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Use of the King–Devick test for sideline concussion screening in junior rugby league

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ABSTRACT

Aim: To determine whether the King–Devick (K–D) test used as a sideline test in junior rugby league players over 12 matches in a domestic competition season could identify witnessed and incidentally identified episodes of concussion.
Methods: A prospective observational cohort study of a club level junior rugby league team (n = 19) during the 2014 New Zealand competition season involved every player completing two pre-competition season baseline trials of the K–D test. Players removed from match participation, or who reported any signs or symptoms of concussion were assessed on the sideline with the K–D test and referred for further medical assessment. Players with a pre- to post-match K–D test difference >3 s were referred for physician evaluation.
Results: The baseline test–retest reliability of the K–D test was high ($r_s = 0.86$; $p < 0.0001$). Seven concussions were medically identified in six players who recorded pre- to post-match K–D test times greater than 3 s (mean change of 7.4 s). Post-season testing of players demonstrated improvement of K–D time scores consistent with learning effects of using the K–D test (67.7 s vs. 62.2 s).
Discussion: Although no witnessed concussions occurred during rugby play, six players recorded pre- to post-match changes with a mean delay of 4 s resulting in seven concussions being subsequently confirmed post-match by health practitioners. All players were medically managed for a return to sports participation.
Conclusion: The K–D test was quickly and easily administered making it a practical sideline tool as part of the continuum of concussion assessment tools for junior rugby league players.
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1. Introduction

Once trivialised by coaches, sport-related concussions were viewed as a transient injury void of long term consequences [1]. Clashes to the head that were often thought of as "just a ding" [2] and "playing through the pain" were regarded as a sign of the individual's toughness and commitment to the team [1]. All sports participants are at risk of receiving a concussive event [3]. This risk is increased in players with a history of a previous or multiple concussive events [4]. Concussion has become one of the most troublesome injuries facing the sports medicine professional [5], especially in regard to early identification of concussive signs and symptoms and appropriate concussive management facilitation [6]. Often the identification of a sport-related concussion is left to the team coach as trained health care professionals are usually not available at amateur games and training sessions [5]. Concussive signs may be missed, as the coach may be unable to take the required time to fully assess the player and may overlook the signs of a concussion [7].

Eye function movements may become impaired following brain trauma [8,9]. In acute traumatic brain injuries latency and inaccuracy of saccades occur following the injury [10]. This can remain in people with post-concussion syndrome where there are a higher number of saccades occurring and poor motor movement timings with longer durations and slower velocities of movement [11]. Poor oculomotor function is one of the most robust discriminators for the identification of [11], and most widely reported visual problems in [8,9], a mild-traumatic brain injury.

The King–Devick (K–D) test was originally developed as a reading tool to assess the relationship between poor oculomotor functions and learning disabilities. The K–D test utilises a series of charts of numbers that progressively become more difficult to read in a flowing manner [12]. The K–D test requires eye movements, language function and attention in order to perform tasks shown to be reflective of suboptimal brain function in hypoxia [13], extreme sleep deprivation [14], multiple sclerosis [15,16], Parkinson's [17] and concussion [18–25]. The K–D test has been utilised in representative rugby league [24] and domestic

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rugby union [23] and has identified non-witnessed or 'incidental' concussions [26]. Players identified with changes in their baseline K–D test were further assessed with the Sports Concussion Assessment Tool v. 2 (SCAT2) and the identification of a sport-related concussion was confirmed. These studies have highlighted the potential of the K–D test to detect sub-concussive impacts that may accumulate over a period and can lead to neurological changes [24].

Although the K–D test has been utilised as a sideline concussion screening tool in several contact sports at various age groups [18–25, 27,28], no study, has reported the use of the K–D test with rugby league players participating in an under 11 age group competition. This study used the K–D test as a sideline assessment in junior rugby league players over a domestic competition season to identify: (1) the test–retest reliability of the K–D test in junior players aged 9 and 10; (2) if the K–D test could identify concussive events that occurred from match participation; (3) to identify the over-season learning effect of utilising the K–D test; and (4) if the changes observed in the K–D test were clinically meaningful.

2. Methods

A prospective observational cohort study was conducted on a junior club level rugby league team during the 2014 competition in New Zealand. Nineteen players (males n = 14, females n = 5) were enrolled in the study with a mean age, mass and height of 10.4 ± 0.9 years; 54.9 ± 17.2 kg and 1.52 ± 0.11 m. Parental consent was obtained from the player's parents/guardians prior to enrolment in the study. All players participated in the modified version of Rugby League (Mod-League) over a single competition season administered through a zonal region under the jurisdiction of the New Zealand Rugby League (http://www.nzrl.co.nz/pdf/guide_to_the_laws_2010.pdf). The match rules for rugby league have been adjusted to accommodate for younger participants. Similar to the adult version of rugby league, the team in possession must carry the ball forward to attempt to score a try, but can only pass the ball backwards for a maximum of six tackles before handing the ball to the opposition. Unlike the adult version of rugby league, both males and females participated in the same game against teams with a similar mixture of male and female players.

The researchers' University ethics committee approved all procedures in the study (AUTEC 12/156).

3. King–Devick (K–D) test

The King–Devick (K–D) test is a rapid number naming test that takes less than 2 min to administer [19,20]. The K–D test involves the player's reading aloud a series of random single-digit numbers from left to right. The K–D test includes one practice (demonstration) card and three test cards varied in format on either a moisture-proof 6 × 8 in. spiral bound physical test or as an application on a IPad platform. Using the IPad platform for the K–D test, players were asked to read the numbers from left to right across the card as quickly as they could without making any errors using standardized instructions. Time was kept for each test card, and the K–D test summary score for the entire test was based on the cumulative time taken to read all three test cards. The number of errors made in reading the test cards was recorded. Baseline K–D test times for all participants were established either pre-season (n = 11) or when participants joined the team after the season had commenced (n = 8). The best time (fastest) of the two trials without errors became the established baseline K–D test time [19]. When head trauma was suspected the K–D test is used as a screening tool. The K–D test is administered once using the same instructions and the time and errors are recorded then compared to the participant's baseline. The K–D test has been reported to have an inter-class correlation for test–retest reliability of 0.96 [25] and 0.97 [19]. The K–D tests utilised were v2.2.0 (http://www.kingdevicktest.com) on an IPad2. The IPad2 testing platform enables the use of the K–D test with two different number set test versions and these were varied over the duration of the study to reduce possible learning effects..

4. Testing procedures

Players were tested on the side of the training field twice within a 10 minute period before a training session by the same examiner. No player undertook any match activities until they had established a baseline K–D test on the IPad platform. All players were asked to read aloud the practice (demonstration) card before reading aloud all three test cards. Only the three test cards times were recorded. The number of errors made in reading the test cards were recorded [21]. The fastest error-free time of the K–D test was recorded as the baseline score [24]. Players were asked to additionally complete the K–D test after each match they participated in and at the end of the competition season (post-season K–D test).

During matches, the team medic (and lead researcher), observed players for any signs of a direct blow to the head, for being slow to rise from a tackle or collision, or for being unsteady on their feet following a collision. If this occurred the players were assessed on-field. If there were any signs of delayed answering, incorrect answers to questions, or if the player appeared to be impaired in any way, the player would be removed from the match activity and rested on the sideline. Players reporting any sign(s) or symptoms of a concussion, were suspected to have incurred a concussion or were removed from match participation were assessed with the K–D test on the sideline, not allowed to return to play on the same day and referred for further medical assessment. No players identified with delayed (worsening) post-match K–D times were allowed to return to training or match activities without a full medical clearance. Players who were referred for further medical assessment were required to see their own health practitioner. The parents were asked to provide the team medic with the results of the health practitioner's assessment, either confirming a concussion or having medically cleared the player for return to sporting activities. Concussions were only recorded if they were formally diagnosed by a health practitioner.

5. Statistical analyses

All data collected were entered into a Microsoft Excel spread sheet and analysed with SPSS v22.0.0. Data are presented as mean (±SD) for player data and median values [25th–75th interquartile range] for K–D test scores. Given the small sample size (n = 19), non-parametric statistical tests were utilised. Differences in K–D test scores from pre-season (baseline establishment) and post-match K–D test scores or post-season K–D test scores, were compared using the Wilcoxon signed-rank test. A Spearman's rank correlation coefficient was conducted to test for baseline test–retest reliability of the K–D. Statistical significance was set at $\alpha = 0.05$.

6. Results

The season consisted of twelve competition matches resulting in a match exposure of 88.0 match h. Throughout the competition, no on-field concussions were observed. The characteristics and K–D testing data for the study cohort are shown in Table 1. There were improved K–D test time scores for the second K–D test times when compared with the first time test during baseline testing (67.7 s vs. 62.2 s; $p = 0.001$). The baseline test–retest reliability of the K–D test was high ($r_s = 0.86$; $p < 0.0001$). Post-season testing of the players demonstrated improvement of the time scores which is likely consistent with learning effects of using the K–D (62.0 s vs. 54.6 s; $p = 0.002$). A total of seven concussions were formally identified in six players that recorded post-match K–D test times greater than 3 s from their baseline with a mean change of 7.4 s (±7.0 s; $p = 0.018$) (see Table 2). Player 1 recorded two post-match K–D test times greater than 3 s from their baseline

Table 1
Player characteristics and the scores, changes and differences in the results of the King–Devick test for junior rugby league players.

	All players (n = 19)	Players with no post-match K–D changes (n = 13)	Players with post-match K–D changes (n = 6)*c
Age, y ± SD	10.4 ± 0.9 years.	10.5 ± 0.8	10.2 ± 1.2
Pre-season K–D test 1, s, mean (±SD)	67.7 (±10.1)	64.6 (±9.3)	74.4 (±8.8)
Pre-season K–D test 2, s, mean (±SD)	62.2 (±10.2)[a]	59.4 (±9.8)	68.2 (±9.0)
Difference test 1 vs. test 2, s, mean (±SD)	−5.5 (±6.1)	−5.2 (±4.7)	−6.1 (±8.8)
Baseline K–D test score, s, mean (±SD)	62.0 (±9.8)	59.4 (±9.8)	67.4 (±7.9)
Post-match K–D test, s, mean (±SD)	58.8 (±10.0)	55.5 (±9.2)	70.0 (±15.4)[b]
K–D change baseline vs. post-match, s, mean (±SD)	−1.2 (±5.0)	−3.9 (±3.3)	7.4 (±7.0)‡
Post-season K–D test, s, mean (±SD)	54.6 (±10.5)[b]	51.8 (±9.3)	60.7 (±11.0)
K–D change pre-to post-season, s, mean (±SD)	−7.4 (±5.4)	−7.7 (±5.2)	−7.6 (±5.7)
ICC (95% CI), K–D test baseline 1 vs. baseline 2	0.92 (0.79 to 0.97)	–	–
ICC (95% CI), K–D test baseline vs. post-season	0.92 (0.80 to 0.97)	–	–
Sensitivity (95% CI) K–D test	1.00 (0.73 to 1.00)	–	–
Specificity (95% CI) K–D test	0.85 (0.42 to 0.97)	–	–

Abbreviations: K–D = King–Devick test; SD = standard deviation; IQR = inter-quartile range; CI = confidence interval; s = seconds; significant difference ($p < 0.05$) than [a] = test 1 of baseline; [b] = established baseline; * = one player recorded post-match changes >3 s twice throughout the competition; [c] = all players with post-match K–D changes were medically assessed and diagnosed with a concussion by their own health practitioner; ‡ = positive numbers for change in K–D score indicates longer (worsening) than baseline score.

throughout the study period and was identified to have incurred a concussion by a health practitioner on both occasions. Player 6 recorded a post-match delay score (101.4 s vs. 78.4 s) when compared with their baseline, and also had two errors on post-match K–D test evaluation. No other player enrolled in the study had errors on their post-match K–D test evaluations.

7. Discussion

This study is the first to report the results for K–D test monitoring for junior rugby league players. Although no witnessed concussions were recorded over the duration of the study, six players recorded post-match changes with a mean delay of 4 s from their baseline resulting in seven concussions being reported by health practitioners. All players who recorded a delay from their baseline and their parents were advised of their results and referred for further medical assessment for a possible concussion. Signs and symptoms of concussion can develop over time [29,30] and, as some players, coaches and parents may not be fully unaware of the actual signs and symptoms of a concussion [31], the requirement for a full medical clearance was to ensure that these players were medically assessed. All players referred for further medical assessment were identified to have had a concussion by their health practitioner and were medically managed in their return to sports participation. No player with a delay in their post-match K–D test score was allowed to return to match or training activities until medically cleared. Although Player 1 recorded two concussive injuries over the duration of the study she was medically cleared to return to full sporting activities each time post-concussion.

In the absence of concussion, the K–D test has been shown to have learning effects associated with repeat testing [20]. This finding is commonly associated with repeated performance measures, or timed testing [20] and can be seen by the mean improvement of 5.5 s between the two tests undertaken to establish the individual player's baseline score. This was similar to previous values for the K–D test in sports activities with improvements of 1.9 s to 3.1 s [19–21,23–25] for establishing the baseline score of participants. The use of dual baseline assessments allows familiarization of the test and can help alleviate any possible confounding factors [32] such as previous exposure to similar tests. Although employing serial K–D test assessments has a learning effect, there should be an improvement in the score upon each subsequent test administration [32]. The IPad version of the K–D test (v2.2.0) utilised in our study had two sets of demonstration and test cards with different numbers along the same pattern. The post-match K–D test evaluations were varied weekly on the IPad to reduce the possibility of players learning the numbers. Although tests were varied, players showed faster times when compared with their baseline results. Any worsening of the scores are therefore likely to be a valid indicator that players should be evaluated further for a possible concussive event [20].

Table 2
Baseline and post-match King–Devick test results and differences (in seconds) for players identified with a concussive injury in junior rugby league in New Zealand.

Player	Baseline (seconds)	Post-match (seconds)	Difference (seconds)
1[a]	57.9	64.3	6.4
	47.5	51.1	3.6
2	61.4	64.8	3.4
3	67.6	72.5	4.9
4	63.6	69.7	6.1
5	61.6	66.3	4.7
6	78.4	101.4	23.0
Average ± SD	62.6 ± 9.4	70.0 ± 15.4	7.4 ± 7.0

[a] = Same player recorded two concussive events over the duration of the study; SD = standard deviation.

The procedures utilised for the assessment and management of players identified to have a worsening of their K–D test score are identical to a previous study [24]. The post-match testing was undertaken at least 15 min after the game had finished to allow for any of the complex cascade of ionic, neurometabolic, neurochemical and physiologic events to occur [33]. These events are reported to occur in the first 10 min from a concussion event and then a neuronal depression period occurs where cognitive dysfunction manifests [33]. Previous studies [19–21,23–25] have reported K–D test times of participants with a concussive injury having a median of 5 s slower (range 3.2 s to 18.0 s) than their baseline. Our study had a mean of 7.4 s slower than baseline for players who were either removed from match participation or tested post-match and all these players underwent medical evaluation through their own medical practitioner.

Any changes from the baseline K–D test >3 s post-match was the limit identified for the possibility of a concussive injury having occurred, and is similar to previous studies [23,24,26]. Although other studies have utilised a threshold of any worsening of the K–D test time from baseline with additional tools for the identification of concussion (e.g. Post-Concussion Symptom Scale (PCSS), Sports Concussion Assessment Tool 2 (SCAT2) and 3 (SCAT3)) [19–21,28] these were not utilised with this cohort of players. The decision to only use the K–D test on the sideline was to ascertain whether this would enable the identification of youth players at risk of a concussive injury to enable them to be referred for further medical evaluation. The PCSS is a component of the SCAT3 and should be used by a medical professional as part of the continuum of assessment tools for the identification of a concussion [29] which may include the K–D test. This is similar to the ChildSCAT3 for players under the age of 12 years [29]. The K–D test was able to identify players at risk with six players identified with worsening post-match times

greater than 3 s. Although not reported, several players did have a worsening of their K–D but this was <3 s and these players were retested again at the next training activity with all of these players recording a score equal to or faster than their baseline score. Future studies may consider using a threshold of any worsening from the K–D test baseline for the identification of a possible concussive injury.

The detection, and removal from play, of players with a possible concussion may help minimize the deleterious outcomes of concussion. The use of a practically implemented, rapid assessment tool for sideline evaluation of sports participants is vital in the detection of concussive injuries. The K–D test is a portable tool that can be utilised on the sideline and is simply based on the time taken to complete a rapid number naming task [34]. The K–D test requires the coordination of visual processes, eye movements (saccades, convergence and accommodation), attention and language function to complete this rapid number naming task [34]. This task requires the integration of functions of the cerebral cortex, cerebellum and brainstem and this has been shown to correlate with suboptimal brain function [34]. It does not require a medical professional to administer [25] making this a realistic sideline assessment tool for amateur sporting activities at all levels of participation, especially where there is minimal or no access to on-site medical personnel.

Although there were no witnessed concussive events throughout the duration of the study, the use of the K–D test was useful in identifying when a concussive injury had occurred. Players can be exposed to a high number of impacts per season [35]. It has been suggested [36,37] that brain injuries come from concussive events and also from the accumulation of subconcussive impacts that result in pathophysiological changes in the brain. Subconcussive events are impacts that occur where there is an apparent brain insult with insufficient force to result in the hallmark signs and symptoms of a concussion [38–40]. Although subconcussive events do not result in observable signs and apparent behavioural alterations [41,42], they can cause damage to the central nervous system [43] and these are often not medically diagnosed. The worsening of time and/or errors identified on the sideline or post-match K–D test have been associated with concussive injury [18–24]. K–D test performance has been previously shown to be unaffected in various noise levels and testing environments [44]. The K–D test has been reported to have significant correlations ($p < 0.0001$) with the visual motor speed (VMS), reaction time (RT), verbal memory (VEM) and visual memory (VIS) of the Immediate Post-concussion Assessment Cognitive Test (ImPACT®) [27] computerised concussion evaluation system. A benefit to the use of the K–D test on the sideline for all players post-match is the ability to identify possible concussive events and to have these players medically evaluated ensuring player safety from a young age.

A benefit of conducting this research in the current cohort of junior players was the ability to discuss concussions with the parents on an informal basis resulting in some parents presenting their child for assessment after they felt there was a possible concussive event that was not identified during the game. The ability to pass on information relating to the education of parents, coach and manager about what a concussion is and to be able to identify signs of a concussion was beneficial to the group as a whole. It has been previously reported that coaches' knowledge and management of concussion identified that 16% [45] to 51% [46] of coaches were unable to correctly identify factors relating to concussion recognition, management and prevention techniques. Between 40% [47] and 42% [46] of coaches thought that a player needed to lose consciousness for a concussion to occur. Over a quarter, 26% [47] to 32% [46] would not remove a concussed player from the field of play. In assessing parents' understanding of concussion [48] it was reported that 83% of parents believed they could recognize a concussion in their teenager, 5% reported that a player needed to lose consciousness for a concussion to occur, 19% of parents would not have their teenager see a medical practitioner if there was a suspected concussion, and 4% would let a symptomatic teenager return to play. The ability to be able to show the team management and parents the results of the K–D test on the sideline post-match and the changes identified for the player enabled the facilitation of information sharing about concussions and the identification and management of these injuries.

There are some limitations to this study and the reader should consider these when viewing the results identified. Firstly, the sample size is small ($n = 19$) as only one team was followed for a single season and rules for playing rugby league at this age group in New Zealand only 11 players per team are on the field at any time. In eight participants who joined the team after the competition had started and, although this enabled interchanging of players to occur, these players had joined as they became available from other sporting activities or were invited to participate by other players involved in the team. Secondly, no history of previous playing experience or concussion histories were obtained from any of the players involved in this study. Thirdly, as no concussion was identified during match participation, the ability to compare the K–D test post-match changes did not present itself and the comparison of the changes that can occur post-concussion was not available. The finding that a player was 23 s slower in a post-match K–D test evaluation may be an outlier given that the small sample size and this result should be considered within the context of this limitation.

8. Conclusion

The finding of unwitnessed, or incidental, medically assessed and confirmed concussions in the current study was unexpected, but similar to previous studies [21–24]. The variety of symptoms that may go unreported by athletes, and undetected by trained observers, emphasize the need for a quick and reliable sideline screening tool to assist team management and parents to accurately detect if a concussive type event has occurred. The results of this study further validate the K–D test as a reliable and rapid sideline tool that provides supportive evidence of a concussive event and assists with removal from play decisions.

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