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How does a 4-week motor–cognitive training affect choice reaction, dynamic balance and cognitive performance ability? A randomized controlled trial in well-trained, young, healthy participants

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Abstract

Background: We aimed to investigate the potential effects of a 4-week motor–cognitive dual-task training on cognitive and motor function as well as exercise motivation in young, healthy, and active adults.

Methods: A total of 26 participants (age 25 ± 2 years; 10 women) were randomly allocated to either the intervention group or a control group. The intervention group performed a motor–cognitive training (3×/week), while the participants of the control group received no intervention. Before and after the intervention period of 4 weeks, all participants underwent cognitive (d2-test, Trail Making Test) and motor (lower-body choice reaction test and time to stabilization test) assessments. Following each of the 12 workouts, self-reported assessments (rating of perceived exertion, enjoyment and pleasant anticipation of the next training session) were done. Analyses of covariances and 95% confidence intervals plotting for between group and time effects were performed.

Results: Data from 24 participants were analysed. No pre- to post-intervention improvement nor a between-group difference regarding motor outcomes (choice-reaction: $F = 0.5$; time to stabilization test: $F = 0.7$; $p > 0.05$) occurred. No significant training-induced changes were found in the cognitive tests (D2: $F = 0.02$; Trail Making Test A: $F = 0.24$; Trail Making Test B: $F = 0.002$; $p > 0.05$). Both enjoyment and anticipation of the next workout were rated as high.

Discussion: The neuro-motor training appears to have no significant effects on motor and cognitive function in healthy, young and physically active adults. This might be explained in part by the participants' very high motor and cognitive abilities, the comparably low training intensity or the programme duration. The high degree of exercise enjoyment, however, may qualify the training as a facilitator to initiate and maintain regular physical activity. The moderate to vigorous intensity levels further point towards potential health-enhancing cardiorespiratory effects.

Keywords

Integrated multimodal training, cognition, coordination, dual task

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Background

Current research suggests that exercise positively impacts cognitive abilities in all age classes.[1,2] A possible underlying mechanism is suggested in exercise-induced neurogenesis and increased interconnections between synapses, as well as in a local increase in blood circulation. Beyond these hypothesized effects of motor training solely, dual tasks may have another effect. As dual tasks of simultaneous movement and

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cognitive activity require and promote selective attention, training them may improve both cognitive and motor functions.[3] Adding a cognitive part to exercise is hence expected to enhance the beneficial effect of physical training on neuroplasticity and cognition.[4] The combination of motor whole-body coordination and cognitive dual- and choice-reaction tasks may be such a combined training.

In a recent study, such a combined dual-task training focussing on visual perception, peripheral visual fields, limb–eye coordination and adaption to unfamiliar challenges has been demonstrated to enhance brain plasticity.[5] The trainings enhanced functional connectivity, presumably induced by increased brain regions co-activation. The intervention implemented in the Demirakca study is called Life Kinetic, a typical motor–cognitive training of coordination tasks with increasing complexity. The training is combined with additive cognitive tasks assumed to tap the working memory. Although the intervention was invented to be adopted in athletic populations, a study population with unknown physical activity status was included in the Demirakca study.[5] First hints indicate effects of the training on cognitive abilities like flexibility, inhibition, working memory, spatial ability, and fluid intelligence, in particular in sedentary young adults.[6] In contrast, the training induced no significant effect on cognition in physically active participants within the same study; but an improvement in coordinative performance was found in the same training group, which was larger than the one in the control group.[6] In studies on children and adolescent athletes, the training showed systematic improvements elicited by the neurocognitive training on eye–hand coordination[7] and football-specific dual task or coordination tests.[8] If these findings can be transferred to adults is yet questionable. Both the design of the intervention (motor–cognitive combination and no solely training of one out of these abilities) and the controversial findings in physically active adults highlighted above (benefit on coordination and no benefit on cognition) call for a more detailed investigation on potential effects of the intervention on motor–cognitive coordination abilities.

We thus aimed to investigate the potential effects of a motor–cognitive dual-task programme on a collective of physically active young adults. We hypothesize that the programme increases motor–cognitive coordination abilities like choice reaction and dynamic balance ability when compared to an inactive control group.

Methods

Study design and ethical aspects

We adopted a randomized-controlled, longitudinal study design. The trial was approved by a local ethics committee and conducted in accordance with the ethical standards set by the Declaration of Helsinki (1964) with its modifications (Fortaleza 2013). Each participant signed informed consent prior to study enrollment.

Participants

A total of 26 healthy and adult male and female (age = mean 25 ± standard deviation (SD) 2 years; height = 176 ± 6 cm; weight = 71 ± 9 kg; 10 women, 16 men) were recruited. The participants were students in an academic sports science programme and reported regular engagement in physical activity. Exclusion criteria included engagement in other integrated multimodal exercise regimes, acute injuries, or diseases influencing liveability or physical performance, the intake of substances modifying perception (e.g. drugs or medication). The participants flow (Consolidated Standards of Reporting Trials (CONSORT)) is given in Figure 1.

Experimental setup

Prior to and following a 4-week-intervention period, all participants performed cognitive and motor tests. A cognitive testing battery (d2 test, Trail Making Test (TMT)) was followed by a motor test battery (choice-reaction tasks and dynamic balance). Following the measurements, the participants were randomly allocated (1:1, complete balanced randomization, BIAS for Windows (version 11.02, 2016, Goethe University of Frankfurt)), either to the intervention group (IV) or to the control group (CG). The IV performed the training intervention for 4 weeks, three units per week. The participants were excluded as dropouts if they completed less than 9 (out of 12) intervention sessions or in the case of incomplete data sets (per protocol analysis). The CG received no treatment.

The intervention

The interventional approach was derived from concepts aiming to connect motion and brain activity evoked by cognitive tasks. The exercises in this study were adapted from the Life Kinetik training concept. Ten different exercises were performed (Table 1), and each subexercise lasted at least 2 min. Each task was divided into levels with increasing exercise intensity; a higher level was reached if the participant was able to adequately perform the task. Several tools, for example, balls, scarfs, and a speed ladder, were used.

Cognitive assessment

The d2 test assesses concentration and attention. It is an internally consistent and valid measurement.[9] The test consists of a paper with 14 rows filled with ‘d’ and ‘p’ letters. Over and/or beneath each letter, various numbers of strokes are placed (stroke no to two strokes both over and below each letter). The participant’s task is to figure out and mark

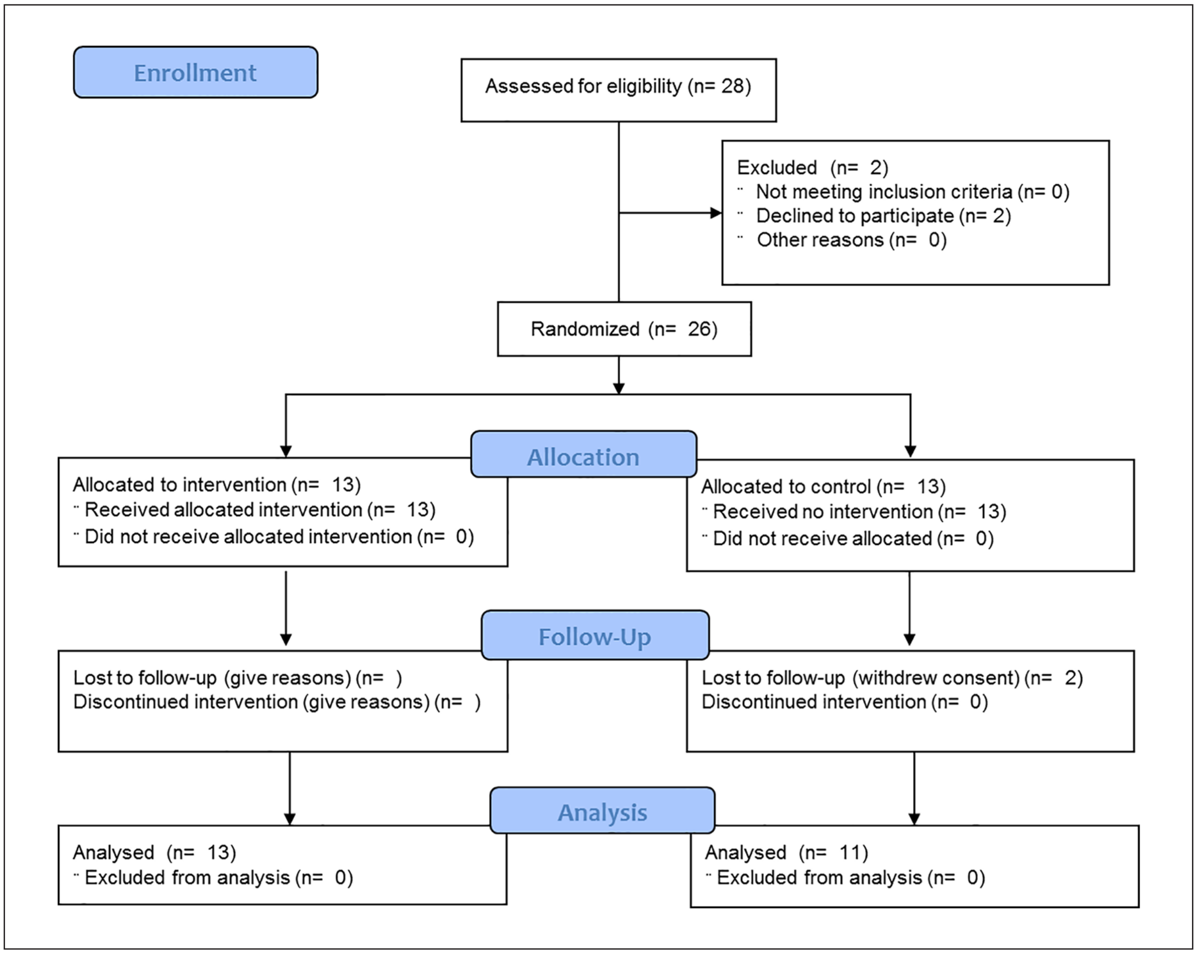

Figure 1. Study and participant flow (CONSORT). N, number.

Table 1. The 10 categories of exercises used during intervention with description of the content and examples.

Number and name	Content	Example
1. Parallel ball	Throwing two balls upwards, cross the arms and catch the balls	
2. Speed ladder	Jumping through a speed ladder with cognitive perturbation	Recite the alphabet
3. Go and throw	A trainer calls different commands while walking and throwing a ball	Throwing the ball and stepping forward, backward and sideways
4. Passing a ball	A trainer gives a command while he or she throws a ball, the participant had to catch it in different ways	While stepping with one foot forward
5. Dancing with a scarf	Different scarf movements and stepping combinations	Circle a scarf with one hand and throw a ball with the other hand
6. Finger skills	Upright standing, knees slightly flexed. An examiner gives the respective command, based on a random order	Left and right hand alternating have to show/mimic the letter 'L' and 'O'
7. Hand skills	A trainer gives commands for moving both or one hand in different directions	Up, down, to the right and to the left
8. Head skills	A trainer calls the direction the participant shall look and simultaneously has to point with his hand into the other direction	
9. March parade	A trainer calls different numbers with different meanings, touching one leg with one hand	#1: right hand touches the right thigh; #14: sidestep left and the leaving the right hand
10. Imitation	A presentation is shown where triangles are placed at the body parts the participant should lift	Hands, arms, feet and legs

all 'd' letters with (in total) two strokes. For each line, test duration is 20 seconds. Concentration, computed as discovered targets minus committed mistakes, was used for further calculations.

The TMT captures visual search velocity and processing speed.[10] We used a digital version which exhibits moderate to high correlation with the paper-based version.[11] The reliability of the TMT has been found to be high.[12] The test is divided into parts A and B. In part A, the participants, as quickly as possible, had to connect 25 numbers in ascending order. In part B, participants had to connect numbers and letters in an alternating manner (1 – A – 2 – B etc., until 13). Time to complete each TMT was employed for further analysis.

Motor assessment

Choice reaction test (intraclass correlation coefficient (ICC): 0.89) was performed on the Quick Board (The Quick Board, LCC), a panel (100 cm × 76 cm) equipped with five sensor pads (upper right and left, lower right and left, and centre) linked to a control box, providing visual stimulus and feedback information via five lights corresponding to the sensor pads.[13] For testing, participants started upright standing in neutral position, with the right foot placed between upper and lower right sensors and the left foot between upper and lower left sensors. Both feet did not touch the centre sensor. After a 5-s countdown, one of the five lights, representing the foot sensors on the control box, turns on. Participants were asked to tap as fast as possible with their right or left foot on the respective sensor on the board. The upper and lower right sensors had to be tapped with the right foot and the upper and lower left sensor with the left foot. The centre sensor can be tapped with the right or left foot. After tapping the correct sensor, another light turns on randomly. The participants then returned to the neutral position and taped the next indicated sensor. The number of correct foot contacts during task time (10 s) and average reaction time were recorded. Testing procedure was repeated two times after 60 s of rest in upright standing, respectively.

The time to stabilization test (TTS) was used to measure dynamic postural control after a one-legged countermovement jump of self-selected high and single leg horizontal distance. Participants' leg length was measured from the trochanter major to the malleoli. The participants started standing on the dominant leg in front of the force plate. After landing on the same leg, they were instructed to stand as still as possible, positioning the hands on the hips and looking at a marker ahead of them placed at the wall. The duration of each measurement was 20 s; the participants had to complete five trials. The time to stabilization was computed as the time until ground reaction force returned to stability (mean ground reaction force over trial duration ± 0.25 SD)[14] and the median value of the five trials was used for analysis. The TTS has moderate to high reliability.[15]

Self-reported outcomes

Self-reported ratings of coordination skills were performed before and after the programme. The participants had to judge their hand–eye coordination, reactivity and balance ability with regard to daily living and sporting activities. For each of the six parameters, the participants selected their self-estimated ability on a numerical rating scale spanning from 1 (poor) to 10 (excellent).

In addition to these pre- and post-intervention ratings, self-estimated data were collected following each training session in the intervention group. The participants rated exercise enjoyment regarding the finished workout as well as anticipation of the next session on an ordinal scale from 1 (no fun/anticipation) to 5 (maximal fun/anticipation).[16] To assess self-reported exertion, Borg ratings of perceived exertion (RPE) were assessed using a 6–20-point Likert-type scale.

Statistical analysis

Statistical calculations were performed using SPSS Statistics 23 (IBM, 2015), BIAS for Windows (version 11.02, 2016, Goethe University of Frankfurt), or Excel (Microsoft, 2016). The level of significance (Alpha) was set to 5% for all statistical analyses, p-values below were considered significant. Univariate gain story analyses of covariance (ANCOVAs), using the difference between the pre- and post-results of the main parameters, were performed for the detection of group differences (after checking the underlying assumptions). The baseline values were used as co-variates. In the case of significance, absolute or *z*-transformed (in the case of systematic co-variate influence) post hoc analyses for group differences were calculated.

Results

Two participants (control group) withdrew their consent for participation without stating a reason. No participant had to be excluded. Thus, data from 24 participants (13 intervention and 11 control) were analysed. Overall, training frequency was 2.7/week (=10.6 trainings during the intervention period). Compliance rate was thus 88%. On an individual level, n = 5 volunteers participated in each of the scheduled 12 trainings, n = 2 in 11, n = 2 in 10, and n = 4 in 9.

Motor function

The ANCOVAs for motor function demonstrated no between-group difference (choice-reaction: $F = 0.5$; TTS: $F = 0.7$; $p > 0.05$). Baseline values were (mean ± SD): choice-reaction: IV: 12.1 ± 1.2 hits, CG: 12.1 ± 1.4 hits; TTS: IV: 1.51 ± 0.37 s, CG: 1.44 ± 0.27 s. The pre- to post-differences for each group are illustrated in Figure 2. While no pre- to post-difference occurred in the TTS, both groups increased their number of hits in the choice reaction test.

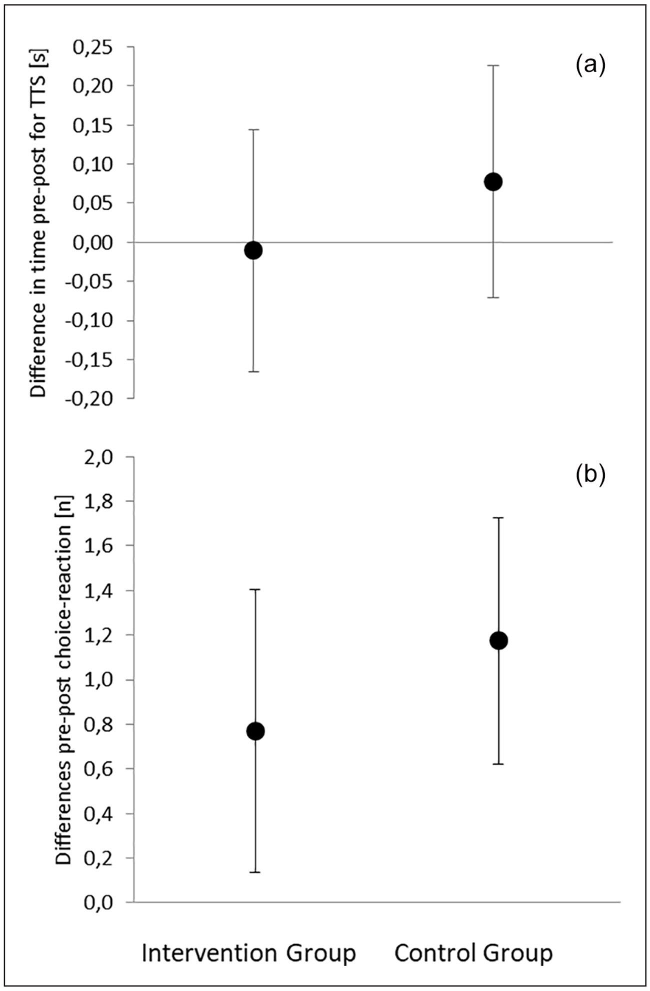

Figure 2. Mean and 95% confidence intervals for the pre- to post-intervention period differences in functional outcomes: (a) time to stabilization test and (b) choice reaction test. Δ = difference in pre-to-post; s = seconds; hits = number of hits in the choice reaction test.

Cognition

Comparable results are shown in the cognitive tests (D2: F=0.02; TMT A: F=0.24; TMT B: F=0.002; $p > 0.05$). The corresponding pre- to post-differences for each group are illustrated in Figure 3. Baseline values were (mean ± SD): TMT A: IV: 11.6 ± 2.7 s; CG: 14.1 ± 2.3 s; TMT B: IV: 26.6 ± 12 s; CG: 27.2 ± 7.6 s; d2 error frequency: IV: 11 ± 9, CG: 18 ± 11.

Self-reported outcomes. The outcomes of RPE maximum, RPE mean, and fun and pleasant anticipation remained unchanged during the study period ($p > 0.05$). Figure 4 displays the values for each training session.

Fun was rated high during the entire intervention. Similarly, most participants looked forward to the next training session. Perceived exertion was constant at an average level between 10.3 and 12.2 and at a maximum level between 12.7 and 14.3.

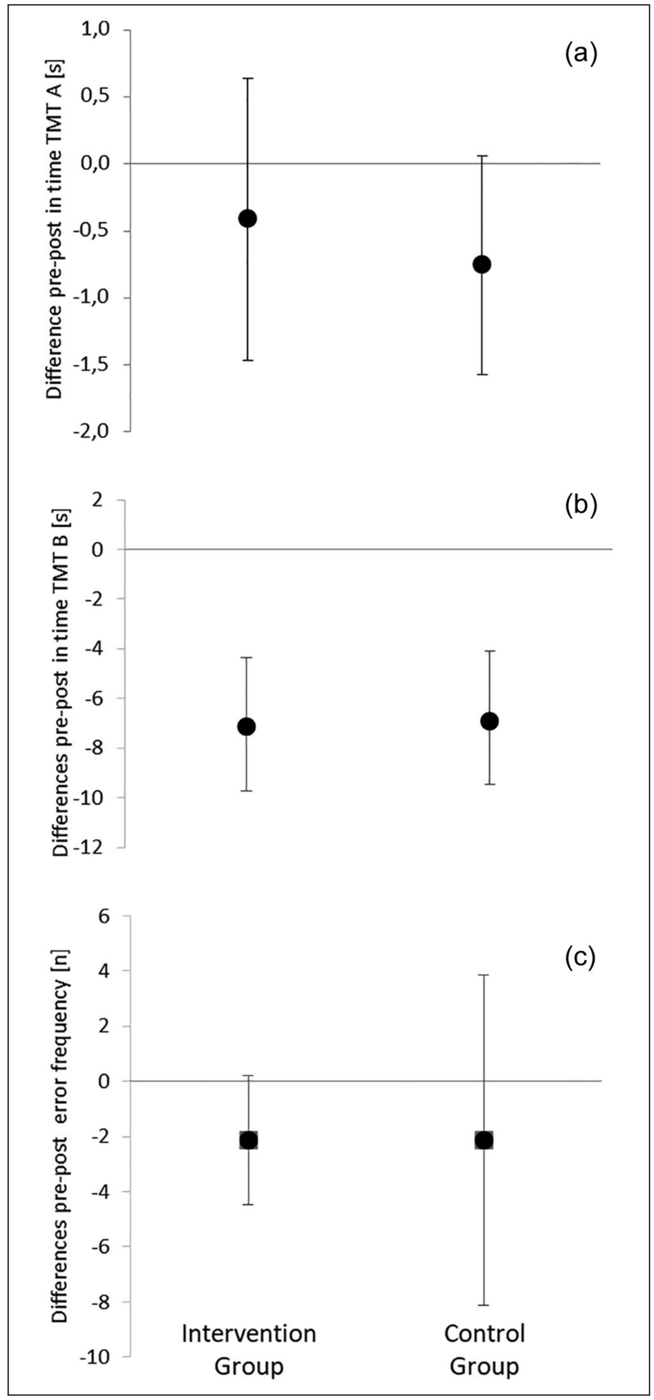

Figure 3. Mean and 95% confidence intervals for the pre- to post-intervention period differences in cognitive outcomes: (a) time for the Trail Making Test A, (b) time for the Trail Making Test B, and (c) D2 frequency of errors F; n = numbers.

Discussion

We adopted a motor–cognitive dual-task programme in a collective of physically active, young adults, aiming to increase cognitive and motor abilities. No additional effect of the motor–cognitive multimodal training on motor or

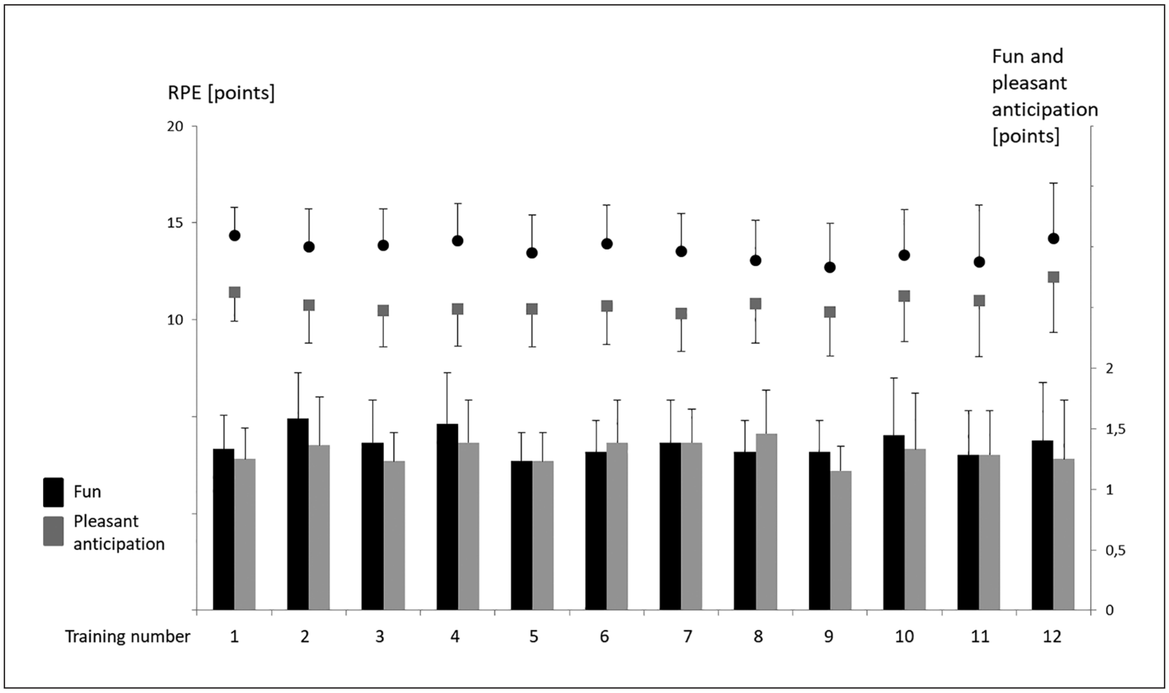

Figure 4. Self-reported outcomes at each training session. Fun and pleasant anticipation (right y-axis) are displayed as bars; maximal (upper dots) and mean (lower dots) RPE values (left y-axis) are displayed as points. Error bars display 95% confidence intervals.

cognitive outcomes occurred. The a priori assumed hypotheses are consequently falsified.

Our findings are, partially, in contrast to the results of Demirakca et al.,[5] who demonstrated an impact of the intervention on brain co-activity. If such a co-activity, without being pictured in the indirect assessments, occurred in our participants, likewise, is unknown. Having a closer look at the study design,[5] the authors included participants with unknown physical activity status and coordinative control ability. Our sample was composed of athletic young participants, and hence, higher baseline performance may explain the lack of effects in this study. Furthermore, the baseline value of the TMT A 11.6/14.1 s is faster than the reference values for highly educated 18–24-year-old persons. The TMT B values of 26.6/27.2 s are even ways below that (mean 11 s faster).[17] If not totally attributed to the digital version, the sample of this study may be characterized as high performer in terms of education and physical fitness. Despite that, our sample is comparable to one subsample in the study of Johann et al.[6] Herein, no effects of the intervention on physically active young adults were found, likewise. Supporting that finding, a recently published crossover trial found, in comparison to a standard short exercise bout, no superior acute effects of the neuro-motor intervention on visual search, speed of processing, mental flexibility, and executive functions.[18] Our findings expand the findings of these working groups by adding motor and coordination outcomes to their solely cognitive assessment. In any case, the initial evidence on the relevance of adding a cognitive part to exercise with the goal to increase beneficial effect of physical training on neuroplasticity and cognition[4] is not supported by our data, at least not in young healthy and physically active adults. Again, this is only partially in line with the results of Gabbett et al.[19] They recruited young, healthy rugby players. The participants performed a dual-task training, which is comparable to ours (e.g. jumping on the speed ladder while reciting the alphabet or while counting backwards). The authors concluded that ‘the differences in draw and pass proficiency [in high-performance rugby league players] were not statistically significant’,[19] but that there was an improvement in draw and pass proficiency under dual-task conditions. Nevertheless, these and our (non-significant, likewise) results highlight the need for further research regarding dual-task motor–cognitive training in athletic populations. On a non-significant level, dual-task training seems to support the ability to perform dual-task draw and pass tasks.

Exercise enjoyment was rated as ‘high’ over the entire intervention period. In addition, most participants looked forward to the next training session. Bauer et al.[20] pointed out that ‘fun’ was one of the main reasons for being/staying active in underweight/normal weight compared to overweight/obese women. Although the transferability to young healthy and physical active adults may be limited, exercise enjoyment may be a decisive factor in performing a dual-task training. The RPE ratings corresponded to those of moderate aerobic exercise training. The maximal values were at the level often described as vigorous.[21] Hence, and although no superior effects on coordination, choice reaction or cognition were detected, a health-enhancing activity level seems to be given. It thus may be seen as a variety of health-enhancing physical activity schedules. Its potential as a diversified training opportunity in health-enhancing training may be investigated in future studies.

Our small sample size may limit the transferability of the results. It is assumable that the programme may enhance cognitive or motor–cognitive skills in less experienced participants (or even patients); this should be subject to further research. Although a ceiling effect is often seen in trained adults after a certain (i.e. 4 weeks) time,[22] a longer intervention period might evoke larger/significant changes in the measured outcomes.

Conclusion

We demonstrated that a 4-week, dual-task intervention does not affect motor and cognitive abilities in healthy, young, and physically active adults. The high scores of exercise enjoyment and the moderate to vigorous intensity levels, however, may qualify the training as a facilitator to initiate and maintain regular exercise and point towards potential health-enhancing cardiorespiratory effects.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethical approval

Ethical approval for this study was obtained from Lokale Ethikkommission des Fachbereich 05 der Goethe-Universität FRankfurt (2016-47).

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Informed consent

Written informed consent was obtained from all subjects before the study.

Trial registration

This randomized clinical trial was not registered because no clinical trial in its inherent meaning but a training study with healthy participants was performed.

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