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Reliability of 5 Novel Reaction Time and Cognitive Load Protocols

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Context: Reaction time (RT) is crucial to athletic performance. Therefore, when returning athletes to play following injury, it is important to evaluate RT characteristics ensuring a safe return. The Dynavision D2® system may be utilized as an assessment and rehabilitation aid in the determination of RT under various levels of cognitive load. Previous research has demonstrated good reliability of simple protocols when assessed following a 24- to 48-hour test–retest window. Expanding reliable test–retest intervals may further refine novel RT protocols for use as a diagnostic and rehabilitation tool. ***Objective:*** To investigate the test–retest reliability of a battery of 5 novel RT protocols at different time intervals. ***Design:*** Repeated measures/reliability. ***Setting:*** Interdisciplinary sports medicine research laboratory. ***Participants:*** Thirty healthy individuals. ***Methods:*** Participants completed a battery of protocols increasing in difficulty in terms of reaction speed requirement and cognitive load. Prior to testing, participants were provided 3 familiarization trials. All protocols required participants to hit as many lights as quickly as possible in 60 seconds. After completing the initial testing session (session 1), participants waited 1 hour before completing the second session (session 2). Approximately 2 weeks later (average 14 [4] d), the participants completed the same battery of tasks for the third session (session 3). ***Main Outcome Measures:*** The intraclass correlation coefficient, standard error of measurement, minimal detectable change, and repeated-measures analysis of variance were calculated for RT. ***Results:*** The intraclass correlation coefficient values for each of the 5 protocols illustrated good to excellent reliability between sessions 1, 2, and 3 (.75–.90). There were no significant differences across time points ($F < 0.105$, $P > .05$). ***Conclusions:*** The 1-hour and 14-day test–retest intervals are reliable for clinical assessment, expanding the time frames previously reported in the literature of when assessments can be completed reliably. This study provides novel protocols that challenge cognition in unique ways.

Keywords: testing and measurement, clinical-evaluation, evaluation

In athletic situations, reaction time (RT), or the time it takes one to respond to a stimulus,[1] is crucial to an individual's ability to protect themselves from opponents and dangers of the sport. Previous research has found that athletes have faster RTs and movements compared with nonathletic individuals, potentially to avoid risk of game play such as player-to-player contact or to react quicker than opponents providing an advantage.[2,3] Therefore, when returning athletes to play following a concussion, it is important to evaluate RT characteristics to ensure a safe return to participation. RT is vital following concussion and is often impaired as a result of these injuries.[4] Postinjury standard of care typically involves complete cognitive and physical rest, although emerging evidence suggests more active management strategies may be more effective.[5] Both stress the importance of ensuring an athlete has recovered before returning to sport. Restoration of RT is important following concussion as it serves as a protective mechanism and effects performance.[6] Therefore, identifying a reliable means of objectively quantifying RT may aid in improving return to participation decision making.

The Dynavision D2® (Dynavision; Dynavision International LLC, West Chester, OH) light board provides an objective measure to assess RT and visuomotor response. This device is equipped with customizable protocols capable of measuring and training RT. The light board consists of 64 raised tactile targets (buttons) arranged in 5 rings, 4 quadrants, with a central tachistoscope (T-scope) LED screen (Figure 1). The targets illuminate at random intervals for an individual to strike to extinguish. The device enables the user to measure the number of successful "hits," RT, and overall response patterns. Previous studies have investigated the test–retest reliability of some Dynavision protocols. With the shortest between-session duration of 48 hours, Wells et al[7] found intraclass correlation coefficient (ICC) values of .63 to .84 in recreationally active individuals. When separated by 2 weeks, Klavora et al[8] found moderate interclass reliability (.71 and .73) for each of the 2 protocols examined. Yet, an additional study investigated the test–retest reliability of 3 different protocols over a period of 8 weeks found excellent reliability (.88, .92, and .97) for all 3 protocols.[9] With moderate reliability detected at past time points, we would expect that this study's different time points and novel protocols would have similar reliability.

The Dynavision has been reported to have utility for both assessment and rehabilitation following a traumatic brain injury or concussion as well as improving visuomotor performance in healthy populations.[10] Following injury, not only do athletes require the ability to react quickly but also require cognitive processing ability to make split-second decisions. Although previous studies found good to excellent test–retest reliability for Dynavision protocols, determining additional reliable test–retest intervals for novel protocols is necessary for future use as a clinical diagnostic and rehabilitation tool.

Past research has observed reliability for simple RT protocols, whereas the protocols included in this study incorporated additional cognitive loads similar to game play scenarios. Cognitive load has been defined as "a multidimensional construct representing the load that performing a particular task imposes on the learner's cognitive system," that can be measured through performance.[11,12] Sports involve a challenging degree of multitasking

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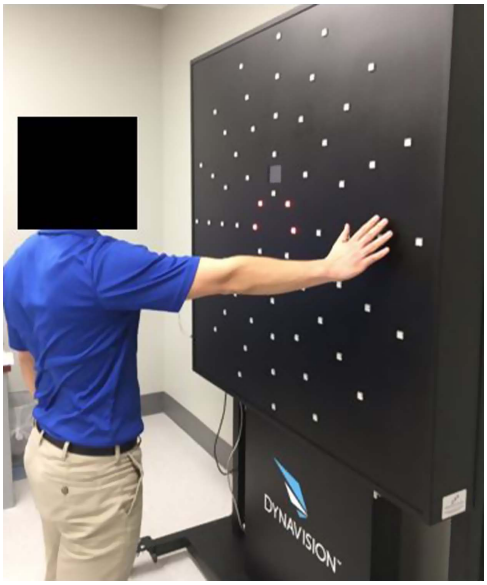

Figure 1 — Dynavision D2®.

with varying cognitive demands. Our novel protocols were designed to challenge patients (1) to test an individual's ability to react at varying cognitive demands to determine if they have returned to preinjury levels and (2) to aid in rehabilitation to meet the demands of everyday activities. Therefore, the aim of this study was to investigate the test–retest reliability of a battery of 5 novel protocols at 3 time points, separated by 1-hour and 2-week intervals.

Methods

Participants

A sample of 30 healthy adults (6 males and 24 females; age 27.0 [5.7] y, height 166.6 [12.9] cm, mass 70.2 [20.8] kg) participated in this study. Prior to participation, individuals were screened to ensure they met the inclusion criteria for the study. Participants were excluded if they were not between the ages of 18 and 55 years, had sustained a traumatic brain injury or concussion within the last year, had known vision problems beyond correction of glasses or corrective lenses, or were currently participating in vision/visuospatial training. Participants did not have extensive experience with the Dynavision prior to this study. Participants who met the eligibility criteria signed an institutional review board approved protocol consent form from the University of Kentucky.

Procedures

Participants stood in a relaxed stance, approximately 30.5 cm from the Dynavision light board (Figure 1). The board was adjusted to the field of view and reach of the participant to accommodate height.[13] Participants were instructed to focus their gaze on the T-scope in the center throughout testing and to rely on their peripheral vision. Following setup, participants completed three 60-second familiarization trials,[9] using the Speed protocol described in Table 1.

For each visit, participants completed the protocols in the same order as presented in Table 1. Research personnel provided standardized instructions prior to each protocol to ensure that the information given was the same across participants and trials. All protocols were 60 seconds in duration and increased in difficulty in terms of speed of response requirement and cognitive load. The protocols that increased the required cognitive load utilized simple math or reading an excerpt from a novel while simultaneously extinguishing the illuminated lights. For each protocol, the participant was instructed to hit or make contact with as many of the illuminated red lights as possible before time expired. In the Moderate and Go–No-Go task, errors, such as an incorrect solution to a math problem or hitting a green light, were recorded. Participants were permitted to use both hands to strike the illuminated lights in the manner they desired. Average RT, calculated by averaging the time between a light's illumination and the individual extinguishing it within the 60-second protocol, was recorded. Participants were then given 1 hour between session 1 and session 2. They repeated the 5 protocols with the same instructions given, but without familiarization trials.[7]

Approximately 2 weeks (average: 14 [4] d) after the second test, participants returned for session 3. This time frame was selected to decrease the likelihood of a carryover effect of learning tasks from the first 2 sessions, therein reducing the potential for training effects.[9,14] In addition, this delay expands possible assessment time frames and clinical relevance. Participants were positioned in similar proximity to the board and reminded of protocol directions. No familiarization session was included at this time point.[7] All 5 protocols were repeated in the same manner as the first and second sessions.

Statistical Analysis

Data were examined to ensure no assumptions were violated prior to analysis. To detect RT differences across sessions, a repeated-measures analysis of variance was used. To determine reliability and variance, $ICC_{3,1}$, standard error of measurement, and minimal detectable change at a 90% confidence interval were calculated.

Table 1 Novel Protocol Descriptions

Protocol	Description 60-s duration
Speed	A self-paced protocol in which participants were instructed to extinguish as many lights as quickly as possible. A new light would illuminate at random once contact was made with the one prior.
Simple	A time-based protocol where participants were instructed to extinguish as many lights as possible before lights extinguished after 0.75 s.
Moderate	A time-based protocol where participants were instructed to solve simple math problems (addition and subtraction) aloud as they appeared on the screen as they extinguished as many lights as possible before the lights went out after 0.75 s.
Difficult	A time-based protocol where participants read a passage aloud as it scrolled across the screen while extinguishing the lights. All participants read an excerpt from the same novel.
Go–No-Go	A time-based protocol where participants read aloud as it scrolled across the screen while extinguishing the lights. In addition, green lights would appear. Participants were instructed to avoid the green lights as they appear continuing to hit the red.

An ICC value of .50 to .75 was considered moderate, between .75 and .90 was considered good, and a value above .90 was considered excellent according to Portney and Watkins.[15] An alpha value of $P \leq .05$ was used to determine significance. All analyses were computed in SPSS (version 24; IBM Corp, Armonk, NY).

Results

Data were found to be normally distributed ($P > .06$) using the Shapiro–Wilk test. RTs for all sessions are presented in Table 2. A repeated-measures analysis of variance detected no significant differences across time points ($F < 0.105$, $P > .05$, $\eta^2 = .02–.07$). The reliability data are presented in Table 3. The ICC values were calculated between sessions 1, 2, and 3. The ICC values for each of the 5 protocols illustrated moderate to good reliability[15] between sessions 1, 2, and 3 (.75–.90). The minimal detectable change at a 90% confidence interval of the protocols ranges from 0.024 to 0.89 seconds indicating a change greater than 0.89 seconds is necessary to be 90% confident that a change has occurred which exceeded measurement error.

Discussion

This study sought to determine the reliability of 5 novel protocols using the Dynavision in a healthy population. The findings of this study suggest all protocols were reliable for assessing RT with this visuomotor device at both 1-hour and 14-day intervals. Moderate to good reliability (ICC = .75–.90) for RT provides support for use of the 5 novel Dynavision protocols within a healthy, adult population. This study has expanded time frames and protocols that can be used reliably for assessment in clinical practice. The protocols used in this study stress additional cognitive load similar to the dual tasking required of athletes during game play, providing a better measure of return to participation readiness in relation to RT.

Table 2 Reaction Times in Seconds for Each Session (Mean [SD])

Protocol	Session 1 (baseline)	Session 2 (1 h)	Session 3 (14 [4] d)
Speed	0.78 (0.08)	0.78 (0.08)	0.78 (0.10)
Simple	0.57 (0.03)	0.57 (0.03)	0.58 (0.03)
Moderate	0.60 (0.03)	0.60 (0.02)	0.60 (0.03)
Difficult	0.62 (0.03)	0.61 (0.04)	0.60 (0.04)
Go–No-Go	0.62 (0.03)	0.62 (0.03)	0.62 (0.04)

Table 3 Reliability Data for Reaction Time Trials Between Sessions 1, 2, and 3

Protocol	$ICC_{3,1}$	Standard error of measurement	MDC_{90}
Speed	.88	0.031	0.089
Simple	.90	0.008	0.024
Moderate	.75	0.012	0.033
Difficult	.83	0.014	0.039
Go–No-Go	.83	0.014	0.039

Abbreviations: ICC, intraclass correlation coefficient; MDC, minimal detectable change.

The results of this study are similar to that of previous studies evaluating reliability.[7–9] Mean RTs in this study were also comparable with that of Wells et al.[7] A preliminary study by Klavora et al[8] recorded and analyzed the number of hits the participants made during all protocols. These protocols were repeated on multiple occasions separated by 2-week intervals, much like our session 3. The results indicated only moderate reliability of .73 for the equivalent of the Speed task in this study. Klavora et al's[8] speed test–retest reliability fell within similar ranges as this study but instead examined the number of hits where the current study examined RT; however, our results still determined the protocol to be reliable. A later study by the same authors examined participant hits on the device and detected extremely high reliability of their Simple, Moderate, and Complex protocols indicating reliable testing procedures.[9] Unlike the previous literature, this study was unique in that the novel protocols built on one another and gradually increased in cognitive demand. Although previous literature has also used protocols with dual tasks, this study introduced the different protocols at varying time points.

A more recent study[7] examined 3 protocols similar to those of Klavora et al[8,9] on 6 separate occasions, at least 48 hours apart. The first of the 3 protocols was a Choice Reaction Test where participants were instructed to begin at a "home" position on the board and extinguish lights that illuminate within the horizontal plane. The second protocol, mode A, was identical to our Speed protocol. Compared with the findings in Wells et al,[7] our ICC values for this protocol were higher (.88). This difference in ICC values may be due to allowing the participants in our study to have 3 familiarization trials versus their one. The third protocol was mode B that built on mode A with the addition of having the participants repeat a series of 5 numbers that were presented on the T-scope. Our study challenged participants' cognitive abilities in a slightly different manner, as participants were asked to solve simple math equations. Overall, motor RT reliability of their 3 protocols ranged from 0.63 to 0.72, or fair to moderate.[7] Our 3 most similar protocols to the ones used in previous studies are the Speed, Simple, and Moderate which obtained ICC values ranging from .75 to .90. Differences may be due to additional familiarization trials or a potential training effect. All protocols were based around the first protocol that required participants to strike as many lights as possible in 1 minute, creating a potential training effect. This may also contribute to our higher ICC values within each session.

The protocols used within this study, especially the Moderate, Difficult, and Go–No-Go, are novel and have not previously been studied to determine reliability. The Moderate protocol requires cognitive processing of simple mathematical equations; once the participant solves the equation, the participant is required to state the answer aloud. The Difficult protocol continues to challenge cognitive load by implementing the dual-task concept of having to read aloud. Finally, the Go–No-Go protocol requires the participant to make the critical decision to hit a light or not based on the color illuminated. These tasks are all dual concept in nature much like what would be necessary in a sporting situation. The importance of these novel protocols is the increased level of cognitive demand required to complete the task. As it is highly necessary for athletes to dual task and be able to respond on the field to changes in play, RT and decision making become crucial. The results of this study indicate these novel protocols have moderate to good reliability between sessions 1, 2, and 3 (.75–.90). For clinicians returning athletes to participation following an injury, having a reliable protocol that increases cognitive load causing the athlete to respond

quickly under varying conditions may indicate readiness to return. This requires the athlete to dual task, respond to a stimulus as well as additional cognitive task, similar to during play.

The 1-hour and 2-week test–retest intervals are reliable for clinical assessment, expanding the time frame for reliable utilization of the Dynavision. Our results support that performance is stable and does not change across these time points for individuals who do not train on the Dynavision. Prior to utilizing the Dynavision in clinical practice for rehabilitation, more research is needed to determine a treatment schedule that may invoke change across time. Future studies should aim to identify the most effective time points for both assessment and rehabilitation purposes in specific clinical populations including but not limited to those recovering from concussions.

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