Are 8 weeks of Nordic Walking training sufficient to benefit cognitive performance in healthy older adults?

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ABSTRACT

Introduction: Nordic walking (NW) requires the association of walking and coordination of limbs while orienteering in a natural environment, and it has been shown to improve functional capacities more than normal walking. However, cognitive benefits are less clear.

Purpose: The main hypothesis was that NW training improves visuospatial capacities and inhibition functions.

Methods: 14 healthy older adults were included. NW training was performed 3 sessions of 75 min a week for 8 weeks. Pre-, intermediate, and post-tests were carried out. Cognitive functions including global cognition (MoCA), executive functions (Color-Words Stroop test), information processing speed, switching capacities (Trail Making Test – A and B), and visuospatial capacities (Rey Complex Figure Copy Task), were assessed. Motor functions including balance control (Unipedal Balance Test), functional mobility (Timed Up and Go), hamstring flexibility (Chair-Sit and Reach test), and motor coordination (Four-Square Stepping Test) were evaluated and physical function including lower limb strength (Timed Sit-To-Stand), and cardiovascular capacities (Incremental Shuttle Walking Test) was measured.

Results: Cardio-vascular capacity, strength of lower limbs and coordination were positively affected by training. NW improved visuospatial capacities. Switching capacities, information processing speed and executive functions did not improve, probably needing longer programs to show benefits. However, analyses of respondents suggested that NW positively affected cognitive functioning in a subpart of participants.

Conclusion: 8 weeks of NW training was enough to produce some physical, motor and cognitive improvements. Longer training duration could be necessary to extend the benefits to executive functions.

INTRODUCTION

Aging is associated with physical, motor, and cognitive declines, which are even more marked in sedentary individuals[1]. Accordingly, delaying or (even partially) compensating for age-related alterations of functional capacities is critical for the growing number of older adults in the general population. In particular, improving cognitive functions (attention, inhibition, visuospatial capacities…) is of major importance due to their role in monitoring behavioral adaptability in everyday life situations and complex movement tasks[2-5].

It is widely admitted that both endurance and muscular resistance training, when performed separately or in association, are effective to counteract the effects of aging on cognitive capacities[6-9]. However, more recently, it has been suggested (and, in some cases, demonstrated) that training programs that combine physical, motor, and cognitive stimulations could be more effective than separated training programs to improve brain plasticity and cognition in older adults (for detailed development, see[10]). However, the question remains of which type of "conventional" physical activity can ensure an effective combination of cognitive, motor, muscular, and cardiovascular stimulations.

Nordic walking (NW) could be considered a good candidate in this respect. Indeed, it is a safe and much-appreciated activity in older adults. Also, it is more effective than normal walking in improving functional capacities and, in particular, maximal oxygen consumption[11,12]. Moreover, it has been suggested that NW could be more appropriate than most conventional activities to improve cognition since it requires a combination of aerobic effort, complex motor skills, and cognitive stimulations[13]. According to the predictions of the Adaptive Capacity Model (ACM[14]), it should promote brain plasticity and cognitive performance[10,14]. In particular, in addition to stimulating brain plasticity through the increase in neurotrophic factors concentrations, Nordic Walking could improve cognitive functions by requiring the coordination of upper and lower limbs, while orienteering in a natural environment, as in dual-task training[13].

However, in spite of its potential interest in improving brain plasticity and cognition in older adults, very few studies have addressed the cognitive benefits resulting from NW, and remain controversial. Indeed, several studies showed significant benefits of NW on cognition[13,15-18] while others did not[19-21]. Therefore, as pointed out by Nemoto et al. (2021)[13], additional cognitive testing should be conducted to determine whether and under which conditions cognitive functions may be enhanced by NW training.

Two main questions deserve to be addressed in this respect. First, what is the minimum training duration for Nordic Walking to be effective to improve cognitive capacities? Most studies have shown improvements in physical, motor, and cognitive functions with training programs lasting

12 weeks or more[15-17]. Other studies have also reported the beneficial effects of shorter NW training programs (i.e. 8-9 weeks) on physical and motor abilities[11,22-24], but cognitive performance was not measured in these works. Thus, it remains unknown whether short NW training programs (even 4 weeks) can benefit cognition, together with physical and motor fitness. A second question concerns which cognitive functions are positively affected by repetitive practice of Nordic walking. In a previous study, we showed that executive functions and speed of information processing were enhanced after a NW training program[17] but a global picture of the cognitive functions that can be improved by NW is still lacking since measured cognitive functions and the used tests are frequently different from one study to the other.

The present study addressed this issue by investigating the time-dependent effect of an NW training program on physical, motor, and cognitive performance in healthy older adults after 4 and 8 weeks, respectively (i.e., 12 and 24 sessions). Our main hypothesis was that, in addition to improving physical and motor capacities, NW training should enhance cognitive functions, at least though maybe with different time profiles of performance over the two subparts of the training program (i.e., first and second 4 weeks periods).

METHOD

Participants

Participants were recruited among the community-dwelling independent-living older adults based in Marseille (France) through an advertisement in the local newspaper. After contacting the project manager, either through phone calls or e-mails, volunteers were screened for the first time for inclusion. Participants were considered eligible if: i) they were between 65 and 80 of age, ii) they did not participate in any physical activity training program in a club or an association during the last 3 months, and iii) they had no previous experience of Nordic Walking. Exclusion criteria were: i) to have a score lower than 26 on the Mini-Mental State Examination (MMSE)[25]; ii) cognitive impairment or language disorders that would preclude understanding instructions, iii) uncontrolled psychiatric or cardiovascular affections, iv) uncorrected vision and hearing, and v) psychotropic or bradicardizing medical treatments.

Participants were informed about the organization of the training programs (location, schedule, attendance, coaches, tests, etc.), as well as their rights, benefits, and potential risks. To volunteer to participate in the study they had to provide informed consent. After consenting, participants underwent medical screening by a geriatrician during which they were assessed for general health status and lifestyle behaviors.

Their capacity to perform moderate to vigorous effort (i.e., 60–70% of maximum) was assessed through a submaximal stepping test conducted at the Clinique Provençale de Médecine du Sport of the local hospital Saint Marguerite in Marseille and supervised by a cardiologist. Adaptation of the exercise protocol was considered by medical doctors for participants reporting previous cardiovascular problems. The sample descriptive characteristics are presented in Table 1.

Sample size

The sample size calculation was performed using G. Power 3.1.9.7 (Kiel, Germany)[26]. In order to detect relevant differences in the changes from the pre-test to the intermediate test and the post-test, respectively, we calculated a sample size sufficient to detect medium effect sizes. Therefore, f = 0.35, = 0.05, and p = 0.80, were chosen to favor clinically significant effect sizes. To test the main hypotheses of the present study, 15 participants were required. 15 volunteers were initially recruited to participate but one dropped out during the course of the inclusion, and 14 healthy older adults completed the study.

Table 1. Sample characteristics (M ± SD)

	M ± SD
Age (years)	71.1 ± 3.7
Gender	10 F – 4 M
Height (cm)	160.6 ± 6.5
Weight (kg)	68.4 ± 9.6
BMI	26.5 ± 3.7

Study design & training intervention

The study was conducted in accordance with the Declaration of Helsinki, and the protocol had been approved by the French National Ethics Committee (CPP IDF10 no. 2019-A03263-54).

The 8 weeks Nordic Walking training intervention took place in a natural park, with rugged terrain offering multiple ways of different lengths to modulate the difficulty and, consequently, orientation processes, the required level of endurance effort, as well as the complexity of gait and postural control.

The program consisted of 3 sessions of 75 min each per week (i.e., 24 h in total). Each training session was organized as follows: i) a 15 min warm-up phase including exercises for muscular activation and motor coordination; ii) a 50 min core training phase, and iii) a 10 min cool-down phase with stretching exercises to restore baseline HR values. Participants were provided with heart rate monitors (Decathlon HR300™) and were instructed on how to record their heart rates, at rest and during NW sessions. The heart rate monitor allowed the coach and the scientific team to ensure that mean heart rates reached during each session were close to 70–80% of their predicted HRmax, calculated with the conventional Tanaka et al.'s formula (208 - 0.7 x age)[27].

The training intervention was supervised by an experienced coach, officially licensed in a multisport club (i.e., Stade Marseillais Université Club), which proposes programs of adapted physical activity to older adults. The coach volunteered to participate in the experiment. The participants were informed that their data, recorded during assessment tests, would be anonymized and analyzed to determine the effectiveness of the training program.

The scientific team (i.e., the authors) had several work sessions with the coach before the training intervention to define the different parts of the sessions and their contents. They allowed to fix the training strategy according to general principles. In particular, the coach was asked to design exercises requiring spatial orientation in the natural park where the sessions took place. Also, he was asked to include, during the warm-up of the sessions, technical exercises to learn coordinating the upper limbs with walking, in order for the participants to optimally use the sticks. Also, the coach was asked to progressively increase the level of difficulty of endurance effort and step control on cluttered terrain, over the 8 weeks, trying to individualize, as far as possible, the requested effort level while managing the whole group, as in our previous study[17].

Finally, a member of the scientific team was observing all the sessions to check whether the instructions were respected, by both the coach and the participants. The reported observations were discussed after each session with the coach and the team, which allowed us to adapt the contents of the sessions over the training period, as a function of the behaviors produced by the different participants.

Assessment procedure

Pre-tests were carried out one week before the training period started. Intermediate tests (i.e., after 4 weeks) and post-tests (i.e., after 8 weeks) were also carried out. Cognitive, physical, and motor performance were assessed at the Institute of Movement Science (ISM) (Marseille, France). All test sessions were organized and managed by several scientific team members with the help of students of the Faculty of Sport Sciences in Marseille, specializing in Adapted Physical Activity. The coach did not participate in the assessment sessions and he was not informed about the results of the different tests before the end of the training program.

Cognitive assessments

Global cognitive status was evaluated with the Montreal Cognitive Assessment (MoCA). This test is considered highly sensitive to detecting Mild Cognitive Impairment (MCI). Three different versions of this test were randomly assigned in the pre-test, intermediate test, and post-test sessions to each participant, to avoid test-retest effects[28].

Executive functions were assessed through three different tests dedicated to i) cognitive inhibition, ii) information processing speed and cognitive switching, and iii) visuospatial capacities, respectively.

Inhibition processes were tested with a computerized version of the Color-Words Stroop test (CWST). Participants were seated on a chair in front of a computer screen and a modified keyboard with only four adjacent keys [R-rouge (red), V-vert (green), J-jaune (yellow), and B-blue (blue)]. Different words written in French (since all participants were French natives) were presented on the screen, one by one, written in one of the previously mentioned colors. Participants were asked to indicate the color in which the word was written by pressing, as quickly as possible, on the corresponding letter on the keyboard with the forefinger of the dominant hand while inhibiting the word's semantics. Thus, depending on the consistency between the word's semantics and its color, the condition was considered either congruent (C, e.g., the word "green" written in green), incongruent (I, e.g., the word "green" written in red), or neutral (N, e.g., words as arm, leg, etc., written in one of the different colors). After a quick familiarization session with 9 random words, 75 words were presented for the test (25 C, 25 N, and 25 I). Each word remained on the screen until the response was given. Response time (RT), which is the time elapsing between the appearance of the word on the screen and the manual pressing of the key on the keyboard, as well as error rates were measured and averaged for each participant in each of the three conditions.

Speed of information processing and switching capacities were evaluated with the Trail Making Test (TMT) parts A and B, respectively. Part A required participants to draw lines sequentially to connect 25 encircled numbers distributed on a sheet of paper. Part B required participants to connect alternate numbers and letters (e.g., 1, A, 2, B, 3, C, etc.) while respecting the chronological and alphabetical order[29]. Total execution time (in milliseconds) and the number of errors were recorded.

Visuospatial capacities were tested using the Rey Complex Figure Copy Task[30] (RCFCT). It consisted of a complex figure comprising 18 graphical elements, placed in front of the participant, who was asked to reproduce it to the best of his/her ability with a pen on a blank sheet. Self-correction was allowed if needed. The total execution time required to copy the figure was measured in seconds and a score was given for each element that was reproduced correctly (maximum score = 18).

Motor fitness assessments

Balance control was assessed with the Unipedal Balance Test (UBT). Participants, with eyes open, were asked to lift one of their legs while placing the foot of the free leg on the ankle of the supporting leg[31]. Participants were instructed to keep their arms along the trunk a mark was vertically placed on the wall in front of each participant at different eye heights, to establish a fixation point. During the test, participants were requested to keep a stable balance on their preferred leg for as long as possible. The maximum trial duration was 1 min. One familiarization trial allowed deciding the preferred leg to be used. Then, two trials were performed and the best performance was recorded. The examiner measured the time (in seconds) elapsing from the go signal (starting the chronometer) until the balance was lost using that is, when the participant loses their balance and lifts them more than hip height, constituting the signal to stop the chronometer).

Timed Up and Go test (TUG) was used to assess functional mobility. Participants were instructed to sit down on a chair with their feet on the floor and their hands on their legs. At the "go" signal, they had to stand up, walk at their own pace, turn around the cone placed 3 meters away from the chair, walk back, and sit down again. The examiner recorded the total time to perform the test, starting the stopwatch during the initial movement performed to raise from the chair, and ending it when the participant sat down again. Two trials at self-paced walking speed were performed. The duration of the two best trials of the two different conditions was used for the analysis[32].

Motor coordination was assessed using the Four-Square Stepping Test (FSST)[33]. The square was created by crossing two 90 cm long scotch tape lines in their middle point, on the floor. The four squares created were enumerated with 1 in the high-left square, 2 in the high-right square, 3 in the low-right square, and 4 in the low-left square. To start the trial, the participant was asked to stand in square number 1, facing square number 2. Participants must step as fast as possible into each square in the following sequence: 2, 3, 4, 1, 4, 3, 2, and 1, which requires the participant to step forward, backward, and sideways to the right and left with the following instruction: "completing the sequence as fast as possible without touching the drawn lines, with both feet contacting the floor in each square, while facing forward during the entire sequence". First, the sequence was demonstrated slowly to the participant by the examiner. Then, one familiarization trial was completed to ensure the participant had memorized the sequence. Performance was quantified by the time taken to complete the sequence (in seconds). The stopwatch started when the first foot contacted the floor in square 2 and finished when the last foot came back to touch the floor in square 1. Two trials were completed and only the best performance was considered for the analysis. A trial was repeated if the participant failed to complete the sequence successfully, lost balance, or touched a line during the sequence. Subjects who were unable to face forward during the entire sequence and needed to turn before stepping into the next square also received a score. Participants were constantly supervised by the examiner to avoid falls and injuries.

Attendance rate & Training load assessment

Adherence to training programs was measured by calculating the attendance rate (in % of the number of sessions) over the first and second training parts (i.e., after the first and the second periods of 4 weeks, respectively), as well as over the entire 8-weeks period (see Table 2). During each session, exercise intensity was assessed by recording the mean and maximal HR reached during the training sessions thanks to the heart rate monitor. They were calculated as % of the theoretical maximal HR, which was calculated for each subject using the classic formula proposed by Tanaka et al[27] (see [17] for a similar procedure).

Data management

All the included participants were registered with a specific identification number and the data collected were anonymized. Data were saved on a separate hard disk and treated anonymously or, for each identification code, a logbook was started in which test results from baseline, intermediate, and post-intervention assessments were collected as well as the documentation on each training session. In terms of data quality, a trained project assistant had to verify the data entries and check the digitalized version after all training and assessments are finished.

Data analysis and statistics

Data were analyzed using SPSS (SPSS Inc., Chicago, IL, USA). All data were checked for normality with the Shapiro-Wilk test before statistical analysis. Then, repeated measures ANOVA, with "Time" as a within-subject condition, were carried out to test the effects of the training intervention in normally distributed dependent variables. Friedman tests were performed for the non-Gaussian data.

The analysis included the subjects who completed all the pre-, intermediate, and post-tests. The alpha level of significance was set at .05. The Greenhouse-Geisser correction was applied in case of violation of the sphericity assumption; effect sizes were calculated using partial eta squared ($\eta p2$) and Newman-Keuls post hoc tests were then performed to detect differences over the three-time points. Wilcoxon signed-rank test was performed right after significant Friedman tests and the effect size was calculated using the following formula: $r=Z/\sqrt{N}$ [36].

We analyzed the amplitude of progress, expressed in % of initial performance (Δ% = [post-test score–pre-test score)/pre-test score] *100) in three time periods that is, pre-int (first 4 weeks - F4W), int-post (seconds 4 weeks - S4W), and pre-post (total of 8 weeks - T8W), respectively. Finally, we also counted the number of respondents for the different time periods (i.e., participants who progressed by more than 1%) and we calculated the corresponding amplitude of progress. No statistical analyzes were carried out on these data (for a similar procedure, see [17]).

Results

Attendance to the training program

Over the twenty-four sessions were planned (3 sessions × 8 weeks), and all participants attended more than 80% of the training sessions (see Table 2).

Table 2. Attendance rates

	F4W (12 SESSIONS = 100%)	**S4W (12 SESSIONS = 100%)**	**T8W (24 SESSIONS = 100%)**
NO. OF PARTICIPANTS	Mean No.; Mean %; (SD)	Mean No.; Mean %; (SD)	Mean No.; Mean %; (SD)
14	10.29; 85.71% (1.33)	9.86; 82.14% (1.61)	20.14; 83.93% (2.21)

Training load

Descriptive results for training load are presented in Table 3. These data reveal that the training load was within the range that was defined and targeted for the present training program (60-80% of the max).

Table 3. Mean and Max HR during the Nordic walking sessions

	F4W			**S4W**			**T8W**		
NO. OF PARTICIPANTS	Mean HR	Mean HR max	HR%	Mean HR	Mean HR max	HR%	Mean HR	Mean HR max	HR%

14	102.9	134	85%	103.9	118.7	75%	103.9	131.7	83%

Physical assessments

A significant effect of time was found for the distance covered during the SWT [$\chi 2$ (N.14, df.2) = 7.51, $p<.05$]. Specifically, according to the Friedman test, the distance covered significantly increased from the intermediate test to the post-test ($p<.05$, 590 m and 668 m, respectively), but neither from the pre-test to the intermediate test (612 m and 590 m, respectively), nor from pre-test to the post-test (612 m and 668 m, respectively). Consistent with these observations, the number of respondents appeared larger during S4W (64%) than during F4W (14%) and T8W (36%). Finally, on average, the participants progressed by about 10% during the training program, especially during the second 4 weeks period (S4W). On the other hand, when measured for respondents only, the progress of the distance during the SWT was much larger that is, 15.3% (F4W), 26.5% (S4W), and 19.1% (T8W), respectively.

Maximal HR after the SWT did not show significant differences over time periods ($p>.05$). On the other hand, HRR significantly changed over time periods [F (2,26) = 15.4, $p<.05$, $\eta p2= 0.54$]. Specifically, it decreased between the pre-test and the intermediate test ($p<.05$, 87.8 beat/min and 74.4 beat/min, respectively) and between the pre-test and the post-test ($p<.05$, 87.8 beat/min and 74.8 beat/min, respectively). No significant decrease was reported between the intermediate and post-test (74.4 beats/min and 74.8 beats/min). Thus, with respect to HRR, participants progressed by about 14% during F4W and stabilized this progress during the 8 weeks of the training program (T8W). Notably, for HRR, the number of respondents was higher during F4W (93%) and T8W (93%), while it was lower during S4W (36%).

In the STS test, repeated measures ANOVA reported significant decreases in execution time overtime periods [F (2,26) = 11.17, $p<.05$, $\eta p2= 0.46$]. Specifically, execution time decreased from the pre-test to the intermediate test ($p<.05$, 18.0 sec and 15.5 sec, respectively) and from the pre-test to the post-test ($p<.05$, 18.0 sec and 14.6 sec, respectively), but no significant difference was found between the intermediate test and the post-test (15.5 sec and 14.8 sec). Thus, all the participants progressed by about 16% from the pre-test to the post-test. Concomitantly, the percentage of respondents was high during F4W (100%) and T8W (86%), while it was lower during S4W (64%). In addition, respondents progressed by about 24% from the pre-test to the post-test.

Motor assessments

For the FSST, repeated measure ANOVA showed significant decreases in time performance over the different tests [F (2,26) = 18.54, $p<.05$, $\eta p2= 0.59$]. Post-hoc comparisons showed that execution time decreased from the intermediate test to the post-test (9.1 sec, and 6.9 sec, respectively, $p<.05$), and from the pre-test to the post-test (9.6 sec and 6.9 sec, respectively, $p<.05$). No difference was observed between execution times measured during the pre-test and the intermediate test ($p>.05$, 9.1 sec and 9.6 sec, respectively). Thus, the participants progressed by about 24% during S4W, which was also the amplitude of changes over the 8 weeks (T8W). Concomitantly, an increase in the number of respondents was observed during S4W (93%) and during T8W (86%), relative to F4W (57%). Respondents progressed by about 33% from the pre-test to the post-test.

Non-significant effects of time periods were found for the other tests that is, the one-leg stance test and the TUG at preferred walking speed ($p>.05$). Accordingly, the number of respondents observed in the one-leg balance test and in the TUG were low (See Table 5 for details).

Cognitive assessments

No significant effects of time periods were observed for response times in the CWST (C, I, and N conditions), the TMT A and B, and the MoCA ($p>.05$). These results reflected the small number of respondents observed in these tests (about 50-60%) and, as a consequence, low progress for the whole group of participants (i.e., around 4-5%). On the other hand, when calculated for the (small number of) respondents in the different tests, the progress of performance was larger. For instance, a decrease of 27.8% was observed for response time in TMTA and 31% in TMTB after 8 weeks. Similarly, in the CSWT, response times decreased by about 26% (Neutral condition), 14.7% (Congruent condition), and 12.2% (Incongruent condition) after 8 weeks of training.

On the other hand, significant effects of training periods were observed for the time to complete the Rey test [$\chi 2$ (N.14, df.2) = 7.00, $p<.05$]. Post-hoc comparisons carried out with the Wilcoxon Rank Sum Test showed significant decreases in execution time from the pre-test to the intermediate test ($p<.05$, 155 msec, and 125 msec, respectively), and from the pre-test to the post-test ($p<.05$, 155 msec and 110 msec, respectively). On the other hand, no significant difference was observed between the intermediate test and the post-test ($p>.05$, 125 msec, and 110 msec, respectively). Concomitantly, the number of respondents observed for response time in the Rey test was over 70% in all three time periods (F4W=71%, S4W=71%, T8W=79%). Thus, all the participants progressed by 19% during F4W and by 30% after 8 weeks of training (T8W), while the respondents progressed by about 30% and 41% during the same periods. For the performance scores, statistically significant differences were observed between the different time periods [$\chi 2$ (N.14, df.2) = 10.94, $p<.05$]. Post hoc comparisons showed a significant increase in the performance scores between the pre-test and the intermediate test ($p<.05$, 16.5, and 17.8, respectively). In contrast, a significant decrease in performance was observed between the intermediate test and the post-test ($p<.05$, 17.8, and 16.8, respectively). Finally, no significant difference was observed between the pre-test and the post-test. (16.5 and 16.8, respectively) (see Table 4).

Table 4. The number of responders and their amplitude of progress (Δ%) over the three-time points for each cognitive and motor test.

COGNITIVE TESTS									
	F4W			S4W			T8W		
TEST	**Δ% All PRE-INT**	**N. Resp(%) PRE-INT**	**Δ% Resp PRE-INT**	**Δ% All INT-POST**	**N. Resp(%) INT-POST**	**Δ% Resp INT-POST**	**Δ% All PRE-POST**	**N. Resp(%) PRE-POST**	**Δ% Resp PRE-POST**
Rey test time	-14.3	71	-30.2	-4.9	71	-16.4	-21.4	79	-41.7
Rey test scores	11.6	50	2.5	-5.6	0	0	5.0	21	2.5
TMT A Time	-4.1	57	-15.9	-5.8	71	-14.3	-11.7	64	-27.8
TMT A n° of error	-40*	36	-95	0*	7	-66.6	-40*	29	-75
TMT B Time	-0.2	50	-22.6	8.5	50	-9.6	-2.8	36	-31
TMT B n° of error	-76*	50	-95.8	-40*	14	-100	-116*	50	-100
CWST RT-C	-3.7	57	-8.5	-2	43	-6.5	-2.4	57	-14.7
CWST RT - I	-0.5	43	-5.5	-3.5	64	-6.9	-4.8	57	-12.2
CWST RT - N	-6.7	57	-18.8	2	57	-8.7	-5.2	64	-26
CWST n° of error - C	0*			32*			32*		
CWST n° of error - I	-8*	36	-90	-4*	36	-85	-12*	36	-90
CWST n° of error - N	-8*	14	-100	32*	21	-100	24*	14	-100
MoCA	1.6	43	3.9	2.7	57	9.7	4.1	50	13.9

MOTOR TESTS

FSST	-0.8	57	-16.7	-23.6	93	-20.7	-25.7	86	-33.9
Balance	208.1	79	373.5	-7.1	36	179.8	59.3	64	180.5
TUG	5.1	36	-8.4	-0.2	50	-5.7	4.8	29	-10.5
PHYSICAL TESTS									
SWT-Maximal HR	-3.6	71	-12.2	6.8	29	-9.7	2.6	43	-20.7
SWT-HRR	-15.7	93	-18.1	1.8	36	-7.1	-14.9	93	-23.9
SWT-Distance covered	-4.7	14	15.3	14.2	64	26.5	9.5	36	19.1
STS	-12.9	100	-11.7	-4.1	64	-14.4	-16.7	86	-24.3

Discussion

The general objective of the present study was to determine whether 8 weeks of Nordic Walking training was effective to improve cognitive capacities and, if affirmative, to identify the most strongly affected functions. In this context, a secondary objective was to describe the temporal dynamics of progress during the training period by comparing performance observed during the first and the second 4 weeks of training periods, respectively. Accordingly, participants were tested three times on cognition (global cognitive functions, visuospatial capacities, inhibition, flexibility, and information processing speed) but, also, on motor and physical functions. In addition, we analyzed the individual response of participants by counting the number of respondents for each training period and calculating the amplitude of their progress as a piece of complementary information to classic statistical analyses (for a similar procedure, see Temprado et al.[17]). Thus, we were able to compare the results of the present study with those observed on similar functions after a longer training program (e.g., 12 weeks longer[15-17]). Also, the present results add supplementary information to studies that reported positive effects of shorter NW training programs (i.e., 8-9 weeks) on physical and motor capacities[11,22-24] but did not measure cognitive performance.

Effects of the NW training program on physical and motor functions

Results observed for the SWT confirmed that endurance capacity was enhanced by training in all the participants. Indeed, the distance covered significantly improved during the second half of the training program (S4W) by about 10% and, finally by about a similar amplitude after 8 weeks. Notably, progress was even larger among the respondents (i.e., 26.5%), the number of which reached 64% during the second half of the training program. These results can be compared to those observed in our previous study17, for the 6 minutes walking test (6WT), after 12 weeks of NW training: 90% of the participants were respondents but their amplitude of progress was smaller than those observed in the present study (17%). Thus, it can be concluded that: i) the present training program strongly loaded cardiovascular capacities (as attested by the measure of training load during the sessions through HR) but ii) a longer duration of the training intervention would be more effective to produce effects in (almost) all participants. Notably, progress in the distance covered was accompanied by a decrease in HRR, for which the number of respondents was high, meaning that almost all participants were concerned by this benefit, mainly during the first 4 weeks of training, while progress in the distance covered was rather observed during the second 4 weeks period. This result suggested that training led to a deep cardiovascular effect (i.e., change in HRR), which could be a functional precursor of progress in distance covered during the SWT.

Performance in the STS test, presumably reflecting muscular force, was also improved during the first 4 weeks of training and was then stabilized during the second 4 weeks period. With respect to motor functions, only coordination capacities were affected by NW training. In this test, the number of respondents was high (> 85%) and progress observed was large (24%) during the second 4 weeks and, finally, at the end of the training period. This result is fully consistent with those observed in the same test in our previous study[17].

NW training also improved coordination capacities, as attested by the results observed in the FSST. Indeed, progress was large in this domain (>24%), which is consistent with our previous study.

Notably, 8 weeks of training was not enough to improve the TUG at the preferred speed. This result is consistent with those observed in our previous study. Indeed, in this study, even after 12 weeks, progress was small (12%). On the other, the lack of significant effect of NW training on equilibrium control (i.e., one-leg stance test) is more surprising. Indeed, in our previous study participants progressed by about 60% in this test after 12 weeks. Again, maybe the program duration was too short to lead to progress in equilibrium control.

Finally, it can be concluded from these results that an 8 weeks training program of Nordic Walking may be effective to improve endurance capacities, lower limb strength, and motor coordination. However, a caveat is in order with respect to endurance capacities. Indeed, it appeared that only a small part of the group was significantly responsive after 8 weeks of training. Thus, a 12 weeks duration of training can be recommended to ensure that large benefits in physical and motor functions will be observed for almost all participants.

Effects of NW training on cognitive functions

With respect to cognition, we were expecting to confirm the results of our previous study[17], showing that NW training intervention led to significant progress in performance in different cognitive domains. Specifically, we expected to observe training-related benefits on inhibition and switching, together with information processing speed and visuospatial capacities. Beyond the facilitation role of aerobic effort through the release of neurotrophic factors[14], benefits on cognition were also expected to be related to the strong involvement of complex motor skills during NW training (as attested by the results observed for the FSST) [3,5,18,37]. Specifically, effects on inhibition were expected, due to the demonstrated role of these cognitive processes in gait control[38,39]. Effects on switching could be observed since these processes were required during NW to change cognitive focus from one task to another that is, to orient oneself in the natural environment to control upright balance, to modify the length of the steps, to coordinate the two arms or to use the biomechanical support on the sticks[40,41]. Effects on information processing speed were expected according to the results reported in previous studies on physical activity, in particular those requiring endurance effort[42]. Benefits on visuospatial capacities could result from the particular attention devoted to exercises requiring spatial orientation in natural environments during the present training program.

All these predictions were not fully confirmed by statistical results for the whole group of participants. Indeed, analyses carried out for all participants' raw data only reported benefits on visuospatial capacities. This is not surprising since visuospatial capacities were strongly engaged in most exercises during the training period. Nevertheless, this result only partially aligned with those reported in our previous study[17], in which only 40% of the participants improved their visuospatial capacities, while they were more than 70% in the present study. In addition, in the present study, the amplitude of progress observed for all participants was large after 8 weeks of training (20-30%), and roughly similar to progress observed in Temprado et al.'s study[17] in the group of respondents only. Notably, progress was mainly observed during the second 4 weeks of the training period.

More surprising was the lack of significant effects observed for the other cognitive functions (i.e., inhibition, switching) and information processing speed when considering the whole group of participants. This was probably due to the small number of respondents in these different cognitive domains. However, this is not to say that NW was ineffective in improving EF and information processing speed. Indeed, when considering the respondents only, the amplitude of progress observed in the different tests after 8 weeks of training was rather large (i.e., >26% in TMTA&B and the different conditions of the CSWT). These results suggest that NW has the potential to improve EF and, especially switching and inhibition, under the reserve that the training duration is long enough to generalize its effects in a majority of participants. Further studies should better explore the underlying mechanisms explaining the differences between respondents and non-respondents.

Another possible explanation for the lack of effects of NW training of EF in the majority of participants is that the effort intensity individually made by the participants over the program duration was too low[16,43]. Indeed, it is now well-admitted that the intensity of aerobic training is one of the prominent moderators of brain plasticity and improvement of cognitive performance, through the release of neurotrophic factors in the blood[44]. Though, on average, the training load fall within the prescribed range over the training period (60-80% of HRmax), it might be that individual intensity varied from one session to the other, thereby precluding strong effects in all the participants, as suggested by the results reported for the distance covered during the SWT. This hypothesis is in line with the results reported by Mortimer and colleagues[45], who showed that, when stratifying their group of participants into slow and fast walkers, fast walkers significantly improved the performance of EF compared to slow walkers. In the present study, our external observer reported that, though participants were encouraged to keep the intensity within the fixed range, the pace adopted by a number of them during some sessions was relatively slow in order to reach a more comfortable and habitual walking pace, in particular during the first 4 weeks training period. Combined with the short duration of the intervention, this could explain why effects on EFs are not observed in a sufficient number of participants to result in statistically significant improvements.

Conclusion

In summary, the results of the present study suggest that 8 weeks of NW training are sufficient to give rise to progress in functionally important physical and motor functions that may help to preserve autonomy in older adults. On the other hand, to improve cognition in almost all participants, a 12 weeks training program would be presumably more effective, as suggested by our previous study[17].

In addition, our results suggest that benefits on visuospatial capacities are easy to obtain thanks to the inclusion of exercises requiring spatial orientation in natural environments. For the other cognitive functions, a combination of longer program duration (e.g., 12 weeks) and higher intensity of endurance effort could be recommended. However, since the benefits of NW on cognition could also result from the repetitive practice of complex movement (coordination, postural control, a real-time adaptation of gait...) together with cognitive tasks (eg spatial orientation[3,5,10,13,46] the question arises of whether these cognitive-motor processes were sufficiently loaded during the NW intervention, despite the progress observed in the FSST. Accordingly, future studies should try to isolate the effects that come from aerobic effort and those triggered by repetitive practice of coordination and complex movements on cognitive performance during Nordic Walking training.

Contributions

M.M.T. and J.-J.T. designed the study protocol, M.M.T. and C.C. analyzed data, wrote the manuscript, and worked on the editing, J.-J.T. supervised the writing and A.L. added minor corrections. J.L. and N.H. participate in the design of the physiological part involved such as the design of the physical tests and they will run it during the pre and post-test, additionally, they took charge of the editing of the same editing sections. All authors have read and agreed to the published version of the manuscript.

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REFERENCES

1. Edwards MK, Loprinzi PD. The Association Between Sedentary Behavior and Cognitive Function Among Older Adults May Be Attenuated With Adequate Physical Activity. J Phys Act Health. 2017;14(1):52-58. doi:10.1123/jpah.2016-0313
2. Pesce C. Shifting the focus from quantitative to qualitative exercise characteristics in exercise and cognition research. J Sport Exerc Psychol. 2012;34(6):766-786. doi:10.1123/jsep.34.6.766
3. Temprado JJ, Torre MM, Langeard A, et al. Intentional Switching Between Bimanual Coordination Patterns in Older Adults: Is It Mediated by Inhibition Processes?. Front Aging Neurosci. 2020;12:29. Published 2020 Feb 18. doi:10.3389/fnagi.2020.00029
4. Seer C, Adab HZ, Sidlauskaite J, et al. Bridging cognition and action: executive functioning mediates the relationship between white matter fiber density and complex motor abilities in older adults. Aging (Albany NY). 2022;14(18):7263-7281. doi:10.18632/aging.204237

5. Torre MM, Langeard A, Alliou L, Temprado JJ. Does bimanual coordination training benefit inhibitory function in older adults?. Front Aging Neurosci. 2023;15:1124109. Published 2023 Apr 6. doi:10.3389/fnagi.2023.1124109

6. Angevaren M, Aufdemkampe G, Verhaar HJ, Aleman A, Vanhees L. Physical activity and enhanced fitness to improve cognitive function in older people without known cognitive impairment. Cochrane Database Syst Rev. 2008;(3):CD005381. Published 2008 Jul 16. doi:10.1002/14651858.CD005381.pub3

7. Erickson KI, Voss MW, Prakash RS, et al. Exercise training increases size of hippocampus and improves memory. Proc Natl Acad Sci U S A. 2011;108(7):3017-3022. doi:10.1073/pnas.1015950108

8. Kramer AF, Colcombe S. Fitness Effects on the Cognitive Function of Older Adults: A Meta-Analytic Study-Revisited. Perspect Psychol Sci. 2018;13(2):213-217. doi:10.1177/1745691617707316

9. Herold F, Törpel A, Schega L, Müller NG. Functional and/or structural brain changes in response to resistance exercises and resistance training lead to cognitive improvements - a systematic review. Eur Rev Aging Phys Act. 2019;16:10. Published 2019 Jul 10. doi:10.1186/s11556-019-0217-2

10. Torre MM, Temprado JJ. A Review of Combined Training Studies in Older Adults According to a New Categorization of Conventional Interventions. Front Aging Neurosci. 2022;13:808539. Published 2022 Feb 1. doi:10.3389/fnagi.2021.808539

11. Gomeñuka NA, Oliveira HB, da Silva ES, et al. Nordic walking training in elderly, a randomized clinical trial. Part II: Biomechanical and metabolic adaptations. Sports Med Open. 2020;6(1):3. Published 2020 Jan 13. doi:10.1186/s40798-019-0228-6

12. Schiffer T, Knicker A, Hoffman U, Harwig B, Hollmann W, Strüder HK. Physiological responses to nordic walking, walking and jogging. Eur J Appl Physiol. 2006;98(1):56-61. doi:10.1007/s00421-006-0242-5

13. Nemoto Y, Satoh T, Takahashi T, et al. Effects of Isometric Handgrip Training on Home Blood Pressure Measurements in Hypertensive Patients: A Randomized Crossover Study. Intern Med. 2021;60(14):2181-2188. doi:10.2169/internalmedicine.5865-20

14. Raichlen DA, Alexander GE. Adaptive Capacity: An Evolutionary Neuroscience Model Linking Exercise, Cognition, and Brain Health. Trends Neurosci. 2017;40(7):408-421. doi:10.1016/j.tins.2017.05.001

15. Gmiąt A, Jaworska J, Micielska K, et al. Improvement of cognitive functions in response to a regular Nordic walking training in elderly women - A change dependent on the training experience. Exp Gerontol. 2018;104:105-112. doi:10.1016/j.exger.2018.02.006

16. Lipowski M, Walczak-Kozłowska T, Lipowska M, et al. Improvement of Attention, Executive Functions, and Processing Speed in Elderly Women as a Result of Involvement in the Nordic Walking Training Program and Vitamin D Supplementation. Nutrients. 2019;11(6):1311. Published 2019 Jun 11. doi:10.3390/nu11061311

17. Temprado JJ, Julien-Vintrou M, Loddo E, Laurin J, Sleimen-Malkoun R. Cognitive functioning enhancement in older adults: is there an advantage of multicomponent training over Nordic walking?. Clin Interv Aging. 2019;14:1503-1514. Published 2019 Aug 22. doi:10.2147/CIA.S211568

18. Voelcker-Rehage C, Godde B, Staudinger UM. Cardiovascular and coordination training differentially improve cognitive performance and neural processing in older adults. Front Hum Neurosci. 2011;5:26. Published 2011 Mar 17. doi:10.3389/fnhum.2011.00026

19. Górniak M, Rybakowski F, Jaracz J, Rybakowski J. The influence of Nordic walking on the general functioning and cognitive performance of patients with Alzheimer's disease. Postep Psychiatr Neurol. 2021;30(3):154-161. doi:10.5114/ppn.2021.110779

20. Miyazaki A, Okuyama T, Mori H, Sato K, Kumamoto K, Hiyama A. Effects of Two Short-Term Aerobic Exercises on Cognitive Function in Healthy Older Adults during COVID-19 Confinement in Japan: A Pilot Randomized Controlled Trial. Int J Environ Res Public Health. 2022;19(10):6202. Published 2022 May 19. doi:10.3390/ijerph19106202

21. Niemann C, Godde B, Staudinger UM, Voelcker-Rehage C. Exercise-induced changes in basal ganglia volume and cognition in older adults. Neuroscience. 2014;281:147-163. doi:10.1016/j.neuroscience.2014.09.033

22. Gomeñuka NA, Oliveira HB, da Silva ES, et al. Nordic walking training in elderly, a randomized clinical trial. Part II: Biomechanical and metabolic adaptations. Sports Med Open. 2020;6(1):3. Published 2020 Jan 13. doi:10.1186/s40798-019-0228-6

23. Parkatti T, Perttunen J, Wacker P. Improvements in functional capacity from Nordic walking: a randomized-controlled trial among elderly people. J Aging Phys Act. 2012;20(1):93-105. doi:10.1123/japa.20.1.93

24. Takeshima N, Islam MM, Rogers ME, et al. Effects of nordic walking compared to conventional walking and band-based resistance exercise on fitness in older adults. J Sports Sci Med. 2013;12(3):422-430. Published 2013 Sep 1.

25. Folstein MF, Folstein SE, McHugh PR. "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. J Psychiatr Res. 1975;12(3):189-198. doi:10.1016/0022-3956(75)90026-6

26. Faul F, Erdfelder E, Lang AG, Buchner A. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav Res Methods. 2007;39(2):175-191. doi:10.3758/bf03193146

27. Tanaka H, Monahan KD, Seals DR. Age-predicted maximal heart rate revisited. J Am Coll Cardiol. 2001;37(1):153-156. doi:10.1016/s0735-1097(00)01054-8

28. Nasreddine ZS, Phillips NA, Bédirian V, et al. The Montreal Cognitive Assessment, MoCA: a brief screening tool for mild cognitive impairment [published correction appears in J Am Geriatr Soc. 2019 Sep;67(9):1991]. J Am Geriatr Soc. 2005;53(4):695-699. doi:10.1111/j.1532-5415.2005.53221.x

29. Partington JE, Leiter RG. Partington's pathways test. Psychol. Serv. Cent. J. 1949; 1, 11–20

30. Osterrieth PA. The test of copying a complex figure: A contribution to the study of perception and memory. Arch. Psychol. 1944;30, 206–356.

31. Springer BA, Marin R, Cyhan T, Roberts H, Gill NW. Normative values for the unipedal stance test with eyes open and closed. J Geriatr Phys Ther. 2007;30(1):8-15. doi:10.1519/00139143-200704000-00003

32. Podsiadlo D, Richardson S. The timed "Up & Go": a test of basic functional mobility for frail elderly persons. J Am Geriatr Soc. 1991;39(2):142-148. doi:10.1111/j.1532-5415.1991.tb01616.x

33. Dite W, Temple VA. A clinical test of stepping and change of direction to identify multiple falling older adults. Arch Phys Med Rehabil. 2002;83(11):1566-1571. doi:10.1053/apmr.2002.35469

34. Csuka M, McCarty DJ. Simple method for measurement of lower extremity muscle strength. Am J Med. 1985;78(1):77-81. doi:10.1016/0002-9343(85)90465-6

35. Woolf-May K, Meadows S. Exploring adaptations to the modified shuttle walking test. BMJ Open. 2013;3(5):e002821. Published 2013 May 28. doi:10.1136/bmjopen-2013-002821

36. Rosenthal R, et al. Parametric measures of effect size. The Handbook of research synthesis, 1994; 621.2: 231-244.

37. Voelcker-Rehage C, Godde B, Staudinger UM. Physical and motor fitness are both related to cognition in old age. Eur J Neurosci. 2010;31(1):167-176. doi:10.1111/j.1460-9568.2009.07014.x

38. Langeard A, Houdeib R, Saillant K, Kaushal N, Lussier M, Bherer L. Switching Ability Mediates the Age-Related Difference in Timed Up and Go Performance. J Alzheimers Dis. 2019;71(s1):S23-S28. doi:10.3233/JAD-181176

39. Langeard A, Desjardins-Crépeau L, Lemay M, Payette MC, Bherer L, Grenier S. Cognitive performances better identify fallers than mobility assessment among older adults with fear of falling. Aging Clin Exp Res. 2021;33(10):2709-2714. doi:10.1007/s40520-019-01338-9

40. Al-Yahya E, Dawes H, Smith L, Dennis A, Howells K, Cockburn J. Cognitive motor interference while walking: a systematic review and meta-analysis. Neurosci Biobehav Rev. 2011;35(3):715-728. doi:10.1016/j.neubiorev.2010.08.008
41. Schäfer S, Huxhold O, Lindenberger U. Healthy mind in healthy body? A review of sensorimotor–cognitive interdependencies in old age. European Review of Aging and Physical Activity, 2006; 3.2: 45-54.
42. Zettel-Watson L, Suen M, Wehbe L, Rutledge DN, Cherry BJ. Aging well: Processing speed inhibition and working memory related to balance and aerobic endurance. Geriatr Gerontol Int. 2017;17(1):108-115. doi:10.1111/ggi.12682
43. Ossowski Z, Wawryniuk M, Česnaitienė VJ. Influence of nordic walking training on static and dynamic body balance among the elderly. Baltic J of Health and Physical Activity, 2015; 7.1: 7.
44. Chapman RF. The individual response to training and competition at altitude. Br J Sports Med. 2013;47 Suppl 1(Suppl 1):i40-i44. doi:10.1136/bjsports-2013-092837
45. Mortimer JA, Ding D, Borenstein AR, et al. Changes in brain volume and cognition in a randomized trial of exercise and social interaction in a community-based sample of non-demented Chinese elders. J Alzheimers Dis. 2012;30(4):757-766. doi:10.3233/JAD-2012-120079
46. Torre MM, Langeard A, Hugues N, Laurin J, Temprado JJ. Comparison of Three Physical-Cognitive Training Programs in Healthy Older Adults: A Study Protocol for a Monocentric Randomized Trial. Brain Sci. 2021;11(1):66. Published 2021 Jan 6. doi:10.3390/brainsci11010066