Journal of Science and Medicine in Sport 17 (2014) 580–585

Contents lists available at ScienceDirect

Journal of Science and Medicine in Sport

journal homepage: www.elsevier.com/locate/jsams

Original research

Outcomes, utility, and feasibility of single task and dual task intervention programs: Preliminary implications for post-concussion rehabilitation

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ARTICLE INFO

Article history:
Received 11 June 2013
Received in revised form 28 August 2013
Accepted 13 November 2013
Available online 28 November 2013

Keywords:
Postconcussion syndrome
Recovery
Paradigm
Brain injury

ABSTRACT

Objectives: To examine neurocognitive and balance performance in recreational athletes, prior to and following a dual-task training intervention compared to single-task controls in order to assess the utility and feasibility of these interventions in the clinical setting.
Design: Controlled laboratory study.
Methods: Thirty healthy, physically active recreational athletes (dual-task group = 15; single-task group = 15; age: 20.3 ± 1.9 years) completed neurocognitive and balance assessments before and after a four-week intervention. Sensory Organization Test composite score and ratio scores, Balance Error Scoring System total score, and nine CNS Vital Signs composite scores served as outcome measures. Mixed model analyses of variance were used to examine each measure.
Results: The single-task group showed greater improvement for complex attention ($F_{1,26} = 5.48$, $p = .027$) following the training period. Both groups improved their performance on the complex attention domain ($F_{1,26} = 6.73$, $p = .015$), the Balance Error Scoring System score ($F_{1,26} = 42.34$, $p < .001$), and the Sensory Organization Test vestibular ratio score ($F_{1,28} = 6.55$, $p = .016$) following the intervention.
Conclusions: Our findings suggest combining cognitive and balance tasks as performed does not provide additional benefit to performing these tasks independently among healthy individuals, but appear to be feasible in this setting. Future research should examine integration of single-task and dual-task exercises for concussed patients.

1. Introduction

Concussions are the most frequent form of traumatic brain injury occurring in sport.[1] Previously, the focus of concussion research has been on prevention, evaluation and acute management.[2] Although much more is to be understood in these areas, further research is necessary to determine how rehabilitation[3] and return-to-play progressions may play a role in recovery following a concussion. Although the majority of concussion symptoms resolve within a 7–10 days window,[4] some individuals may suffer from Post Concussion Syndrome (PCS) where physical, cognitive, and emotional symptoms do not resolve for several months to years following injury.[5]

The current standard of care for sports-related concussion centers on cognitive and physical rest followed by gradual return to activity once the athlete is asymptomatic.[2] If concussion symptoms include both cognitive and balance impairment, then it seems rational that clinicians should address these issues during the rehabilitation process to facilitate recovery. Rehabilitation has been used for patients with moderate and severe traumatic brain injury, but has not been considered as a standard of care for mild traumatic brain injury such as sport-related concussion with prolonged recovery.[3] Medical professionals need to address the functional capacity of systems affected by concussion to ensure safe return to play.[6] Following concussion the functional capacities of balance and cognitive resources are often impaired making

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http://dx.doi.org/10.1016/j.jsams.2013.11.006

Table 1
Demographic information.

	ST ($n = 15$) Mean (SD)	DT ($n = 15$) Mean (SD)	Total sample ($n = 30$) Mean (SD)
Age (years)	20.87 (2.23)	19.73 (1.33)	20.30 (1.90)
Height (m)	1.68 (0.11)	1.62 (0.18)	1.65 (0.15)
Mass (kg)	70.65 (14.71)	65.86 (12.81)	68.25 (13.77)
Days between pre- and post-test	33.27 (5.02)	34.80 (3.23)	34.03 (4.22)

dual-task executions more difficult.[7,8] It is unknown if each domain should be addressed separately in a "single-task" model, or if these tasks should be integrated in a "dual-task" model that more accurately represents the conditions a patient is going to encounter when returning to physical activity. This "dual-task" rehabilitation methodology would require a person to execute a secondary cognitive task while being physically exerted to address cognitive, balance, and or visual deficits following concussion.

To the best of our knowledge, no study has attempted to assess single vs. divided attention training intervention programs in an effort to provide background for future paradigms in concussion management. Therefore, the purpose of this study was to examine dual-task neurocognitive and balance performance in healthy collegiate recreational athletes, prior to and following a dual-task training intervention compared to matched single-task controls. The intent of this research was to determine the utility and feasibility of a dual-task training program to potentially be applied following concussion.

2. Methods

The study was conducted following the ethical guidelines set forth by the Department of Health and Human Services Office for Human Research Protection (U.S.A.) and approved by the University of North Carolina at Chapel Hill's (UNC-CH) institutional review board prior to study initiation (Reference Study # 11-0499). Participants represented a volunteer sample from sport clubs at the UNC-CH. All participants signed approved consent forms prior to participation. Thirty physically active males and females participated in the study. The study sample consisted of 15 males and 15 females that reported participating in at least 30 min of self-reported physical activity at least 3 times per week. Demographic information is located in Table 1. Participants were stratified by gender and then randomly assigned to either the *dual-task (DT)* intervention or *single-task (ST)* intervention group (15 DT and 15 ST). All participants were blinded to study hypothesis and group assignment and were not informed of training differences between groups. One additional participant was dropped due to lack of compliance.

The Sensory Organization Test (SOT) performed on the Smart Balance Master System (NeuroCom International, Clackamas, OR, USA) was utilized to assess balance. The SOT utilizes six conditions each lasting 20 s and performed three times in random order. The methods of the SOT have been described in detail in previously.[9,10] Each of the six conditions was used to compute a weighted average of all of the sensory conditions called the composite score. The data collected were used to calculate contributions of the visual, somatosensory, and vestibular system to each participants overall balance in the form of three sensory ratio scores. Higher scores represent improved ability to maintain postural control while other systems are being simultaneously altered.[9,10]

The BESS is composed of a total of six 20-s trials with three conditions including double leg, single leg on the non-dominant foot, and tandem (heel-to-toe) stances with the non-dominant foot behind the dominant foot as described in previous reports.[11] Each condition was completed on a firm surface and repeated on a foam surface (Airex Balance Pad, Alcan Airex, Switzerland) with time kept on a stopwatch (Fisher Scientific, Pittsburgh, PA). Each participants' performance was scored by adding one (maximum 10 points for each trial) point for each of the following errors committed during each condition: lifting ones hands off the iliac crest, opening of the eyes, a step, stumble, or fall, moving the hip into greater than 30° of abduction, lifting the forefoot or heel, and or remaining out of test position for greater than 5 s.

The CNS Vital Signs (CNS Vital Signs, Chapel Hill, NC) contained a battery of seven subtests: verbal memory test; visual memory test; finger tapping test; symbol-digit coding; the Stroop test; the shifting attention test; the continuous performance test; and the non-verbal reasoning test. We analyzed the following domain raw scores for the battery: verbal memory; visual memory; processing speed; executive function; psychomotor speed; reaction time; complex attention; cognitive flexibility; and reasoning.

All participants reported for pre- and post-intervention testing sessions, which each included two balance assessments and a computerized neurocognitive exam. These outcome measures were selected as they represent the battery of tests student athletes typically complete at baseline and following concussion in many settings. Participants were also administered a demographic and health history questionnaire. The BESS trials were captured using video analysis and independently scored by a single research assistant trained in the analysis of BESS errors. The PI was blinded to the baseline and post-intervention balance and neurocognitive performance until the study was complete. The SOT conditions were completed in a randomized order, following the first set, which was completed in ascending numerical order, no matter the task. The computer monitor was covered during administration of the SOT to assure test administrator blinding of balance scores. A member of the research team reviewed the CNS Vital Signs scores for validity.

All 30 participants were required to report to the clinical research center twice a week to complete their intervention program. Participants also completed an additional training session each week at home, which included exercises already completed during in-person intervention sessions. Participants were instructed and given a specific training log tailored to each week's home session with direct instruction and a list of exercises to complete. Participants logged their home training sessions including exercises completed previously and activities completed during the intervention period. In addition to completing the exercise log, participants were asked to report to the investigators whether they had completed the training sessions and exercises at each home training session. Participants completed the intervention over 4 weeks for a total of 12 training sessions (8 in person and 4 at home). Average days between pre- to post-test was 34.03 ± 4.22 days. Participants were required to complete at least one observed session per week and twelve sessions overall (8 in person and 4 home) to be included in study analysis. Participants were allowed a fifth week of intervention progression to account for missed observed sessions due to academic breaks and scheduling issues. All participants, regardless of group and task proficiency completed a mass intervention progression.

Participants in the single-task intervention group (ST) completed activities broken down into separate balance and cognitive exercises of varying degrees of difficulty. Each participant began at the entry level of both balance and cognitive exercises and progressed to the advanced level. Single task intervention difficulty levels are depicted in Fig. 1.

Participants in the dual-task intervention group (DT) completed activities from all four progressive dual-task levels broken down into the entry level, moderate level, advanced level, and the activity specific level. The balance and cognitive activities were always completed concurrently. The progression began with one week of

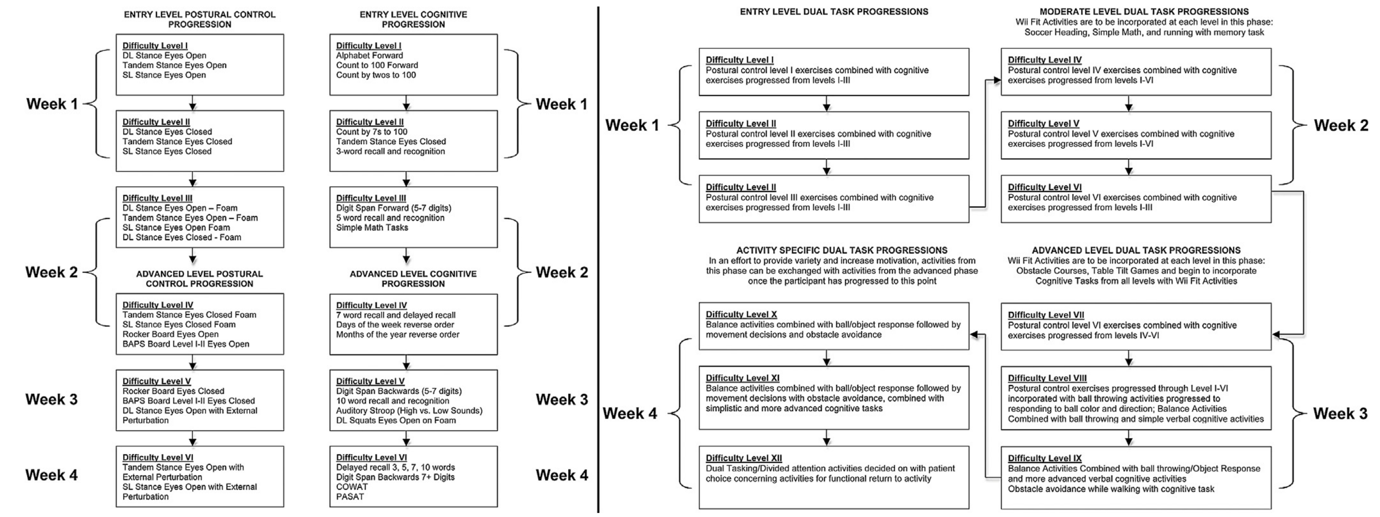

Fig. 1. Single and dual task progressions. SL, single leg; DL, double leg; BAPS, Biomechanical Ankle Platform System. *Levels in the dual-task progression reference those in the single task progression.

entry level tasks. Following week one, participants were progressed to the moderate level, which incorporated WiiFit (Nintendo, Redmond, WA, USA) activities at each level including soccer heading, and running with memory tasks. Following the second week the participant was progressed to the advanced level. The final week consisted of the activity specific tier and was composed of difficulty levels 10–12 (Fig. 1).

Thirteen separate mixed model analyses of variance (ANOVA) were used to compare between the ST and DT groups across all pre- and post-session outcome measures. Post Hoc testing was utilized for interaction effects. All data analyses were conducted using SPSS 19.0 (Chicago, IL). An a priori alpha level set at 0.05 was utilized for each dependent variable. This alpha level was adjusted for the four SOT variables, as the composite score is not independent of the three ratio scores. Alpha level for SOT composite score was set at 0.025 and for SOT ratio scores was set at 0.0167.

3. Results

We observed an improvement in measures of balance for both groups across time. Specifically, all participants, regardless of group, achieved a higher SOT vestibular ratio score and committed fewer errors during the BESS following intervention. No other significant interaction effects or main effects were observed for the balance measures. Descriptive and statistical results for balance measures are located in Table 2.

The single task group showed significantly greater improvement following their four-week training period for the domain of complex attention than the dual-task group. Significant main effects were observed for all participants displaying improvement for domains of executive function pre- to post-test session, complex attention pre- to post-test session, and cognitive flexibility pre- to post-test session. No other significant interaction effects or main effects were observed for the cognitive measures. Descriptive statistics for all neurocognitive domains are located in Table 2.

4. Discussion

The primary findings of this study indicate that regardless of training type, participants significantly improved following both the dual- and single-task intervention on measures of executive function, complex attention, cognitive flexibility, and some measures of balance performance. Single-task controls had greater neurocognitive improvements in the domain of complex attention from pre- to post-test than the dual-task participants. These findings refute our hypothesis that dual-task participants would show greater improvement in measures of cognition and balance when compared to single-task controls. Although our study used healthy recreational athletes, these results and the feasibility of the paradigms may support the use of cognitive and balance rehabilitation paradigms for those suffering from a mild traumatic brain injury and protracted recovery; particularly in sport, where input from these systems are paramount.

Although improvements in balance performance on the SOT were expected, participants who completed the dual-task training were hypothesized to have greater gains in postural stability due to training in an environment where performance was related to resource availability and task difficulty as proposed by researchers.[12] However, athletes that completed the dual-task training intervention did not exhibit significantly better balance performance, as measured by the SOT compared to those in the single-task group. Although there was no difference between groups, improvements in SOT vestibular ratios were similar to previous findings with individuals completing extensive balance training.[13,14] If these vestibular system improvements were seen regardless of group in our healthy sample then the intervention may prove beneficial to injured athletes suffering protracted recovery and vestibular complications due to mild traumatic brain injury.[15]

In order to maintain equilibrium the central nervous system must integrate afferent information from the vestibular, somatosensory, and visual systems to effectively execute a musculoskeletal task.[16] The challenge of completing concurrent balance and cognitive tasks were presumed to place greater stress on these sensory systems, facilitating greater performance gains compared to the single-task intervention exercises. Although some studies suggest that healthy individuals under dual-task conditions do not exhibit improved gait or stability, some studies do suggest improvements in balance.[17,18] However, this does not mimic the nature of our study in which individuals were trained in a dual-task setting yet were tested using a single-task assessment, balance and cognitive tasks completed separately. No significant findings were seen with respect to balance components including SOT composite score, or SOT visual ratio. Due to the extent of the visual innervation and the complexity of the visual pathways within the brain it is highly susceptible to impact and diffuse axonal injury.[19]. Participants may have had greater room for improvement of the vestibular system, as the visual system is often taxed first in a

Table 2
Descriptive and statistical results for study outcome measures.

	Pre-test mean (SD)	Post-test mean (SD)	Collapsed group mean (SD)	Group interaction effect	Session main effect	Group main effect
SOT composite						
Single task	54.8 (3.5)	54.6 (3.5)	54.7 (6.3)			
Dual-task	53.6 (6.3)	52.5 (5.7)	53.0 (6.3)	$F_{1,28} = 0.39$; $p = .535$	$F_{1,28} = 0.80$; $p = .377$	$F_{1,28} = 1.05$; $p = .315$
Entire sample	54.2 (5.0)	53.5 (4.8)	–			
SOT vestibular ratio						
Single task	0.77 (0.10)	0.85 (0.07)	0.81 (0.13)			
Dual-task	0.76 (0.13)	0.79 (0.14)	0.78 (0.13)	$F_{1,28} = 1.47$; $p = .235$	$F_{1,28} = 6.55$; $p = .016$	$F_{1,28} = 1.04$; $p = .317$
Entire sample	0.76 (0.11)	0.82 (0.11)	–			
SOT somatosensory ratio						
Single task	0.98 (0.08)	1.00 (0.05)	0.99 (0.07)			
Dual-task	0.97 (0.05)	1.00 (0.07)	0.99 (0.07)	$F_{1,28} = 0.02$; $p = .891$	$F_{1,28} = 2.74$; $p = .108$	$F_{1,28} = 0.13$; $p = .724$
Entire sample	0.98 (0.06)	1.00 (0.06)	–			
SOT visual ratio						
Single task	0.90 (0.11)	0.92 (0.07)	0.91 (0.10)			
Dual-task	0.87 (0.08)	0.90 (0.07)	0.88 (0.10)	$F_{1,28} = 0.01$; $p = .951$	$F_{1,28} = 3.95$; $p = .057$	$F_{1,28} = 0.98$; $p = .332$
Entire sample	0.88 (0.09)	0.91 (0.07)	–			
BESS total error score						
Single task	8.23 (1.79)	5.00 (2.86)	6.62 (3.28)			
Dual-task	8.73 (3.73)	4.00 (2.12)	6.37 (3.05)	$F_{1,26} = 1.51$; $p = .231$	$F_{1,26} = 42.34$; $p < .001$	$F_{1,26} = 0.09$; $p = 771$
Entire sample	8.50 (2.95)	4.46 (2.50)	–			
Verbal memory						
Single task	54.8 (3.5)	54.6 (3.5)	54.7 (6.3)			
Dual-task	53.6 (6.3)	52.5 (5.7)	53.0 (6.3)	$F_{1,28} = 0.39$; $p = .535$	$F_{1,28} = 0.80$; $p = .377$	$F_{1,28} = 1.05$; $p = .315$
Entire sample	54.2 (5.0)	53.5 (4.8)	–			
Visual memory						
Single task	50.5 (3.9)	50.7 (4.2)	50.6 (5.6)			
Dual-task	50.7 (5.9)	50.8 (4.5)	50.8 (5.6)	$F_{1,28} = 0.01$; $p = .937$	$F_{1,28} = 0.03$; $p = .875$	$F_{1,28} = 0.01$; $p = .929$
Entire sample	50.6 (4.9)	50.8 (4.3)	–			
Processing speed						
Single task	73.6 (13.7)	77.2 (10.3)	75.4 (13.4)			
Dual-task	67.7 (11.6)	71.1 (9.9)	69.4 (13.4)	$F_{1,28} = 0.01$; $p = .978$	$F_{1,28} = 2.24$; $p = .146$	$F_{1,28} = 3.00$; $p = .094$
Entire sample	70.6 (12.8)	74.2 (10.4)	–			
Executive function						
Single task	50.7 (7.3)	54.1 (6.2)	52.4 (9.3)			
Dual-task	50.1 (7.9)	51.9 (7.1)	51.2 (9.3)	$F_{1,28} = 1.04$; $p = .317$	$F_{1,28} = 4.97$; $p = .034$	$F_{1,28} = 0.25$; $p = .978$
Entire sample	50.1 (7.5)	53.0 (6.7)	–			
Psychomotor speed						
Single task	200.3 (20.9)	205.4 (16.6)	202.8 (26.4)			
Dual-task	191.4 (20.3)	194.2 (20.5)	192.8 (26.4)	$F_{1,28} = 0.28$; $p = .601$	$F_{1,28} = 3.23$; $p = .083$	$F_{1,28} = 1.04$; $p = .317$
Entire sample	195.8 (20.7)	199.8 (19.2)	–			
Reaction time						
Single task	602.5 (55.6)	608.9 (78.1)	605.7 (115.4)			
Dual-task	604.8 (102.9)	606.5 (88.7)	605.6 (110.5)	$F_{1,21} = 0.03$; $p = .858$	$F_{1,21} = 0.10$; $p = .753$	$F_{1,21} = 0.00$; $p = .998$
Entire sample	603.7 (81.9)	607.7 (81.9)	–			
Complex attention						
Single task	7.4 (3.2)	4.6 (2.2)	5.9 (3.3)			
Dual-task	6.9 (2.9)	6.7 (2.7)	6.8 (3.3)	$F_{1,26} = 5.45$; $p = .027$	$F_{1,26} = 6.73$; $p = .015$	$F_{1,26} = 0.86$; $p = .362$
Entire sample	7.1 (3.0)	5.6 (2.7)	–			
Cognitive flexibility						
Single task	49.2 (7.4)	53.2 (6.7)	51.2 (9.3)			
Dual-task	49.3 (7.9)	50.8 (6.6)	50.1 (9.3)	$F_{1,28} = 1.44$; $p = .240$	$F_{1,28} = 6.71$; $p = .015$	$F_{1,28} = 0.02$; $p = .639$
Entire sample	49.3 (7.5)	52.0 (6.6)	–			
Reasoning						
Single task	8.2 (2.9)	9.9 (3.2)	9.0 (4.1)			
Dual-task	9.2 (4.7)	9.0 (3.9)	9.1 (3.9)	$F_{1,27} = 1.00$; $p = .326$	$F_{1,27} = 0.61$; $p = .440$	$F_{1,28} = 0.01$; $p = .952$
Entire sample	8.7 (3.9)	9.4 (3.6)	–			

healthy population.[21] The visual, somatosensory, and vestibular systems work together and are heavily dependent on the state, input, and information available from each system utilized.[20] It can be hypothesized without visual impairment due to injury, participants may have increased their reliance on the vestibular system because the visual system was operating at its maximum capacity to maintain equilibrium.

Similarly, athletes that completed the dual-task training intervention did not exhibit significantly better balance performance as measured by the BESS. Both groups committed fewer errors on the BESS following the interventions. Throughout the intervention, athletes were asked to perform various balance tasks on the foam pad used to administer the BESS test. The ability for participants regardless of group to train regularly on the foam pad not only challenged each individual's balance but may have also contributed a practice effect. Practice effects have been previously observed for serial testing using the BESS.[22,23] Although balance improves with balance training[23] BESS scores have been shown to level out after three administrations of the test.[22] In addition, the continued decrease in total error score may indicate balance improvements due to intervention sessions, it cannot be ruled out that improvements were due to repeated exposure, six administrations in total, to the BESS test. With this global improvement, balance training should be an integral part of the rehabilitation process to treat prolonged balance deficits seen following concussion.[9,24]

Balance improvement following training has been shown extensively in previous literature,[25,26] however we did suspect that individuals completing the dual-task progression would show greater improvements, but we did not observe this. Weeks 1 and 2 cognitive exercises may not have been difficult enough to compromise afferent input further stressing balance and thus providing greater opportunity for improvement. Although cognitive exercises did increase in difficulty for weeks 3 and 4, athletes may not have been exposed to these exercises long enough to elicit any group interaction effect when compared to the single-task group.

We found that the single-task group significantly improved from pre- to post-test in the domain of complex attention when compared to the dual-task group. Although this result was unexpected, it is reasonable in that the complex attention domain measures the ability to track and respond to information over extended periods of time and to perform cognitive tasks as quickly and accurately as possible. Single-task participants were asked to complete cognitive exercises separate from balance exercises requiring sustained attention. Participants, regardless of group, improved in neurocognitive domains of executive function and cognitive flexibility as well. Previous research has shown that individuals suffering from a mild traumatic brain injury suffer from cognitive deficits in the domains of complex attention, executive function, and cognitive flexibility suggesting that an intervention that improves these domains would be beneficial.[27] Outside of complex attention, executive function and cognitive flexibility, no other significant finds were observed for neurocognitive measures. It is possible that the cognitive exercises utilized were not broad enough to foster improvement in multiple neurocognitive domains. Greater variance in exercise type and purpose may need to be further investigated to target specific cognitive domains.

If completion of the intervention, regardless of group, resulted in improvements within these cognitive domains, then both methods may prove beneficial to those suffering from protracted recover following concussion. Although our study is unique to healthy participants, previous research with individuals suffering a mild traumatic brain injury as also shown improvements in complex attention with administered neuropsychological rehabilitation strategies including paper-and-pencil test batteries and "real-life" activities.[28] The compliance and feasibility of this study may serve as a guideline or pilot study for future research within an injured population and individuals suffering protracted recovery following concussion. Availability for training sessions dictated training frequency and scheduling, which may have resulted in sub-optimal periodization. This training frequency and duration may not have been enough to challenge balance and neurocognitive systems to elicit optimum performance adaptations consistent with the overload principle,[29] and elicit the change we were expecting in our DT group. We also employed a mass progression, which may have limited the improvements we may have expected with individualized training programs that would be customary with injured participants. Outcome measures utilizing dual-task measures should also be further investigated as pre- and post-test results may have varied based on task.

5. Conclusions

Our findings suggest that combining a cognitive task with a balance task, as performed by the dual-task group, does not have any additional benefits to performing these tasks independently, as with the single-task group among healthy individuals. There are potential benefits to a single-task progression, which may be beneficial to an injured population such as additional attention or balance training and controlled progression back into some activity. Balance and neurocognitive improvements may prove to be clinically significant for sports medicine professionals working with athletes suffering protracted recovery following concussion. A combined approach beginning with a single-task intervention progression followed by dual-task exercises may provide potential benefits for concussed individuals. Future research should examine this approach of single-task and dual-task exercises within an intervention progression for an injured population, as this approach may provide additional benefits to individuals following concussion with prolonged attention issues.

Practical implications

- Healthy participants who completed a balance and cognitive rehabilitation protocol improved in the respective domains over time.
- A paradigm combining both balance and cognitive exercises would be feasible for health care professionals to complete during a rehabilitation session.
- Timing and length of both single and dual-task interventions should be considered as this may influence outcomes.

Conflicts of interest and source of funding

Drs. Register-Mihalik, Mihalik, and Guskiewicz received funding from the NC TraCS institute that supported this project. The NC TraCS Institute is supported by grants UL1TR000083, KL2TR000084, TL1TR000085 from the National Center for Advancing Translational Sciences, National Institutes of Health. The content is solely the responsibility of the authors and does not necessarily represent the official views of the NIH. The remaining authors have no disclosures or conflicts of interest.

Acknowledgement

The authors would like to acknowledge Ms. Mikel Stiffler for assistance with data collection.

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