The effects of low-intensity multi-modal, proprioceptive exercise on cognitive function in older adults

Boyle, Spencer .E[1], *Fothergill, Melissa. A*[2], *Metcalfe, John*[3], *Docherty, Sarah*[4], *Haskell-Ramsay, Crystal. F*[4].

1. Department of Sport, Exercise and Rehabilitation, Northumbria University, Newcastle upon Tyne, NE1 8ST, UK.

2. School of Psychology, Newcastle University, Newcastle upon Tyne, NE1 7RU, UK

3. School of Sport and Wellbeing, University of Central Lancashire, Lancashire, PR1 2HE, UK

4. Department of Psychology, Northumbria University, Newcastle upon Tyne, NE1 8ST, UK.

Corresponding Author:

Spencer E. Boyle

Department of Sport, Exercise and Rehabilitation

Address: Northumberland Building, Northumbria University, Newcastle upon Tyne NE1 8ST, UK.

Email: spencer.boyle@northumbria.ac.uk

Abstract

Background: Physical activity provides a number of physical and psychological benefits. Multi-modal proprioceptive exercise represents a useful balance-based exercise with the potential to reduce falls in older adults. Previous research has also indicated cognitive benefits following multi-modal proprioceptive exercise in young and older adults. This study aimed to assess cognition and mood following two types of physical activity (multi-modal proprioception vs. yoga) compared to control (classroom based) in healthy older adults.

Method: Nineteen older adults (MAge=65, Sex=9 male) participated in this randomised, controlled crossover trial. Participants completed a 20-minute multi-modal proprioceptive exercise class, 20-minute yoga session and 20-minute classroom-based control. Numeric working memory and mood were assessed prior to and immediately following each of the interventions.

Results: The multi-modal proprioceptive intervention significantly reduced numeric working memory reaction time versus the yoga ($p=0.043$) and control ($p=0.023$) group. There were no differences found for accuracy or for mood.

Conclusions: These results indicate that multi-modal proprioceptive exercise is worthy of further investigation as an alternative mode of exercise alongside the more traditional aerobic and strength-based exercise for healthy older adults.

Key Words: physical activity; multi-modal exercise; proprioception; cognition; mood; ageing

Introduction

It has been well reported that participation in physical activity has a number of physical and psychological benefits for older adults, such as reduced risk of cardiovascular disease (CVD) and diabetes [1] and reduced risk of dementia and cognitive decline [2,3]. The recommendation for physical activity in healthy older adults is to engage in at least 150 minutes (2½ hours) of moderate intensity activity per week in bouts of 10 minutes or more, with one suggested way to achieve this being to undertake 30 minutes on at least 5 days per week [4]. Currently only 67 % of adults in England aged 16-64 meet the recommendation, this drops to 44 % of adults over 65 years [5]. Whilst lifelong physical activity is preferential, becoming more physically active at any age, especially given the upward trend in ageing populations, is vitally important to delay associated cognitive decline [6].

Studies exploring the role of habitual exercise on cognitive functioning have mainly focused on quantitative parameters such as intensity, duration, and frequency of exercise [7]. However, exercise modality may also play an important role. In older adults, beneficial effects of aerobic exercise, but not strength-and-flexibility exercise, were shown in terms of both reaction time and errors on a task requiring high levels of executive control [8]. Conversely, indices of inhibition were improved following exercise intervention, irrespective of whether multicomponent training or progressive resistance training was undertaken. However, only multicomponent training appeared to affect inhibitory capacity directly [9], suggesting different mechanisms underlying the effect following different modalities. A comprehensive systematic review and meta-analysis of randomised controlled trials (RCTs) indicated domain-specific effects on cognition following different modes of exercise (aerobic, strength and multicomponent, tai chi and yoga) [6]. For example, resistance training significantly improved executive function, memory and working memory; whereas tai chi showed a specific benefit to working memory . It has also been reported that multicomponent exercise training combining aerobic, resistance and flexibility based exercise may produce the most positive improvements to cognitive function in healthy older adults [10].

However, alternative modes of physical activity such as tai chi and yoga that have been postulated as potentially beneficial modes of exercise for cognitive function in older adults, have not been extensively assessed in RCTs [6]. In terms of exercise to prevent falling, a known increased risk as adults start to age [11], strategies that have shown promise in research studies have included multimodal exercise concentrating on strength and balance [12] and complex functional exercises that include change of direction, reaction, decision making and perception [13]. Balance has been shown to be particularly important to mobility with the ability to balance on one leg significantly predicting number of steps, time spent in dynamic outdoor activity, total distance travelled, and total number of journeys made over the course of a week. Cognitive ability also predicted mobility, indicating that both balance and cognitive ability are important factors for quality of life in older adults through their impact on ability to engage with outdoor activities [14].

Proprioception is a term coined by Sherrington (1906) as “the perception of joint and body movement as well as position of the body, or body segments, in space”. [15]. A previous study has shown improvements in processing speed following 12-weeks’ proprioceptively demanding training designed to reduce falls in adults >65 years, which included balance, strength, endurance and flexibility exercises. However, the lack of a comparator group makes it difficult to draw firm conclusions from this study [16]. A subsequent pilot study provided further insight into the effects of multi-modal proprioceptively demanding exercise on cognition. The authors examined the effects on working memory of Movnat, which is a multi-modal proprioceptively demanding exercise intervention that incorporates core strengthening and hand-eye training. The effects of this intervention on working memory were compared to a yoga and a classroom control in adults from 18-59 years [17]. Results showed that participants who undertook acute, proprioceptively demanding training had increased backward digit span scores following 2 hours’ training compared to classroom and yoga control groups. However, the study was not without its limitations and had self-selecting groups with different exercise exposure durations. Taken together these findings indicate the potential for multi-modal proprioceptively demanding exercise to induce cognitive benefits in older adults and suggest that benefits may be seen acutely, without the need for extended time in a training schedule.

The relationship between acute exercise and cognition is moderated by multiple factors such as fitness levels, exercise intensity, and exercise mode [18]. Duration has also been highlighted as a key factor with positive effects on cognition emerging after 20 minutes of exercise, whereas decrements have been observed when exercising for 2 hours or more [19]. Mood effects may also play a role in the acute exercise-cognition relationship with exercise durations ranging from 5-60 minutes showing favourable effects on POMS-assessed depression, hostility and fatigue [20]. Beneficial effects of exercising for 15 minutes have also been shown in older adults in the form of increased high-arousal positive affect[21]. It is possible that the previous improvements to cognition shown following 2 hours of multi-modal proprioceptive exercise [17] may not be achievable or desirable in older adults [22] and it is therefore important to ascertain the minimum exercise time needed to observe improvement in this population. The aim of the current study was therefore to determine whether a 20-minute multi-modal proprioceptive exercise intervention would benefit working memory and mood in older adults when compared to yoga and a classroom-based control.

Materials and Methods

Participants and Study Design

A large effect size on working memory has previously been shown following multi-modal proprioceptive exercise [17]. However, given the differences in design, a power calculation was based upon a medium effect size of f=0.25, which indicated that a total of 19 participants would allow detection of significant effects with a power of 0.8 at 2-sided significant level of 0.05. A convenience sample of nineteen healthy older adults (9 men; Mean age = 65 years) completed a within-subject crossover design; taking part in a 20-minute multi-modal proprioceptive exercise class, 20 minutes of yoga and a 20-minute classroom-based control session. All the participants met the eligibility criteria of being over 60 years of age and physically active and all completed a physical activity screen to ensure they were in good health and physically able to take part in low-level exercise. None of the participants reported any experience of multi-modal proprioceptive exercise or training protocols. The study received institutional ethical approval from the Faculty of Health and Life Sciences ethics committee at Northumbria University. Participants received a £30 gift voucher for recompense of their time.

Cognitive and Mood Measures

All cognitive and mood measures were delivered using the Computerised Mental Performance Assessment System (COMPASS, Northumbria University, Newcastle upon Tyne, United Kingdom) which is a validated and purpose-designed software system. This software has previously been used in older participants [23,24] and has shown sensitivity to exercise interventions [25]. Tasks were delivered, and responses were made, via Windows touchscreen tablets.

Numeric working memory - Five single target numbers are displayed on the screen, one at a time. Participants are required to memorise these numbers as they appear. Once the target series has been presented, numbers are displayed one at a time and participants are required to indicate if each number was presented in the previous list or not. In this case, three trials were completed. Outcomes were accuracy (%) and reaction time for correct responses (ms).

Bond-Lader mood scales [26] - A series of visual analogue scales were completed at the end of the cognitive assessment. Sixteen bipolar lines anchored at each end by an adjective describing a mood (e.g. tense/relaxed) were presented and participants selected a point on the scale that represented how they were feeling at that point in time. Individual item scores were calculated as % distance along the line from the left. The individual scales were combined as recommended by the authors to form three mood factors: alert, calm, content.

Procedure

Participants were instructed to attend the sports centre at Northumbria University on three occasions each separated by at least 24 hours. Prior to their first visit the participants were randomly allocated to one of three groups [multi-modal proprioceptive/yoga/classroom] they remained in this group and subsequently completed each intervention over three separate visits to the University. The baseline measures for cognition and mood were completed on a touchscreen tablet by all participants before and after each intervention.

Interventions

In the classroom group the participants were seated for 20 minutes and watched live sport streamed and projected onto a whiteboard. In the yoga group, participants removed their shoes and took part in 20 minutes of Hatha based yoga which focussed on body awareness and posture. The postures included standing, seated, prone and supine postures which included relaxation and isometric contraction of different muscle groups and regulated breathing. The yoga session was led by a trained yoga practitioner and the participants were encouraged to be mindful of their body position.

In the multi-modal proprioceptive group the participants removed their footwear and focussed on breathing techniques and body awareness (e.g. breathing with use of the diaphragm). This involved focussing on balance and awareness of relative position of body parts/joints and strength with many of the activities moving contralateral body parts (e.g. inverted position with four points of contact on the ground, lifting contralateral limbs progressed to travel). Further contralateral movements (e.g. dead-bug movement, supine position, lowering of right arm concurrently with the left leg) and hand-eye coordination (e.g. throw and catch using one hand progressing to a concurrent contralateral foot lift) formed the basis of the remainder of the activities. The multi-modal proprioceptive session was led by a trained human movement coach and the participants were also encouraged to be mindful of their bodily movements.

Statistical Analysis

All post-intervention outcome measures were modelled using the MIXED procedure in SPSS (version 24.0, IBM corp.). Analysis included the terms 'condition', 'visit', 'condition x visit' and the respective baseline as fixed factors. Significant effects ($p<0.05$) were followed up with pairwise comparisons (LSD).

Results

Numeric working memory

A significant main effect of condition [$F(2, 46.266)=3.771$, $p=0.03$] was observed on numeric working memory reaction time. Pairwise comparisons revealed that participants were significantly faster following multi-modal proprioceptive exercise relative to control ($p=0.023$; $d=0.77$) and yoga ($p=0.043$; $d=0.67$). There were no significant differences between yoga and control. See Figure 1.
There were no significant effects on accuracy of numeric working memory.

<Insert figure 1 here>

Mood

There were no significant effects on mood.

Baseline and adjusted post-intervention means and standard error (SE) for all outcomes can be found in Table 1.

<insert table 1 here>

Discussion

Participation in 20 minutes of multi-modal proprioceptively challenging physical activity resulted in an acute improvement to numeric working memory reaction time in older adults when compared to 20 minutes of yoga or classroom-based control. There were no significant differences observed for accuracy which indicates the omission of a speed accuracy trade off. No significant effects on mood were observed, which suggests that this did not act as a mediating factor in the effect on reaction time.

The findings are broadly supportive of a previous pilot study showing benefits to working memory span following 2 hours of multi-modal proprioceptive exercise. However, in the current study faster numeric working memory reaction times were observed. It is postulated that the significant improvement in working memory reaction time following the multi-modal proprioceptive intervention compared to yoga and control is due to these exercises involving more dynamic movements. Although multi-component physical activity interventions that have included dynamic exercise have not always shown improvement to cognition in an older population [27] there is evidence for positive effects of aerobic exercise and strength training activity on cognition [16,28-30]. A beneficial aspect of the protocol employed here was that the multi-modal proprioceptive training included the added benefits of weight bearing activity, elements of dynamic coordination and timing and, although not tested here, the potential for low level aerobic conditioning if the protocol was adhered to over the longer term.

There was no evidence for positive effects of yoga on cognition or mood despite the physiological health benefits in older adults that have been shown in the literature [31]. This is perhaps surprising as it could be argued that the yoga exercises in the current study involved body awareness and proprioceptive movement in some respects. However, the yoga movements were a sequence of pre-determined postures carried out in a more static manner and participants did not move from the spot. By contrast the multi-modal proprioceptive exercise involved open-ended, adaptable, movement off the spot with contralateral patterns and focussed, mindful actions in the participant's movements. The contralateral aspect of the intervention could be key here, since studies in humans and primates have shown that contralateral movement of the limbs results in the activity of neurons in the posterior parietal cortex and premotor cortex of the brain [32]. The parietal cortex is crucial to the representation and processing of numbers [33] and prior activation in the parietal cortex has shown to enhance activity and responses in early visual areas, leading to faster reaction times [34]. The contralateral patterning taught to participants during the proprioceptive intervention was something that was not present in the yoga intervention and could potentially be the novel aspect that has led to the effects seen on numeric working memory reaction time.

Interestingly the multi-modal proprioceptive session included some visual spatial perception exercises in the 20-minute bout (in the form of a group throw and catch activity which included challenges such as participants lifting a foot or using the non-dominant hand to receive and send the object). Although, studies such as Guan, Wade [35] show that a cognitive decline results in less efficient eye-hand coordination as adults age, the effect of visual, spatial tasks like this have shown positive results on memory [36]. Humans utilise several sensorimotor systems, proprioception, the vestibular system, visual system, and the eye, head, and arm control, plus aspects of cognition in sequence with the use of hand-eye coordination throughout their daily activities [37]. Although there was no evidence collected, it is assumed that these tasks of sending and receiving using non-dominant hand have not been trained in these adults for some time, from anecdotal comments in participants. Therefore, this new behaviour could potentially have affected the visual feedback and kinematics of reaching for an object in these participants as previously shown [37-41]. Early experiments on memory and a balance task in college students also found a link indicating cognitive spatial processing could have a reliance on neural mechanisms needed to control posture [42].

Proprioceptive function has been shown to alter through the life-course, developing in childhood and peaking in young adults before deteriorating after this point [43]. Therefore, whilst it is probable that the participants all had used these movements at some point in their life, it is unlikely that they had used them in this manner for a very long time. The participants comments and initial execution of movements pointed towards this although it cannot be assured. The multi-modal proprioceptive exercise therefore required elements of skill acquisition, which has been highlighted as key in the exercise-cognition relationship. The combination of physically and mentally challenging activities has been suggested as optimal in modulating information processing, decision-making and movement behaviour [44]. One explanation for this may be increased neuroplasticity following exercise that is both physically and mentally challenging [45,46]. It is important to note that whilst the improvements following multi-modal proprioceptive exercise were shown on a working memory task, they were observed as decreased reaction time rather than improved accuracy and so may reflect increases in motor speed independent of working memory as has been shown previously [47,48]. However, the lack of effects following a similar 20-minute yoga session suggest specific benefits following multi-modal proprioceptive exercise rather than a general impact of exercise. It is also possible that a lack of effects on accuracy was due to ceiling effects as indicated by the average 96 % accuracy in participants at baseline. In order to explore this further future studies should incorporate a broader array of cognitive tasks.

The findings demonstrated here indicate an acute benefit of multi-modal proprioceptive exercise in older adults. Although a previous study has shown working memory improvements following multi-modal proprioception in younger adults following a 2 hour intervention [17], the effects of a single 20-minute session in young adults are currently unknown. Given the deterioration of working memory [49] and processing speed [50] in ageing, multi-modal proprioception potentially has a particular benefit for older adults. In addition, targeted proprioceptive programmes have been encouraged in the older population as a prevention strategy for falls by clinicians [51]. There is also evidence that training proprioceptive aspects of motor control can improve older adults postural control [52,53]. However, this is the first study to demonstrate immediate effects following a single 20-minute proprioceptively demanding, multi-modal exercise session in this older population. With further investigation this finding could have potential benefits in terms of recommendations for physical and cognitive functioning in older adults using proprioceptively demanding training methods. Currently the Chief Medical Officer annual report [54] recommends two days of strength training activities and two days of activities to improve balance in the over 65 age group. The nature of the multi-modal proprioceptively demanding exercise in the current study included body weight bearing activities, similar benefits could potentially be accrued by older participants in a short duration without having to incur separate resistance exercise training sessions. In addition, the proprioceptive type of training protocol utilised in this study requires no special equipment or setting and can be done in the participants' own homes. Proprioceptively demanding multi-modal exercise would seem, therefore, to offer a benefit to older adults, whilst the effects in younger adults require further investigation.

Strengths and limitations

The study has a number of strengths including the use of a control condition as well as an active exercise comparator. The sample size although small was sufficient in accordance with an a priori power calculation. The study also employed repeated measures, which minimises the influence of individual differences. The narrow age range employed also ensures that the results are applicable to a specific age group rather than generalising across the adult lifespan. However, the participants are likely to be high functioning, fit, and healthy as is often the case for research volunteers but particularly research involving exercise and cognition. This point is supported by the high-performance scores observed on numeric working memory accuracy. The inclusion of on-day baseline measures and use of a computerised task has allowed for detection of changes in reaction time, which less sensitive measures may not have captured. However, only one cognitive task was included. Further research is needed to replicate and expand on this finding before any firm conclusions can be drawn. Future research would also benefit from drawing on a wider range of participants with information collected on relevant demographic variables such as fitness level as well as prior experience of multi-modal proprioceptive exercise or yoga. Inclusion of qualitative measures of the participants experience of the exercise and likelihood of doing the exercises on their own would also be useful to ensure the greatest impact of this research.

Conclusions

In conclusion, a 20-minute multi-modal proprioceptively challenging activity resulted in acute improvement to numeric working memory reaction time when compared to yoga or classroom control in healthy older adults. Future research should examine if the acute improvement in working memory reaction time is retained, enhanced or diminished when using short multi-modal proprioceptive movements over a longer time scale with this healthy older population. This is important given that the benefits potentially relate to the real-time, problem solving novelty of the movements while on the move learned during training, so it is possible that the proprioceptive movements would have to continually change in order to sustain this positive effect on numeric working memory reaction time.

In addition it would be of interest to examine if the contralateral patterning of the movements programmed are a key trigger for the positive impact on numeric working memory reaction time.

The findings presented here suggest that this type of multi-modal proprioceptively demanding exercise should be explored further as an alternative mode of exercise alongside the more traditional aerobic and strength-based exercise for healthy older adults.

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Tables

Table 1 - Baseline and adjusted post-intervention scores for all outcomes

Outcome	Condition	N	Baseline	SE	Post	SE
Numeric Working Memory Accuracy (%)	Classroom	19	96.78	1.42	96.09	0.95
	Yoga	19	95.97	1.04	93.78	1.38
	Multi-modal	19	96.38	1.44	96.33	0.91
Numeric Working Memory RT (ms)	Classroom	19	1057.45	64.53	1018.79	30.09
	Yoga	19	1069.03	59.87	1035.52	46.23
	Multi-modal	19	1070.03	53.17	926.88*	24.37
Alert (%)	Classroom	19	66.47	2.88	67.05	1.80
	Yoga	19	65.83	1.96	67.46	2.65
	Multi-modal	19	68.22	2.83	70.67	1.71
Content (%)	Classroom	19	72.99	2.40	71.29	2.17
	Yoga	19	70.26	2.61	70.37	3.20
	Multi-modal	19	70.61	2.80	74.94	2.09
Calm (%)	Classroom	19	62.05	3.79	60.87	3.39
	Yoga	19	58.68	3.38	60.17	4.97
	Multi-modal	19	57.37	4.53	56.74	3.36

*Indicates significant difference between the multi-modal proprioception exercise and the classroom control ($p<0.05$) and yoga ($p<0.05$)

Figures

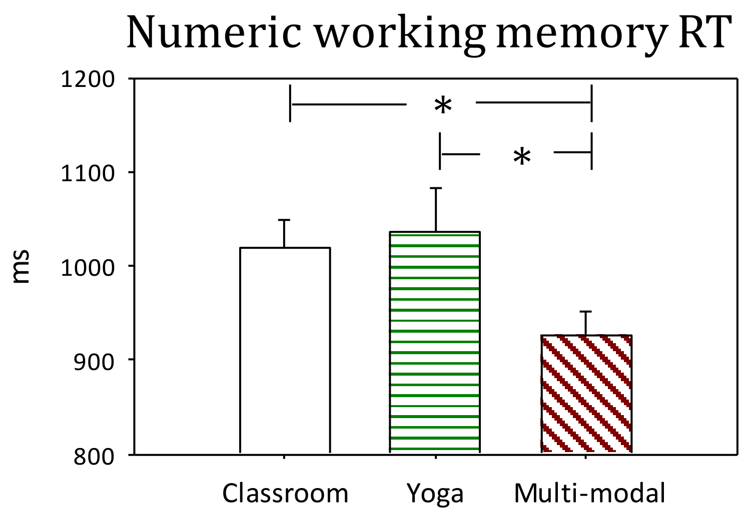

Figure 1 - Adjusted means + standard error for numeric working memory reaction time (RT) measured in milliseconds (ms). *<0.05.