Balance and cognitive performance during a dual-task: Preliminary implications for use in concussion assessment

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Abstract

Objectives

To determine the reliability and effects of a dual-task paradigm on balance and cognitive function compared to a single-task paradigm.

Design

Repeated measures.

Methods

Healthy participants (n = 23) completed a variation of the Sensory Organization Test and the incongruent Stroop test individually (single-task) and concurrently (dual-task) during two testing sessions.

Results
The Sensory Organization Test and incongruent Stroop test had moderate to high reliability ($1.00 > ICC_{2,k} > 0.60$) under the dual-task conditions. Reaction time was significantly longer ($t_{21} = -2.54$, $p = 0.019$) under the dual-task conditions, while balance scores under one of the four conditions of the Sensory Organization Test (sway floor/fixed wall) were statistically better ($t_{22} = -3.03$, $p = 0.006$) under the dual-task conditions. However, this difference in balance scores may not be clinically meaningful.

Conclusions

These findings illustrate that the Sensory Organization Test and incongruent Stroop task can be reliably incorporated into a dual-task assessment paradigm. The slowed reaction time under the dual-task paradigm indicates that the dual-task provided an additional cost to cognitive function. Dual-task concussion assessment paradigms involving these two tasks are psychometrically appropriate as well as more representative of actual sporting situations. However, more research should be conducted in a concussed population to further validate this claim.

Keywords

Concussion; Dual-task; Reliability; Attention; Cognition

1 Introduction

Sports-related concussions are often diagnosed using a battery of tests, including clinical evaluations, cognitive functioning, postural control, and self-reported symptoms.\(^1\) and\(^2\) While single-task paradigms effectively measure either cognitive functioning or postural control, these paradigms may be limited as they only evaluate domains in isolation and not the interaction of these domains across concurrent tasks. Performance in sport requires simultaneous processing of cognitive, sensory, and motor information.\(^3\) A paradigm including concurrent assessments of these domains is needed to understand capabilities related to complex tasks. The closest suggested paradigm that clinicians have to replicate real sports scenarios while concurrently evaluating concussive effects is a dual-task methodology incorporating cognitive and balance demands.\(^3\) Post-concussive testing should simulate the demands of sport in order to make informed return-to-play decisions. Dual-task paradigms have been described in recent literature.\(^3\) and\(^4\) However, the cognitive tasks used are limited in their difficulty compared to the incongruent Stroop task, which involves inhibitory and interference processes.\(^5\)
Dual-task paradigms provide the best representation of sport, where cognitive function and postural control must be simultaneously processed and attention must be divided. Before dual-task paradigms can be used in a clinically meaningful way, a highly reliable paradigm must be created which actively taxes both cognitive function and postural control.

Therefore, the primary purpose of this study was to examine test–retest reliability of a computerized complex attention task (incongruent Stroop) and the Sensory Organization Test (SOT) performed under dual and single-task conditions. A secondary purpose was to evaluate cognitive and balance performance under single and dual-task conditions.

2 Methods

Participants included 23 healthy, physically active volunteers (11 male and 12 female; age $20.4 \pm 1.7$ years; height $= 173.8 \pm 6.3$; weight $= 70.2 \pm 10.8$). The sample size for the comparison between the single and the dual-task performance was determined a priori using sample sizes presented in previous literature. For the reliability piece, this same sample size was applied to make the study feasible and to provide a basis for further research in this area. The study was approved by the XXX institutional review board prior to study initiation. Participants signed approved consent forms prior to participation. Participants were physically active three or more days per week for at least 30 min per session and were excluded if they had known neurologic deficits, lower body injuries affecting balance or concussion within 6 months of participation, or diagnosis of an attention deficit disorder.

The NeuroCom (Clackamas, OR) Sensory Organization Test (SOT) assesses postural control. The SOT manipulates the force platform (floor) and the surroundings (the machine’s walls) in order to assess three sensory components inherent to balance: vestibular, somatosensory, and visual systems. The SOT has six different conditions: (1) fixed floor/fixed walls, (2) fixed floor/closed eyes, (3) fixed floor/sway wall, (4) sway floor/fixed wall, (5) sway wall/closed eyes, and (6) sway floor/sway wall. For this study, SOT conditions two and five were eliminated due to the necessity of eyesight during the cognitive task. The SOT has been described in detail in previous studies. $^6$ and $^7$ The data collected in each of the four conditions used in this study were combined to form an average equilibrium score. The equilibrium score is the percentage of a person’s unused limit of stability in the anterior–posterior direction for each condition. The calculation for this equilibrium score is as follows: $100 - [100 \times (\text{MaxSwayAP} - \text{MinSwayAP})/12.5]$. 

Therefore, a higher equilibrium score represents less sway and greater postural stability.\textsuperscript{7} and \textsuperscript{8}

A customized version of the incongruent Stroop test from the CNS Vital Signs (Chapel Hill, NC) cognitive battery was used as a measure of cognitive function. The incongruent Stroop displays a color name (red, yellow, blue, or green) in a color of font (also red, yellow, blue, or green). If the color name and font color agrees, the subject is instructed not to respond. If the color name and color font name disagree, the subject is instructed to click a button to report the error. Reaction time for correct responses served as the outcome measure for this task. This measure was chosen as the outcome of interest, as the accuracy on this task alone is near 100\% in healthy participants, making the reaction time measure a more sensitive response variable.

Participants were tested two times, approximately 14 days apart (13.5 ± 2.9 days). This test re-test interval was chosen in an effort to separate the initial session from the post-test session by at least one week to diminish learning effects that may occur. The participants performed the SOT and the incongruent Stroop in both the single and dual-task paradigms in a counterbalanced testing order during each session. Participants completed an orientation to all tasks at the beginning of each session.

Three, randomized trials for each of the four SOT conditions were used to obtain a single-task balance performance score for each SOT condition. The equilibrium scores for the three trials under each condition were averaged to obtain a single-task average SOT equilibrium score. Three single-task iterations of the incongruent Stroop task were used to obtain the Stroop single-task score. The average reaction time of each correctly identified responses for the three trials was used to create the single-task performance variable for the incongruent Stroop test.

Under the dual-task paradigm, the test administrator simultaneously started the SOT and incongruent Stroop test, which was displayed via a computer monitor inside the SOT and formatted into twenty-second trials to coincide exactly with the balance test. The paradigm was set up using two different computers. The computer running the SOT was housed completely outside the walls of the SOT and under complete control of the test administrator. The computer running the Stroop test had its tower and keyboard outside the walls of the SOT. This set-up allowed ensured that the test administrator was in control of running both tests and that they were indeed run simultaneously as the start (enter key) was pressed at the same time for the SOT and the incongruent Stroop task. The
participant held a clicker, connected to the computer, in their dominant hand and used this device to respond to the incongruent Stroop stimuli on the screen. This ensured that divided attention was examined throughout the entire testing period. The participant randomly performed a total of 12 dual-task trials, which corresponded with three trials of each of the four SOT test conditions.

All data were analyzed using SPSS 17.0 (Chicago, IL). The test–retest reliability for both postural control (SOT composite equilibrium score) and cognitive function (incongruent Stroop test reaction time for correct responses), under the single and dual-task conditions, were calculated between the two test sessions using ICC$_{2,k}$. The differences in balance and cognitive function in the dual compared to the single-task paradigm for each test were analyzed using a paired samples t-test for the data collected during the first test testing session. Alpha level was set to 0.05 a priori. The first session data was used to examine single-task vs. dual-task differences due to the high reliability of the measures across both sessions.

3 Results

The ICC$_{2,k}$ and standard error of measurement (SEM) values for each variable under single and dual-task paradigms are found in Table 1. The average SOT condition four (ICC$_{2,k}$ = 0.801) and three (ICC$_{2,k}$ = 0.714) equilibrium scores and average reaction time (ICC$_{2,k}$ = 0.0.745) under the dual-task paradigm were highly reliable.$^9$ SOT condition one and six equilibrium scores under both paradigms and average reaction time during the single-task paradigm were moderately reliable (0.70 > ICC$_{2,k}$ > 0.50).$^9$ SOT condition three equilibrium scores under the single-task paradigm had low levels of reliability (ICC$_{2,k}$ > 0.345).
Table 1. ICC$_{2,k}$ and SEM values for the SOT and the incongruent Stroop test.

<table>
<thead>
<tr>
<th>SOT condition</th>
<th>Equilibrium score</th>
<th>Variable</th>
<th>ICC$_{2,k}$</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOT condition one equilibrium score</td>
<td>Single-task reaction time</td>
<td>0.611</td>
<td>1.26</td>
<td></td>
</tr>
<tr>
<td>SOT condition one equilibrium score</td>
<td>Dual-task reaction time</td>
<td>0.613</td>
<td>1.18</td>
<td></td>
</tr>
<tr>
<td>SOT condition three equilibrium score</td>
<td>Single-task reaction time</td>
<td>0.345</td>
<td>2.14</td>
<td></td>
</tr>
<tr>
<td>SOT condition three equilibrium score</td>
<td>Dual-task reaction time</td>
<td>0.714</td>
<td>1.21</td>
<td></td>
</tr>
<tr>
<td>SOT condition four equilibrium score</td>
<td>Single-task reaction time</td>
<td>0.845</td>
<td>3.95</td>
<td></td>
</tr>
<tr>
<td>SOT condition four equilibrium score</td>
<td>Dual-task reaction time</td>
<td>0.801</td>
<td>3.87</td>
<td></td>
</tr>
<tr>
<td>SOT condition six equilibrium score</td>
<td>Single-task reaction time</td>
<td>0.514</td>
<td>9.61</td>
<td></td>
</tr>
<tr>
<td>SOT condition six equilibrium score</td>
<td>Dual-task reaction time</td>
<td>0.673</td>
<td>6.49</td>
<td></td>
</tr>
<tr>
<td>Stroop reaction time (correct)</td>
<td>Single-task reaction time</td>
<td>0.649</td>
<td>37.05</td>
<td></td>
</tr>
<tr>
<td>Stroop reaction time (correct)</td>
<td>Dual-task reaction time</td>
<td>0.745</td>
<td>30.31</td>
<td></td>
</tr>
</tbody>
</table>

SOT condition four equilibrium scores were significantly better ($t_{22} = -3.028$, $p = 0.006$) under the dual-task paradigm (87.406 ± 8.695) compared to the single-task paradigm (84.430 ± 10.041). There was no significant difference between the single and dual-task paradigms for SOT condition one ($t_{22} = -1.021$, $p = 0.318$), three ($t_{22} = -0.879$, $p = 0.389$), or six ($t_{22} = -0.187$, $p = 0.854$) equilibrium scores. Grouped means, standard deviations, t-values, and p-values for all SOT conditions are found in Table 2.
Table 2. Paired-sample t-test results for the SOT and the incongruent Stroop test.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Single-task mean and standard deviation</th>
<th>Dual-task mean and standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOT condition one equilibrium score</td>
<td>93.261 ± 2.026</td>
<td>94.244 ± 1.903</td>
</tr>
<tr>
<td>SOT condition three equilibrium score</td>
<td>91.585 ± 2.649</td>
<td>92.651 ± 2.271</td>
</tr>
<tr>
<td>SOT condition four equilibrium score</td>
<td>84.430 ± 10.04</td>
<td>87.406 ± 8.695</td>
</tr>
<tr>
<td>SOT condition six equilibrium score</td>
<td>74.776 ± 13.78</td>
<td>75.673 ± 11.35</td>
</tr>
<tr>
<td>Stroop reaction time (correct)</td>
<td>611.470 ± 62.575</td>
<td>625.898 ± 60.056</td>
</tr>
</tbody>
</table>

* Significant difference between the dual and single task.
Reaction time was significantly longer ($t_{21} = -2.54, p = 0.019$) under the dual-task paradigm (625.898 ± 60.056 ms) compared to the single-task paradigm (611.470 ± 62.575 ms). Grouped means, standard deviation, $t_{21}$, and $p$-values for all variables can be found in Table 2.

4 Discussion

The most meaningful findings in our study were slower reaction times under the dual-task paradigm and the moderate to high levels of reliability for the balance and cognitive tasks. The slowed reaction time under dual-task conditions represents a cost to cognitive function in a divided attention scenario as more attentional resources are being used. Before being cleared for competition after a concussion, athletes usually complete serial cognitive and balance testing. The moderate-to-high levels of reliability ensure that clinicians are receiving consistent information to facilitate decision-making.

Guskiewicz suggested that concussed athletes have balance and cognitive deficits post injury.\textsuperscript{7} Bleiberg et al.\textsuperscript{10} and numerous others\textsuperscript{1 and 11} have also found diminished cognitive capacities in concussed athletes. While these findings are important, the interaction of these two abilities requires examination to understand the relative influences of divided attention. The cost of divided attention, as seen in this study through the reaction time variable, is indicative of the interaction between postural and cognitive function. With four of five outcome measures showing higher levels of reliability under the dual-task condition, a dual-task paradigm using the SOT and incongruent Stroop test may be reliably used in the clinical setting.

For the four conditions of the SOT used in this study, low (0.35) to high (0.85) levels of reliability were found. With the exception of SOT condition three under the single-task paradigm, all conditions of the SOT under both paradigms were moderately-to-highly reliable. These overall highly reliable results agreed with those by Dickin, who in two separate studies found moderate to high reliability levels were obtainable after two trials of a SOT condition.\textsuperscript{12 and 13} Wrisley et al. also found fair to high (0.35–0.79) reliability for SOT equilibrium scores.\textsuperscript{9} The use of a highly reliable diagnostic tool for concussion testing is necessary for clinicians to make informed decisions regarding return-to-play decisions.
One explanation for the high reliability found in this experiment is the inclusion of an orientation task during both testing sessions for the cognitive and balance tasks. Reliability results for the computerized incongruent Stroop task were moderate to high for reaction time under both the single and dual-task paradigms. While we recognize that the addition of an orientation task added approximately 10 min to the paradigm, we feel that the need for high reliability is critically in a baseline paradigm to assess concussive injuries and making informed returned-to-play decisions. Strauss et al.,14 Siegrist,15 and Franzen et al.16 all found high reliability in reaction time responses in the Stroop task. Due to the high reliability of the reaction time responses in the current study and in previous literature, the incongruent Stroop test appears appropriate to incorporate into a dual-task paradigm.

We observed significant improvements in balance for SOT condition four under the dual-task, but observed no significant findings for any other SOT condition. This improvement in equilibrium score was supported by Broglio et al.3 Dault et al. cited low-frequency, voluntary eye movement, which can increase visual stabilization, as an explanation for better balance scores, although it is acknowledged that a valid explanation for this hypothesis does not yet exist in literature.17 Hunter and Hoffman argued that, during single-task conditions, more attention than normal is placed on balance, increasing joint stiffness and postural sway.18 This increase in stiffness and sway would combine to lower the equilibrium score during single-task paradigms, making balance during dual-task paradigms appear better.

Another explanation for postural control improvements may be related to the conditions itself. Under dual-task SOT condition one, the stable floor and surroundings may not force a participant to divide attention to balance. Under SOT conditions three and six, the participant may have already been dividing his/her attention between balance and visual surrounding during the single-task paradigm due to the moving surroundings. Dual-task SOT condition four is the only condition where the participant is forced to switch from complete attention on balance to divided attention between postural control and the cognitive task. This explanation agrees with a finding by Wulf et al.,19 suggesting that increased focus on an external stimulus (i.e. the cognitive task) increases a participant’s stability. In Wulf’s20 view, focus on an external task promotes the use of more automatic control processes in the brain as opposed to voluntary muscle control to correct postural perturbation. However, if the external stimuli (focus) becomes too difficult or assumes more attentional resources, this may not hold true. This change toward an external focus
may explain the difference in equilibrium scores between SOT condition four and all other conditions. Along with explaining the SOT condition four results, adding an external focus to baseline testing in the form of a dual-task paradigm may be beneficial. Athletes are constantly forced to focus on external stimuli along with maintaining their balance, so incorporating a paradigm that simultaneously incorporates internal and external stimuli may provide an enhanced testing battery and influence return-to-play decisions.

Although Broglio et al. found similar results for SOT condition four, Broglio et al.\(^3\) and Resch et al.\(^4\) also reported significant improvements in SOT conditions one and three. The lack of additional significant improvements in our study, such as those found by Broglio and Resch, may indicate that our paradigm was better at forcing participants to divide attention between postural and cognitive function. Similar improvements may not have been observed in our study due to the task orientation. Although all studies used the SOT, the different cognitive tasks may have challenged the brain's ability to divide attention differently. Easier cognitive tasks may allow more allocation to postural control mechanisms, resulting in an increase in equilibrium balance scores. Overall, the results of this study did not support the thought that balance would get significantly worse under the dual-task setting. However, the findings that postural control only improved for one of the four SOT conditions, compared to three of four conditions in Broglio et al.\(^3\) and two of six in Resch,\(^4\) may indicate that this paradigm required greater allocations of attentional resources and be clinically meaningful.

Reaction time was significantly longer in the dual compared to the single-task paradigm. These findings are consistent with Resch et al., who reported longer reaction times in a dual compared to a single-task paradigm.\(^4\) While the findings of Resch et al. are consistent with our findings, Broglio et al.\(^3\) reported significantly faster reaction times under a dual-task paradigm. Both Resch et al. and Broglio et al. used a task-switching test as the cognitive function component of their dual-task paradigm, with Resch et al. using an auditory version of the test. In task-switching, a letter and single-digit number were paired together. If the number-letter pair appeared in the left or right upper quadrant, the participant performed an odd/even assessment on the number. If the number-letter pair appeared in the left or right lower quadrants, the participant performed a vowel-consonant judgment on the letter. Since identifying numbers and letters are an integral part daily life, this neurocognitive task is considered easier because of the participant's familiarity.\(^5\)
In Broglio et al.’s computerized version of the task, the letter-number pair was presented in a continuous clockwise order, making the quadrant in which the pair will appear predictable. This, combined with the lack of counterbalancing, may have contributed to significantly shorter reaction times under the dual-task conditions. In a study by Spierer et al., reaction time was found to be significantly slower when presented with an auditory stimulus as compared to a visual stimulus. This difference in processing speed may account for the differing results between the Broglio and Resch study even though they used the same cognitive function task. As compared to task-switching, the incongruent Stroop task, used in our study, forced participants to recognize mistakes in color word-color font association. This recognition of an incorrect association involves higher order brain processes, likely making the incongruent Stroop a more difficult cognitive task. The slowed reaction time in a dual-task setting, seen in this study using the incongruent Stroop test, represented a cognitive function cost during divided attention and supports the possibility of dual-task testing as a more sensitive tool for concussion testing.

Although this study corrected many of the limitations of other dual-task paradigms by matching the trial length of the cognitive function and postural control task completely, providing a difficult cognitive function task, and using a balance test which isolates each of the three systems of balance, this study is not without its limitations. The cognitive function task requires participant’s eyes to be open, losing two of the six standard SOT conditions. Concussions are known to impair the visual system’s role in maintaining balance and excluding the eyes closed portion of the SOT may alter the balance assessment. While there were significant changes in the healthy population used in this study, another limitation of this study is whether the results obtained will be applicable to concussed populations. Future research should assess the utility of this paradigm in a concussed population and should assess the reliability of this paradigm without the implementation of a full orientation task in an effort to make such a paradigm more feasible in the busy athletic setting.

The ability to divide attention between postural and cognitive function is imperative for athletes in sporting situations. Current clinical paradigms for pre- and post-concussive testing only evaluate these abilities individually. The significantly longer reaction time seen in this study indicates additional deficits during concurrent testing. Therefore, individually assessing these abilities may not be the most accurate way to make final decisions regarding return-to-play. The overall high reliability of the measures used in our study, combined with the differences found between the single and dual-task paradigms,
indicate that dual-task paradigms may be an appropriate and sensitive tool for assessing concussed athletes. Before applying dual-task paradigms in a clinical setting, more research should be conducted using concussed athletes as participants to see if the effects found in healthy populations are mirrored in concussed populations.

Practical implications

- The moderate-to-high reliability levels found in this study suggest that both the SOT and the incongruent Stroop test are reliable enough to be used in clinical settings.
- Dual-task activities where attention is clearly divided between a cognitive and motor task is more representative of sport performance than balance or cognitive task performed in isolation.
- The slower reaction times and lack of improvement in SOT scores observed under the divided attention conditions indicate that dual-task paradigms may be useful in the concussion assessment process. Future research should examine these paradigms in concussed populations.

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