary Figure 1). After the twelve-week training program, participants completed the same assessments in the same order as pre-tests. All participants provided written informed consent and the study was approved by the ethical review board of the Research Center of the Geriatric Hospital where the study took place. This study was conducted from May 2015 to December 2017. No study-related adverse events (e.g., injuries) have been reported in any of the groups.

Participants

One hundred and twenty-five community-dwelling participants aged 60 years and older met the inclusion criteria and were interested in this study. Inclusion criteria were to be non-smokers, to consume less than two standard alcohol units per day, and not undergo any hormone therapy treatment (to avoid potential interaction between hormone replacement therapy and physical activity effects; Erickson et al., 2007). Participants were excluded if they: participated in a structured training program in the last year, underwent major surgery or were diagnosed with any medical illness within the previous year known to impact the primary variables (mobility, cognitive functions, or their ability to take part in any of the training programs; assessed by the

geriatrician), had contraindications to perform physical activity or limited mobility, thyroid or pituitary diseases, neurological disease or early signs of dementia (Mini Mental State Examination, MMSE<26; Folstein et al., 1975), depression (Geriatric Depression Scale, GDS \geq 11; Yesavage et al., 1982), major uncorrected sensory impairments, or presence of a somatic or known progressive psychiatric pathology.

Interventions

All programs lasted 12 weeks and included a total of 36 sessions of 60-minutes thrice weekly on Mondays, Wednesdays and Fridays. A certified kinesiologist supervised the AE and GMA groups and a research assistant trained in neuropsychology supervised the COG group. In addition, all participants were instructed not to change their daily habits during the research study.

- *Aerobic intervention*

The AE training was designed to enhance CRF (Berryman et al., 2014). Each training session alternated between high intensity interval exercises and moderate intensity continuous exercises. In each session, participants warmed up for ten minutes at 50% of their maximal aerobic power (MAP), which was established during the maximal graded exercise test prior to the intervention. Each high intensity interval session involved two sets of five minutes (with a two-minute resting period in-between) alternating between 15 second bouts of cycling (LifeFitness, Kinequip, St-Hubert, Quebec) at intensities corresponding to 100% of participants' MAP, with 15 seconds recovery at 60%. For the moderate intensity section, the warm-up was followed by 20 minutes continuous cycling at 65% MAP. Every session ended with a 10-minute cool-down period at 50% of their MAP. The intensity of the aerobic exercise was increased individually according to each participant's MAP by 5% after each month, with all participants

increasing to 75% MAP at the end of training protocol for the moderate intensity part and 110% MAP for high intensity.

- *Gross motor abilities intervention*

The GMA training is based on a protocol elaborated in a previous study (Berryman et al., 2014), intended to improve coordination, balance and agility. Participants started each session on a treadmill with a ten-minute low-intensity walking exercise (of increasing difficulty up to a speed of 4 km/h, 1% incline). Mondays' exercises prioritized locomotion and lower body coordination, Wednesdays' exercises targeted balance and Fridays' exercises prioritized hand-eye coordination (e.g., aiming and throwing). As the intervention progressed, exercises combining multiple skills (coordination, agility, balance) were added to increase the level of difficulty. For instance, participants had to maintain balance on one foot before throwing a ball in a box or walk sideways while holding an object in their hand. Participants did these GMA exercises for approximately 30 minutes, and then completed another ten-minute low-intensity walking period. Each session was concluded with five minutes of stretching to increase overall body flexibility and breathing exercises to allow participants to cool down.

- *Cognitive intervention*

The COG intervention was performed in a seated position, on an individual tablet through a dedicated web-based computerized neuropsychological battery. The training was composed of three different tasks centered on executive functions: Dual-task, Stroop and N-Back. The tasks involved instruction and difficulty manipulations and individualized feedback to maximize performances.

- The *Dual-Task* paradigm (Lussier et al., 2020) involved performing two discrimination tasks alone or concurrently. Participants had to discriminate three different stimuli

by pressing the appropriate button with their left thumb or/and to discriminate three others with their right thumb. Stimuli (fruits vs. means of transportation, letters vs. numbers, or sounds vs. beeps) were presented visually or auditorily. After two training sessions, participants were asked to prioritize one hand over the other during the dual-task condition, according to instructions. This was done in order to increase the level of difficulty and maximize training effects.

- The *Stroop* task involved the same five conditions used at pre- and post-intervention assessments (familiarization, reading, counting, inhibition, switching; see below), but used different stimuli (tasks are identical but included letters and symbols instead of numbers, to avoid training on the pre- and post-tests stimuli).

- The *n-back* task is a continuous performance task requiring to update information. Stimuli (from either a group of 9 consonants or 6 symbols) were presented sequentially and participants had to indicate if the current stimuli matched the one from n steps earlier in the sequence. Stimuli were presented visually, on the screen, and were also heard in each participant's headphones. Two response buttons were displayed on the right side of the tablet. The one presented in the top portion of the screen was used for the response "is the same" and the one in the bottom portion for "is different". Only the right thumb was used for this task. For the present study, the load factor n could vary from one to three. During the first month, only 1- and 2-back were administered. At the beginning of the second month, 3-back was incorporated and for the third month of training, only 2- and 3-back were administered.

Each training session of the cognitive program was composed of approximately 20 minutes of each task, with increasing difficulty throughout the 12-week intervention. Participants were instructed to answer as fast as possible while avoiding errors.

Outcomes

Primary Outcomes:

- *Gait Speed:* Walking speed was assessed by using a 10-m walking test in which participants had to walk in a straight line at their usual pace. Timing gates (TC-System, Brower Timing Systems, Draper, Utah, USA) were used to calculate walking speed in m.s⁻¹ for each participant. Three trials were completed, and the average completion time was recorded for the analyses. Recently, in a cohort of community-dwelling older adults, Donoghue et al. (2019) reported good test-retest reliability for this commonly used measure (SEM_{95% IC} in cm.s⁻¹: 0.0703 (0.062 – 0.0798); ICC_{95% IC}: 0.88 (0.83-0.91)). Of relevance, an important past study has shown that the best initial estimate of small meaningful change is near 0.05 m.s⁻¹ for this test (Perera et al., 2006).

- *Timed-Up and Go test (TUG):* Participants had to rise from a chair (with armrests), walk three meters, turn around a cone, walk back to the chair, and sit down (Podsiadlo et al., 1991). Participants were asked to walk at their usual gait speed. Three trials were administered per condition, and the average performance of the three trials (in seconds) was kept for the analyses. Good test-retest reliability was also found for this test (Donoghue et al., 2019) with a TUG's minimal detectable change at the 95% confidence level of 2.08 s (SEM_{95% IC}: 0.75 (0.66 – 0.85); ICC_{95% IC}: 0.75 (0.66-0.82)).

Secondary Outcomes:

- *Cardiorespiratory fitness (CRF):* Peak oxygen uptake, VO₂Peak, was used to assess participants' CRF. The detailed protocol has previously been described (Berryman et al., 2013). All participants completed a maximal graded exercise test on a cycle ergometer (Lode, CORIVAL). They were equipped with an electrocardiogram to monitor heart rate and wore a mask that covered their mouth and nose for gas exchanges during the test (analyzed using the

Medgraphics Cardio₂ Metabolic Cart and Breezesuite software; Medical Graphics Corporation and Medisoft SA, United States of America). Once calibration was completed, participants began at a pre-defined load (women had an initial workload of 35 Watts and men began at 50 Watts), which was then increased by 15 Watts every minute (regardless of sex). Participants were required to maintain a pedaling rate of 60 to 80 revolutions per minute. Testing was completed when participants were unable to maintain the cadence or according to criteria described by the American College of Sports Medicine (ACSM, 2001). A certified exercise physiologist administered all tests. VO₂Peak was defined as the highest volume of oxygen consumed over a 30 second interval in ml.kg⁻¹.min⁻¹. CRF is generally associated with good test-retest reliability in older adults (see Hugget et al., 2005, for a review; r=0.67-0.90).

- *Energy Cost of Walking (ECW)*: To measure ECW, all participants were equipped with the same mask and utilized the same metabolic cart (and the same calibration procedure) to measure the O₂ consumption and CO₂ production as during the VO₂Peak assessment. They walked on a treadmill for six minutes at a constant speed of 4 km.h⁻¹. The ECW was calculated as described elsewhere (Berryman et al., 2017); briefly, the oxygen uptake of walking (representing the mean VO₂ from the last two minutes of the walking task, in ml.kg⁻¹.min⁻¹) was divided by the walking speed (m.min⁻¹) to obtain the oxygen cost of walking in ml.kg⁻¹.m⁻¹. Thereafter, values in ml.kg⁻¹.m⁻¹ were converted in L.kg⁻¹.m⁻¹. Using the respiratory exchange ratio (RER) corresponding to the last two minutes of walking, an appropriate energy equivalent of oxygen (J.L⁻¹) was used to convert the previously calculated oxygen cost of walking (L.kg⁻¹.m⁻¹) in J.kg⁻¹.m⁻¹ (Peronnet & Massicotte, 1991) to obtain a suitable ECW. These procedures are in agreement with the literature for moderate intensity exercise and have the advantage of considering substrates metabolized during exercise (Fletcher et al., 2009; Xu & Rhodes, 1999).

Oxygen steady-state and RER values less than 1 during the last two minutes of walking were necessary to consider measurements as being valid. Good test-retest reliability for the ECW was observed in a sample of 43 participants (including 20 older adults): ICC = 0.86 and Coefficient of Variation = 3.4% (Gaesser et al., 2018).

- *Cognitive switching*: A Digit-Stroop task was used to evaluate executive functions, and especially cognitive switching (Sedo, 2004). It consisted of five different conditions, all presented on a touch-sensitive tablet (a 3rd generation 9.7 inches Ipad). First, in the Familiarization part, participants had to press the button corresponding to the digit presented on the screen (“1” to “3” with their left thumb, “4” to “6” with their right thumb). Second, in the Reading condition, multiple identical digits were presented in a small group; the identity of the digit corresponded with the quantity of the digits presented (e.g., four copies of the digit “4”) and participants had to press the corresponding button with their thumb. In the Counting condition, groups of one to six asterisks were presented and the participants had to report how many asterisks were present. In the Inhibition condition, multiple identical digits were presented on the screen and the digits’ identity was incompatible with the quantity presented (e.g., five copies of the digit “4”). Participants were asked to identify the quantity of digits, and to avoid reporting the identity of the digits. Finally, stimuli in the Switching condition were identical to those of the Inhibition condition, except that, for some random trials, the group of digits was surrounded by a white frame, indicating a switch of goal: for those trials only, participants had to report the identity instead of the quantity of digit(s). For each condition, mean reaction times (RT, in seconds) of the correct trials were collected. For the present study, the variable of interest extracted from the digit-Stroop task was the *Switching* condition, due to its documented relevance in mobility (Langeard et al., 2019).

Sample Size

To estimate the correct sample size, three power analyses were done (one per intervention group). To detect a pre-to post-intervention difference on each key determinant of mobility, with an α risk of .05% and 80% power, 12 individuals were required in the COG group, 20 in the AE group and 32 in the GMA group. The higher estimation (n=32) has thus been selected. Considering a dropout rate of approximately 25% (based on previous intervention studies conducted in our lab), a minimum of 120 participants have been recruited.

Randomization and masking

A random sequence was generated using SPSS, then individually altered, one participant at a time, until the three training groups were equivalent for gender, age, education level, and usual gait speed at baseline (within a 95% confidence interval). The coordinator of the study was responsible for randomizing participants and kept confidential all the information linking data to participants' identity in a password-protected computerised file.

Participants were aware of the three intervention groups available and knew after the pre-intervention evaluations which of the three groups they were assigned to. Evaluators administering the pre- and post-intervention tests were blind to participants' assigned interventions and, overall, trainers were not involved in the pre- and post-intervention evaluations (the certified kinesiologist who supervised the AE and GMA training programs was present to guide the evaluators during the CRF and ECW pre-intervention testing).

Numbers Analyzed

Among the 125 participants who completed baseline screening, 30 ceased the program prior to or during pre-training evaluations due to exclusion criteria or scheduling conflicts. From the remaining 95 participants that were randomized (AE: 32, GMA: 32, COG 31), 17 abandoned

the intervention voluntarily before its completion (6 from AE: study too demanding = 1, sickness/health issues = 2, no longer interested = 3; 6 from COG: study too demanding = 1, sickness/health issues = 2, no longer interested = 2, too many absences = 1; 5 from GMA: study too demanding = 1, sickness/health issues = 2, no longer interested = 1, involved in another parallel study = 1), leaving a total of 78 healthy older adults in the final sample (see Supplementary Figure 2). Participants were required to attend at least 75% of the training sessions to be included in the final analysis. Only one participant (COG) met this exclusion criteria. All the statistics were performed with the data from the 78 participants.

Statistical Analysis

Data distribution was checked by probing the kurtosis and skewness of all variables, and, to decrease the impact of outliers, data were winsorized at 3 SD away from the mean (Tabachnick & Fidell, 2019). Less than 1.5% of the data was missing, and Little's MCAR test using expectation maximization showed that the data was missing at random ($X^2 = 1452.548$, $p = 1.00$). As a result, the missing data was replaced with an average obtained from five multiple imputations using the SPSS built-in Mersenne Twister Random Number Generator, following the Markov chain Monte Carlo method. All statistical analyses were performed using IBM SPSS Statistics software v20 for Windows (IBM, Inc., Chicago, IL).

To investigate the effect of the three training interventions on our primary outcomes (gait speed and TUG performances), and on secondary outcomes (CRF, ECW, and cognitive switching), repeated measures ANOVAs were used with time (pre-post) as the within-subjects factor, and group (AE, COG, GMA) as the between-subjects factor. Where necessary, Bonferroni post-hoc tests were used. All reported p-values are two-tailed, and the significance level was set to .05. Effect sizes were calculated using Hedges' G (see Dupuy et al., 2014). As

proposed by Cohen (Cohen, 1988), the magnitude of the effect was considered small ($.2 \leq ES < .5$), moderate ($.5 \leq ES < .8$), or large ($ES \geq .8$). Correlations were used to evaluate potential associations between the primary (potential change in gait speed and TUG performances) and secondary outcomes (changes in the training related variables within each group (CRF, ECW, and cognitive switching)).

RESULTS

Baseline data

There were no group differences observed at baseline for any of the general characteristics (see Table 1).

Training Effects on the primary outcomes

The gait speed did not differ between groups and did not significantly change after the training (all $p > .05$; Hedges' G: AE=.05; GMA=.10; COG=-.07).

The TUG showed a significant time effect ($F_{(1,75)}=14.92$, $p<.001$) but no group*time interaction ($F_{(2,75)}<.44$, $p=.645$), which indicates that all groups significantly improved TUG performances after the intervention (see Figure 1; $\Delta_{\text{Post-Pre}}$, in seconds, with 95% CI: AE = -.44 [-.81 to -.08]; GMA= -.60 [-1.10 to -.10]; COG= -.33 [-.71 to .05]). The magnitude of the pre-to-post difference was considered small for each group (Hedges' G: AE=-.31; GMA=-.39; COG=-.22).

Training Effects on secondary outcomes

Cardiorespiratory Fitness: While there was no significant time effect ($F_{(1,75)}=1.12$, $p=.293$), the group*time interaction on CRF was significant ($\text{VO}_{2\text{Peak}}$ values: $F_{(2,75)}=7.13$, $p=.001$). The AE group was the only one to show improvement ($F_{(1,25)}=9.18$, $p=.006$): $\Delta_{\text{Post-Pre}}$, in

ml.kg⁻¹.min⁻¹, with 95% CI: AE= 1.932 [618 to 3.245]; GMA= -.329 [-1.144 to .486]; COG= -.639 [-1.710 to .432]). The magnitude of the pre-to-post difference was considered small (Hedges' G=.27) for the AE group (Hedges' G: GMA=-.06; COG=-.11) (see Figure 1).

Energy Cost of Walking: The gross ECW revealed a significant time effect ($F_{(1,74)}=23.18$, $p<.001$) but no significant group*time interaction ($F_{(2,74)}=.70$, $p=.502$). All groups improved after the intervention: $\Delta_{\text{Post-Pre}}$, in J.kg⁻¹.m⁻¹, with 95% CI: AE= -.197 [-.361 to -.033]; GMA= -.317 [-.466 to -.168]; COG= -.194 [-.408 to .019]). The effect sizes suggest a difference between groups though, with a numerically higher relative change in magnitude for GMA (Hedges' G= -.78 [moderate effect]), compared to AE and COG groups (Hedges' G: AE=-.39, COG=-.36 [both small effects]); see Figure 1).

Cognitive switching: a significant time effect ($F_{(1,75)}=127.166$, $p<.001$), and a group*time interaction were found in the switching block of the Stroop task ($F_{(2,75)}=42.23$, $p<.001$). Although all groups showed an improvement (AE: $F_{(1,25)}= 8.77$, $p<.01$; GMA: $F_{(1,26)}=6.54$, $p<.02$; COG: $F_{(1,24)}=189.00$, $p<.001$; $\Delta_{\text{Post-Pre}}$, in ms, with 95% CI: AE= -119 [-202 to -36]; GMA= -76 [-137 to 14.92]; COG= -500 [-575 to -425]), COG had the highest change in magnitude (Hedges' G: COG=-1.93 [large effect]; AE=-.42, GMA=-.21, [both small effects]; see Figure 1).

The correlations between changes in TUG and changes in the training related variables within each group only revealed a significant positive association in the GMA group: the improvement in mobility (TUG change) is associated with the improvement in ECW for these participants ($r=.461$, $n=27$, $p=.016$). The other correlations are non-significant ($p > .05$ for all correlations; see Supplementary Table 1).

DISCUSSION

The objective of the present study was to compare the impact of three specific physical and cognitive interventions on determinants of mobility performance in a cohort of healthy older adults. As expected, results revealed similar benefits induced by AE, GMA and COG interventions on TUG performances. Interestingly, and as hypothesized, each intervention improved key determinants associated with mobility: CRF, ECW and cognitive switching abilities, although these specific improvements were only partially correlated to changes in TUG performances.

In contrast to our main hypothesis, the three training programs did not induce gait speed improvements in this cohort. Intervention studies have previously demonstrated the positive impact of aerobic, gross motor and even cognitive exercises on older adults' walking performance (Boyne et al., 2017; Cadore et al., 2013; Henderson et al., 2017; Intzandt et al., 2018). However, these past studies have focused on improving gait speed in older adults at risk (post-stroke or frail patients, obese individuals, or older adults with Parkinson's disease). In addition, when included populations were healthy older adults, previous intervention studies showing mobility improvements used more complex walking tests such as pathways with longer distances and/or a curved path, similar to the TUG test (Hortobágyi et al., 2015; Pothier et al., 2018). Moreover, the population included in the present study was relatively young ($m=69.28 \pm 4.85$ yo), highly educated ($m=16.35 \pm 3.82$ years of education) and with a mean gait speed at baseline above normal values ($m=1.38 \pm .17$ m.s⁻¹ – expected values being around 1.29 m.s⁻¹ for this age; see Bohannon et al., 2011). Therefore, the absence of a gait speed pre-to-post change in this study could be explained by a ceiling effect due to the use of a too simple walking test considering our fit sample.

The present study reports an overall pre-to-post change related to a more complex assessment of mobility (higher TUG performance, a crucial determinant of functional mobility) in older adults without significant health or mobility deficits. Of importance, this improvement, following three different training programs targeting key mobility-related mechanisms (CRF, ECW, cognitive switching), is equivalent among training groups. Due to the multi-determined design of the TUG test, reflecting a sum rather than a single entity of physical abilities (Benavent-Caballer et al., 2016), it is not surprising to observe improvements in mobility following both AE and GMA trainings in our population. These results are in line with previous studies showing a positive impact of aerobic, strength, or balance training programs on functional mobility (Steadman, Donaldson, and Kalra, 2003; Hess and Woollacott, 2005; Freiburger et al., 2007; Coetsee and Terblanche, 2017). Conversely, this is one of the very few studies in healthy older adults demonstrating TUG improvements after a computerized cognitive intervention focused on EF (see also Smith-Ray et al., 2015). Previous intervention studies reported better TUG scores after multicomponent training programs such as cognitive-motor dual-task exercises (Vaillant et al., 2006) or computerized sport games (Pichierri et al., 2011). Results reported here extend previous findings by demonstrating that seated cognitive stimulation alone, targeting executive functions, can help improve older adults' functional mobility. Although the observed TUG improvement must be interpreted with caution since it is most likely within the TUG's minimal detectable change, it should nevertheless be highlighted that such small changes might be quite relevant in a highly functional population with a much smaller margin for improvements compared to participants with mobility limitations. From a clinical standpoint, reinforcing that multiple roads (i.e., AE, GMA, and COG trainings) can be followed to maintain or improve such a crucial outcome is of great interest. Older adults could

therefore choose their own program (different physical or cognitive exercises) based on their motivation, abilities, or the available facilities and human resources, and expect similar improvements in functional mobility, and therefore in daily autonomy. The current findings are in line with the WHO's recommendations on healthy ageing (WHO, 2015) promoting better preventive care (rather than reacting to a disease) by supporting specific interventions enhancing healthy older adults' intrinsic capacities over time. In addition, healthcare professionals (e.g. kinesiologists, neuropsychologists) could consider one of these three interventions as an option during the implementation of an older individual's training program.

As predicted, each intervention used in the present studies also improved specific variables associated with mobility, showing higher CRF, ECW, and switching performances following respectively the AE, GMA, and COG training programs. Interestingly, results also showed crossed improvements; while CRF was the only variable to show an exclusive improvement following the AE training, switching performances improved the most in the COG group followed by smaller, but significant, improvements in GMA and AE groups. Similarly, although the largest improvement in ECW was observed in the GMA group, smaller significant improvements were also detected in the two other groups. While cognitive benefits following exercise interventions have been regularly reported (Colcombe and Kramer, 2003; Ludyga et al., 2020; Northey et al., 2018), the present study confirms this phenomenon by showing that *both* AE and GMA were able to enhance switching abilities. Since the two physical groups targeted different training components (aerobic vs. gross motor functions), the cognitive switching improvement is likely linked to different mechanisms. It has been hypothesized that the cognitive benefit of AE training would be associated with production changes of neurotrophic factors, whereas the improvements observed in GMA training could rely on specific neurocognitive

mechanisms, such as a higher activation in the visual–spatial network (see Bherer and Pothier, 2021 for review). Similarly, in addition to the GMA group, the ECW was improved in AE participants and, more surprisingly, in COG group. Considering the strong links between mobility performance and executive functioning (Yogev-Seliman et al., 2008), one could hypothesize that specific cognitive exercises would increase specific brain areas that are also involved in ECW performance, and enhance compensatory mechanisms (Li et al., 2018) to further observe lower ECW values following an efficient cognitive training program centered on executive functions. Although more studies are required to better understand this relationship, the current results expand the available literature by showing that COG training can also improve walking efficiency. We hypothesized that TUG improvements would have been observed through modifications in key secondary outcomes. Results showed a significant positive association between TUG and ECW changes in the GMA group, supporting the role of ECW in complex mobility. However, the absence of significant correlations between primary and secondary outcomes in the other groups, despite observed crossed improvements, support the notion that mobility is a truly complex construct, potentially involving a cascade of other secondary changes that would need to be investigated.

Some limitations associated to this intervention study should also be pointed out. First, regarding the lack of participants' motivation measurement; as is the case with all training intervention studies, it is possible that participants that were more motivated to take part in the study could have benefited more from the training program (Ferrand et al., 2014). Second, it would be interesting to extend these findings to more accurate and precise outcomes, specifically regarding mobility. However, a recent study compared the accuracy of gait testing in natural setting with with gaitmat or electric walk mats and showed the reliability of measuring usual gait

speed with stopwatch (Montero-Odasso et al., 2020). In addition, the fact that no study, to our knowledge, has evaluated the psychometric properties of the digit-stroop task could also be reported as a limitation. Previous RCTs have used the same task and reported a positive impact of physical interventions on executive functioning in older adults (see Esmail et al., 2020) but further research studies would be needed to fully understand the impact that the intervention has versus the test-retest variation in the tests used. Third, and although the present study employed a similar intervention structure, length and intensity based on other successful protocols (e.g., Berryman et al., 2014; Pothier et al., 2018), it still remains unclear if those values are truly comparable. A recent perspective article (Herold et al., 2019) emphasized the fact that the observed interindividual heterogeneity in response to physical exercising could be addressed with an adapted exercise prescription (making doses comparable across the individuals). This improved understanding of dose–response relationships could help designing more efficient training programs approaches against age-related declines. Finally, this study was not considered as an RCT considering the absence of a control group with no exercise at all. Therefore, it was not preregistered, which could be considered as another limit. However, there was no other study comparing in parallel those interventions and it seemed necessary to perform this first study before moving forward with a more comprehensive RCT.

The present results do strengthen the idea that multiple approaches can be followed to maintain functional mobility outcomes in older adults. In addition, the current results show that three types of intervention programs, using aerobic and gross motor exercise or cognitive training can be used to improve mobility in healthy older adults. The specific mechanisms supporting these efficient interventions remain to be elucidated and require further investigation,

including future studies using combined training programs, to better understand the different pathways through which functional mobility can be improved.

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

CONFLICT OF INTEREST

The authors declare that they have no competing interests.

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Table 1. Baseline descriptive values (means or percentage, and standard deviations).

Characteristic	All sample N=78	AE n=26	GMA n=27	COG n=25	<i>F</i> or χ^2	<i>p</i>
Age	69.98 (5.56)	69.28 (4.85)	70.21 (5.86)	70.46 (6.07)	F= .32	.73
BMI (kg/m ²)	26.10 (4.32)	26.46 (4.60)	25.25 (3.62)	26.63 (4.74)	F= .80	.46
Handgrip (kg)	53.21 (18.41)	52.58 (16.93)	53.72 (21.17)	53.32 (18.41)	F= .03	.98
Education Level (years)	16.05 (3.62)	16.35 (3.82)	16.26 (3.73)	15.50 (3.62)	F= .41	.66
Female (%)	65.4	73.1	74.1	48.0	X ² =4.92	.09
Attendance (%)	91.99 (5.46)	92.73 (4.79)	90.84 (6.10)	92.44 (5.41)	F= .92	.40
MMSE	28.49 (1.16)	28.92 (.89)	28.26 (1.29)	28.28 (1.17)	F=2.90	.06
GDS	5.09 (5.66)	3.31 (3.97)	5.74 (5.03)	6.24 (7.33)	F=2.04	.14
Cardiovascular Risk	.73 (1.24)	.97 (1.20)	.70 (1.32)	.60 (1.22)	F= .31	.74

Abbreviations: BMI: Body Mas Index; Handgrip: kg force, sum of both hands; Sit-to-Stand: in seconds; MMSE = Mini Mental State Examination; GDS = Geriatric Depression Scale; Cardiovascular Risk = total number of concurrent conditions analysed by the geriatrician (high blood pressure, diabetes, high cholesterol, coronary artery disease, congestive heart failure, arrhythmia, valvular heart disease)

Table 2. Pre and post mean values (standard deviation) of walking speeds, and all secondary outcomes, for each training group.

Variables	AE		GMA		COG		Group*Time Interaction	
	Pre ^β	Post	Pre ^β	Post	Pre ^β	Post	F	p
Gait Speed (m.s ⁻¹)	1.43 (.23)	1.43 (.21)	1.34 (.13)	1.36 (.12)	1.37 (.17)	1.36 (.15)	.292	.748
Timed-Up and Go, in sec	8.54 (1.45)	8.10 (1.30)	8.93 (1.65)	8.33 (.96)	8.86 (1.48)	8.53 (1.35)	.441	.645
Cardiorespiratory Fitness (VO _{2Peak} in ml.kg ⁻¹ .min ⁻¹)	21.58 (6.43)	23.51 (7.23)	20.26 (5.32)	19.93 (4.82)	20.25 (5.95)	19.61 (5.67)	7.128	.001*
Energy Cost of Walking gross values (J.kg ⁻¹ .m ⁻¹)	3.74 (.48)	3.54 (.50)	3.91 (.44)	3.60 (.32)	3.93 (.57)	3.73 (.44)	.695	.502
Cognitive switching (ms)	1646.95 (263.43)	1527.50 (280.72)	1593.75 (354.74)	1517.71 (297.24)	1691.56 (268.84)	1191.12 (196.32)	42.231	<.000*

Abbreviations: TUG: Timed Up-and-Go test; CRF: CardioRespiratory Fitness; ECW: Energy Cost of Walking.

* p value<.05. ^β: no significant difference between the three groups for primary and secondary outcomes

Figure 1: Pre-to-Post Changes for all groups in Timed-Up and Go (TUG) test, and in each training relevant variables.

