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The King–Devick test was useful in management of concussion in amateur rugby union and rugby league in New Zealand

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ABSTRACT

Aim: To use the King–Devick (K–D) test in senior amateur rugby union and rugby league players over a domestic competition season to see if it could identify witnessed and unwitnessed episodes of concussion that occurred from participation in competition matches over three years.
Methods: A prospective observational cohort study was conducted on a club level senior amateur rugby union team (n = 36 players in 2012 and 35 players in 2013) and a rugby league team (n = 33 players in 2014) during competition seasons in New Zealand. All 104 players completed two trials 10 min apart of the K–D at the beginning of their competition season. Concussions (witnessed or unwitnessed) were only recorded if they were formally diagnosed by a health practitioner.
Results: A total of 52 (8 witnessed; 44 unwitnessed) concussive events were identified over the duration of the study resulting in a concussion injury incidence of 44 (95% CI: 32 to 56) per 1000 match participation hours. There was a six-fold difference between witnessed and unwitnessed concussions recorded. There were observable learning effects observed between the first and the second K–D test baseline testing (50 vs. 45 s; $z = -8.81$; $p < 0.001$). For every 1 point reduction in each of the post-injury SAC components there was a corresponding increase (worsening) of K–D test times post-match for changes in orientation (2.9 s), immediate memory (1.8 s) concentration (2.8 s), delayed recall (2.0 s) and SAC total score (1.7 s).
Discussion: The rate of undetected concussion was higher than detected concussions by using the K–D test routinely following matches. Worsening of the K–D test post-match was associated with reduction in components of the SAC. The appeal of the K–D test is in the rapid, easy manner of its administration and the reliable, objective results it provides to the administrator. The K–D test helped identify cognitive impairment in players without clinically observable symptoms.

1. Introduction

The number of sport-related concussions has raised concern in the public, media and clinical arenas in recent years [1]. The incidence of sport-related concussion has increased over the past decade but the actual incidence is likely higher than documented as there is a tendency for sport participants to under-report their symptoms [2]. Concussion has become one of the most troublesome injuries facing the sport medicine professional [3], especially in regard to early identification of concussive signs and symptoms, and appropriate concussive management facilitation [4]. A sport-related concussion is a unique and individualized injury that can present with a myriad of physical, emotional, somatic, cognitive and sleep-related symptoms and impairments [5]. Due to the nature and variability of concussions, these injuries should have a multifaceted approach in the assessment and management of these injuries.

In the upper levels of sport on-site health professionals are available to assess players on the sideline for the signs and symptoms of concussion. Yet symptoms may not manifest for several hours post-event, so many participants may not produce symptoms that meet the clinical criteria for concussion [6]. More recently interest has increased in the impacts to the head that do not result in clinically-observed symptoms associated with concussion [7]. Termed 'subconcussive', these impacts are often not recognised as a concussion, but may result in a rapid acceleration–deceleration of the body or head, moving the brain within the cranium creating a "slosh" phenomenon [8]. The number of impacts that can occur varies, but over time there are repetitive occurrences of these impacts and the cumulative exposure of these may become deleterious [8]. Players not reporting or showing any signs or symptoms of concussion can still have neurophysiological changes [6].

Following any brain trauma eye function movements may become impaired [9,10]. In acute traumatic brain injuries there are reported

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latency and inaccuracy of saccades following the injury [11]. This can remain in people with post-concussion syndrome, where there are a higher number of saccades and poor motor movement timings with longer durations and slower velocities of movement [12]. Poor oculomotor function is one of the most robust discriminators for the identification of [12], and one of the most widely reported visual problems in [9,10], a mild-traumatic brain injury.

Originally developed as a reading tool to assess the relationship between poor oculomotor functions and learning disabilities, the King–Devick (K–D) test utilises a series of charts of numbers that progressively become more difficult to read in a flowing manner [13]. The K–D test requires eye movements, language function and attention in order to perform tasks reflective of suboptimal brain function in hypoxia [14], extreme sleep deprivation [15], Parkinson's [16] and concussion [17–24]. Several sports, such as boxing and mixed martial arts [18,23], professional ice hockey [20], representative rugby league [22] and domestic rugby union, have utilised the K–D and identified unwitnessed concussive events. These studies highlight the potential of the K–D test to detect sub-concussive impacts that may accumulate over a period and can lead to neurological changes [22]. The K–D test has been recommended as a sideline test to enhance the detection of players with a concussive injury in conjunction with other concussion tests [24,25]. Recently it was identified that larger scale research over a longer period of time may provide increased validity of the K–D test as part of a continuum of concussion assessment tools [24,26]. As such, the purpose of this study was to examine the worth of the K–D test as part of a sideline assessment process of players participating in contact sport over a three year period.

2. Methods

2.1. Experimental approach to the problem

A prospective observational cohort study was conducted on a club level senior amateur rugby union team (n = 36 players in 2012 and 35 players in 2013) and a rugby league team (n = 33 players in 2014) during competition seasons in New Zealand. A total of 104 male players participated in the study with a mean age of 23.7 ± 5.0 years. Two players were enrolled for all three years of the study, 17 players were enrolled for two years (2012–2013) while 85 players completed one year of the study. The first year (2012) of data (22 concussive events; 5 witnessed concussions and 17 un-witnessed concussive events) for rugby union players has been previously reported [21]. All players were amateurs receiving no remuneration for participating in match activities. The matches were played under the laws of the respective codes in New Zealand. The Auckland University of Technology Ethics Committee approved all procedures involved in this study (AUTEC 12/156) and all players participating in the study gave informed consent prior to participating.

2.2. King–Devick (KD) test in association with Mayo Clinic

Based on the time to perform rapid number naming, the K–D test takes less than 2 min to administer [18,19]. The K–D test involved the player's reading aloud a series of random single-digit numbers from left to right. The K–D test included one practice (demonstration) card and three test cards varied in format on either a moisture-proof 6 × 8 inch spiral bound physical test or as an application on a iPad platform. Players were asked to read the numbers from left to right across the card as quickly as they could without making any errors using standardised instructions. The time was kept for each test card, and the K–D 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 times for all participants were established either preseason or when participants joined the team after the season had commenced. The best time (fastest) of two trials 10 min apart without errors became the established baseline K–D test time [18]. When head trauma was suspected the K–D test was used as a screening tool. The test was administered once using the same instructions, and the time and errors are recorded then compared to the subject's baseline. Worsening of time and/or errors identified on the sideline or post-match K–D test have been associated with concussive injury [17–22,24]. The K–D test performance has been previously shown to be unaffected in various noise levels and testing environments [27]. 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®) [1] computerised concussion evaluation system. The K–D test has been reported to have an inter-class correlation for test–retest reliability of 0.96 [23] and 0.97 [18]. The K–D test utilised was v.2.2.0 (http://www.kingdevicktest.com) on an iPad2. The iPad2 version enables the use of the K–D test with two different number sets and these were varied over the duration of the study.

2.3. Sport Concussion Assessment Tool v.3 (SCAT3)

The SCAT3 is a concussion assessment tool developed by combining existing concussion assessment tools [28]. A modification of the SCAT2, the SCAT3 has removed the use of the composite score. The SCAT3 consists of both subjective, and evaluative components comprising of the Post-Concussion Symptom Scale (PCSS), modified Maddocks [29] questions, cognitive assessment (Standardised Assessment of Concussion (SAC)) [30] and neurological screening. The cognitive assessment consists of a five word immediate (upon hearing the words) and delayed (following concentration tasks) recall assessment, reciting the months of the year in reverse order and repeating single digits in reverse order. Balance testing is assessed through the modified Balance Error Scoring System (BESS) [28]. Only the BESS double stance and tandem stance tests [31] were completed as baseline and post-incident tests. All players completed the SCAT3 baseline assessment prior to participating in any match activity. All players identified with a witnessed concussive incident, or a low K–D-test score (unwitnessed concussion — later confirmed by a physicians' clinical assessment), were required to complete a post-match SCAT3 assessment. There were no players with a worsening of the post-match K–D test, and no changes in the SCAT3, that were not diagnosed as having a concussion.

2.4. Concussion definition

Concussions were classified as witnessed (a concussive injury that met the definition of a concussion [5], that was identified during match activities resulting in removal from match activities and had >3 s for pre- to post-match K–D with associated changes pre- to post-match SCAT3, and later confirmed by a physician's clinical assessment) or unwitnessed (changes >3 s for pre- to post-match K–D with associated changes pre- to post-match SCAT3, and later confirmed by a physician's clinical assessment). The 3 s threshold for changes in the post-match K–D is identical to previous studies reporting the use of the K–D test [21,22]. The definition of a concussion utilised for this study was "*any disturbance in brain function caused by a direct or indirect force to the head. It results in a variety of non-specific symptoms and often does not involve loss of consciousness. Concussion should be suspected in the presence of any one or more of the following: (a) Symptoms (such as headache), or (b) Physical signs (such as unsteadiness), or (c) Impaired brain function (e.g. confusion) or (d) Abnormal behaviour.*" [5]. An 'unwitnessed' concussion was defined for the purpose of this study as "*any disturbance in brain function caused by a direct, or indirect force, to the head that does not result in any immediate observable symptoms, physical signs, impaired brain function or abnormal behaviour but had a delay in the post-match K–D score of >3 s and associated changes in the post-match SCAT3*".

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2.5. Testing procedures

At baseline (prior to the player participating in any match activity), every player named for the premier teams completed a baseline SCAT3 and two trials 15 min apart of the K–D test. All players were asked to read aloud the practice (demonstration) card before reading aloud all three test cards. Only the three test card times were recorded. The fastest time of the K–D with no errors was recorded as the baseline score. Players were asked to additionally complete the K–D test after each match they participated in (post-match) and again at the end of the competition season (post-season). Player's with post-match changes in the K–D test >3 s underwent a further SCAT3 assessment to test for signs of concussion. Player's with changes in the SCAT3 from their baseline were referred for further medical evaluation. All witnessed concussions were assessed with the K–D and SCAT3 tests and were referred for further medical evaluation. All concussions (witnessed or unwitnessed) were only recorded if they were formally diagnosed by a health practitioner.

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 who reported any sign(s) of a concussion, who were suspected to have received a concussion, or who were removed from match participation were assessed with the K–D test on the sideline after a 15 minute rest period; not allowed to return to play on the same day; and, referred for further medical assessment. No player identified with delayed (worsening) post-match K–D times was allowed to return to training or match activities without a full medical clearance. Players with a loss of consciousness were treated for a cervical spine injury and managed accordingly. The identification, assessment and management of players identified with a suspected concussive injury were identical to a previous study [22]. All suspected concussive injuries were evaluated by the player's own health professional. All players that were identified with a delay (worsening) of the K–D test from their baseline were assessed by their health professional and were diagnosed as having a concussion underwent the return-to-play K–D test monitoring process. No player that was identified with a delay (worsening) of the K–D test and referred to their health professional was immediately cleared for return to play. All players identified as having a concussion were further evaluated with the K–D test on days 3, 7, 14, and 21 following the injury. No player was allowed to return to full match activities until they were medically cleared and, had returned to their baseline K–D score.

2.6. Statistical analysis

All data collected were entered into a Microsoft Excel spread sheet and analysed with SPSS v.22.0.0. Data are presented as mean (±SD) for player data, concussive injury per 1000 match hours with 95% confidence interval (95% CI) and median [25th to 75th inter-quartile range] for K–D scores. Differences in K–D scores from pre-competition (baseline establishment) were calculated, baseline and post-match K–D scores were compared using the Wilcoxon signed-rank test by the sporting code and as a combined composite score. Risk-ratio was calculated for the number of witnessed vs. unwitnessed concussions with 95% CI. The sensitivity and specificity of the K–D test were calculated using a 2-by-2 contingency table with 95% CI by year and for the total study with a Cohen kappa (κ) with 95% CI to assess for intra-rater concordance [32,33]. Test–retest reliability was also estimated utilising the intra-class correlation coefficient (ICC), with 95% CI, to examine agreement between first and second baseline test scores and the post-season scores. The post-concussive injury return to play test–retest reliability of the K–D test was also estimated utilising the ICC and Pearson correlation coefficient (r). Linear regression models (R^2) were utilised to examine the relationship of components of the SCAT3 SAC to post-match changes of the K–D test. Regression coefficients were reported as measures of the magnitude of association between post-match K–D times and SAC scores of the SCAT3; coefficients represent the number of seconds associated with a 1 point difference in the SAC score. Statistical significance was set at $p = 0.05$.

3. Results

Over the duration of the study there were 43 rugby union (2012–2013) and 19 rugby league (2014) matches resulting in a combined match exposure of 1187 h (see Table 1). A total of 52 concussive events were identified over the duration of the study resulting in a concussion injury incidence of 44 (95% CI: 32 to 56) per 1000 match participation hours. There was a six-fold difference (RR: 5.5 [95% CI: 2.6 to 11.6]; $p < 0.0001$) between the number of witnessed (n = 8) and unwitnessed (n = 44) concussions recorded.

There were observable learning effects observed between the first and the second K–D test baseline testing (50 vs. 45 s; $z = -8.81$; $p < 0.001$) (see Table 1). The ICC between the first and second baseline tests were 0.89 (2012), 0.89 (2013), 0.94 (2014) and 0.92 (combined). Over the duration of the study the K–D test had sensitivity of 1.00 (95% CI 0.93 to 1.00); specificity of 0.94 (0.84 to 0.99), and kappa of 0.98 (95% CI: 0.94 to 1.00). The learning effects were also obvious with the post-season test when compared with the baseline score for all players (45 vs. 38 s; $z = -8.80$; $p < 0.001$).

Witnessed concussive incidents recorded, on average, a longer K–D post-match test score (6 s; $z = -2.52$; $p = 0.012$) than unwitnessed concussive events (5 s; $z = -5.84$; $p < 0.001$) when compared with their baseline K–D test scores (see table 2). The mean (±SD) SCAT3 symptom scores for all concussions recorded were 9 ± 5 symptoms recorded and SAC total score of 24 ± 3 (see Table 2). Unwitnessed concussive incidents had a lower symptom severity (23 vs. 31; $z = -1.60$; $p = 0.109$), lower immediate (13 vs. 14; $z = -0.43$; $p = 0.671$) recall and better delayed (4 v 3; $z = -2.06$; $p = 0.040$) memory scores, had a higher SAC total score (24 vs 23; $z = -0.77$; $p = 0.440$) and a lower BESS score (13 vs. 18; $z = -0.53$; p = 0.598) and a better coordination score (0.5 vs. 0.3′ $z = -2.45$; $p = 0.014$) when compared with witnessed concussive incidents.

Lower scores on the SAC of the SCAT3 were associated with increased (worse) times required to complete the K–D test post-match for players with a concussive injury. For every 1 point reduction in each of the post-injury SAC components there was a corresponding increase (worsening) of K–D test times post-match for changes in orientation (2.9 s [95% CI: 2.7 to 3.2]; $R^2 = 0.85$; $p < 0.001$), immediate memory (1.8 s [1.7 to 2.0]; $R^2 = 0.94$; $p < 0.001$) concentration (2.8 s [2.6 to 3.0]; $R^2 = 0.87$; $p < 0.001$), delayed recall (2.0 s [1.8 to 2.2]; $R^2 = 0.93$; $p < 0.001$) and SAC total score (1.7 s [1.6 to 1.8]; $R^2 = 0.95$; $p < 0.001$) (see Fig. 1).

Post-match K–D test scores were longer than the baseline score (4.6 s; $z = -6.40$; $p < 0.001$) for all concussive injuries identified (see Table 3). Post-injury evaluations of the players with a concussive injury were longer than the baseline score on post-day 3 (6.3 s; $z = -6.33$; $p < 0.001$) before they began to return to the baseline score. By day 14, most, but not all, unwitnessed concussive injury players had improved their K–D test (-0.1 s; $z = -7.14$; $p = 0.475$) when compared with their pre-injury baseline score. Most, but not all, players with a witnessed concussive injury had returned to, or improved on, their K–D test score (0.8 s; $z = -1.99$; $p = 0.046$) when compared to their pre-injury baseline score by day 21 post-injury.

Table 1
Characteristics of participants by mean (±standard deviation) for age and King–Devick test baseline and post-season scores in seconds by median score and 25th to 75th interquartile range.

	2012	2013	2014	Combined
Number of players enrolled	36	35	33	104
Age, years ± SD	22.8 ± 3.4	23.3 ± 6.1	24.9 ± 5.0	23.7 ± 5.0
Matches played [pre-season; match] (match h.)	24 [5,19] (479)	19 [1,18] (379)	19 [2,17] (329)	62 [8; 54] (1187)
Concussive incidents (total) [witnessed; unwitnessed]	22 [5,17]	22 [2,20]	8 [1,7]	52 [8; 44]
Concussion incidence per 1000 match h. (95% CI)	45.9 (26.7 to 65.1)	58.1 (33.8 to 82.3)	24.3 (7.8 to 41.2)	43.8 (31.9 to 55.7)
No with a concussive injury, n =; [re-injury in current season]	17 [5]	16 [6]	6 [2]	39 [13]
Pre-season K–D test 1, s, median [IQR]	50.3 [45.8 to 58.7]	48.1 [43.8 to 53.5]	53.7 [47.5 to 59.0]	50.1 [44.3 to 55.5]
Pre-season K–D test 2, s, median [IQR]	47.3 [41.0 to 54.2][a]	43.6 [39.7 to 49.3][a]	49.7 [44.4 to 54.6][a]	45.1 [41.1 to 50.6]
Difference test 1 vs. test 2, s, median [IQR]	−2.8 [−5.7 to −1.6]	−3.5 [−5.4 to −1.3]	−3.3 [−5.5 to −1.9]	−3.3 [−53.4 to −1.7]
Post-season K–D test, s, median [IQR]	36.4 [31.9 to 43.0][b]	31.2 [26.5 to 38.2][b]	41.8 [37.7 to 49.3][b]	37.5 [30.7 to 43.4]
Difference baseline vs. post-season, s, median [IQR]	−6.0 [−10.0 to −4.0]	−11.3 [−15.2 to −8.6]	−7.0 [−11.7 to −3.3]	−8.5 [−12.0 to −4.9]
ICC (95% CI), K–D baseline 1 vs. baseline 2	0.89 (0.78 to 0.94)	0.89 (0.78 to 0.94)	0.94 (0.88 to 0.97)	0.92 (0.88 to 0.94)
ICC (95% CI), K–D baseline vs. post-season	0.93 (0.87 to 0.97)	0.88 (0.76 to 0.94)	0.94 (0.84 to 0.96)	0.91 (0.82 to 0.94)
Sensitivity (95% CI) K–D test	1.00 (0.80.0 to 1.00)	1.00 (0.84 to 1.00)	1.00 (0.62 to 1.00)	1.00 (0.93 to 1.00)
Specificity (95% CI) K–D test	0.94 (0.73 to 0.99)	0.92 (0.63 to 0.99)	0.97 (0.80 to 0.99)	0.94 (0.84 to 1.00)

K–D = King–Devick test; s = seconds; IQR = [inter quartile range]; ICC: = intraclass correlation coefficient; significant difference ($p < 0.05$) than (a) = test 1 of baseline; (b) = established baseline.

4. Discussion

This study was conducted to assess the worth of the K–D test in amateur senior rugby union and rugby league in New Zealand. The two sporting codes enrolled in the study (rugby union and rugby league) are similar in terms of the physicality required to play the games, and the nature of the tackling and running required in the sports. However, there are differences in the number of players (rugby union 15 vs. rugby league 13) on the field during the match, and rugby league does not have rucks, mauls and lineouts, and players do not push in the scrum. Despite these differences, often players involved in rugby union have participated in rugby league, or vice versa. Two players enrolled in the study did participate in both sporting codes over the duration of the study.

Rugby union has contestable scrums, lineouts, rucks and mauls whereas rugby league does not undertake any of these activities. Rugby league allows for a set of six tackles to be undertaken for the team in possession of the ball and when this is completed the ball is handed over to the opposition. Rugby union allows for contesting for the ball when the tackle is made through the use of rucks and mauls whereas rugby league requires the tackled player be allowed to get off the ground and play the ball back to the attacking team. Likely as a result of these differences there were observable differences recorded in the K–D tests between rugby union and rugby league. Only two of the players involved in the rugby league cohort had been previously exposed to the K–D test through their rugby union participation.

There was a drop in the number of concussive events identified in the final year of the study and an increase in the median K–D baseline score (see Table 1). The 2014 season data was from a different cohort of players (rugby league) whereas the first two years of data was from a similar cohort (rugby union). The differences between years may be related to the number of players involved in the different sporting codes combined with the different match activities undertaken between rugby union and rugby league [34,35].

In this study of amateur senior rugby union and rugby league players, worsening of the K–D test post-match was associated with a reduction in components of the SAC. The changes are likely to be reflective of the anatomical aspects that the K–D and SAC tests capture [20]. Pathways for saccades, or fast eye movements, in the brain are widely distributed and involve several areas of the brain such as the frontal eye fields, supplementary eye field, dorsolateral prefrontal cortex, parietal lobes and deeper structures including the brainstem, necessitating the involvement of several cortical areas in the production, and regulation, of saccades [20]. As saccades can be used to assess cognitive domains such as attention, spatial and temporal orientation and working memory, injuries involving the disruption of the areas involved in saccades production and regulation can result in changes in these cognitive domains [20]. Undertaking the K–D test enables the analysis of numerous

Table 2
Changes and differences in K–D scores in seconds by median [25th to 75th inter quartile range] and SCAT3 scores in means (±standard deviation) for witnessed and unwitnessed concussive incidents of over the 2012 to 2014 amateur senior match competition seasons for rugby union (2012–2013) and rugby league (2014).

	Witnessed concussion	Unwitnessed concussions	Total concussions
Age, years, mean (±SD)	23 ± 3.1	22.8 ± 4.6	22.9 ± 4.4
Baseline K–D score, s, median [IQR]	43.6 [31.1 to 54.3]	40.6 [34.2 to 48.6]	41.4 [34.2 to 48.6]
Post-match K–D test score, s, median [IQR]	48.0 [38.8 to 58.6][c]	45.9 [38.1 to 53.3][c]	46.5 [38.3 to 53.4][c]
K–D change baseline vs. post-match, s, median [IQR]	*6.2 [4.0 to 8.8]*[‡]	*4.6 [3.6 to 6.0]*[‡]	*4.6 [3.8 to 6.7]*[‡]
SCAT3 domain scores			
Symptom evaluation			
Score (22), mean (±SD)	8.6 ± 3.7	8.6 ± 4.8	8.6 ± 4.6
Severity (132) mean (±SD)	31.0 ± 22.8	23.1 ± 17.2	24.3 ± 18.1
Cognitive assessment			
Orientation (5) mean (±SD)	4.0 ± 0.5	4.4 ± 0.8	4.3 ± 0.8
Immediate memory (15) mean (±SD)	13.5 ± 1.2	12.8 ± 1.8	12.9 ± 1.7
Concentration (5) mean (±SD)	2.5 ± 1.1	2.7 ± 1.2	2.7 ± 1.2
Delayed recall (5) mean (±SD)	3.0 ± 1.3[b]	3.6 ± 1.2[a]	3.5 ± 1.2
SAC total (30), mean (±SD)	**23.0 ± 2.1**	**23.5 ± 3.1**	**23.5 ± 3.0**
BESS (20), mean (±SD)	17.5 ± 3.4	12.5 ± 6.2	13.3 ± 6.1
Coordination (1), mean (±SD)	0.3 ± 0.5[b]	0.8 ± 0.4[a]	0.7 ± 0.5
Maddocks Score	4.5 ± 0.8	4.5 ± 1.1	4.5 ± 1.1

K–D = King–Devick test; SD = standard deviation; s = seconds; IQR = interquartile range; ‡ = positive numbers for change in K–D score indicates longer (worsening) than baseline score; significant difference ($p < 0.05$) than (a) = witnessed concussion; (b) = unwitnessed concussion; (c) = baseline score.

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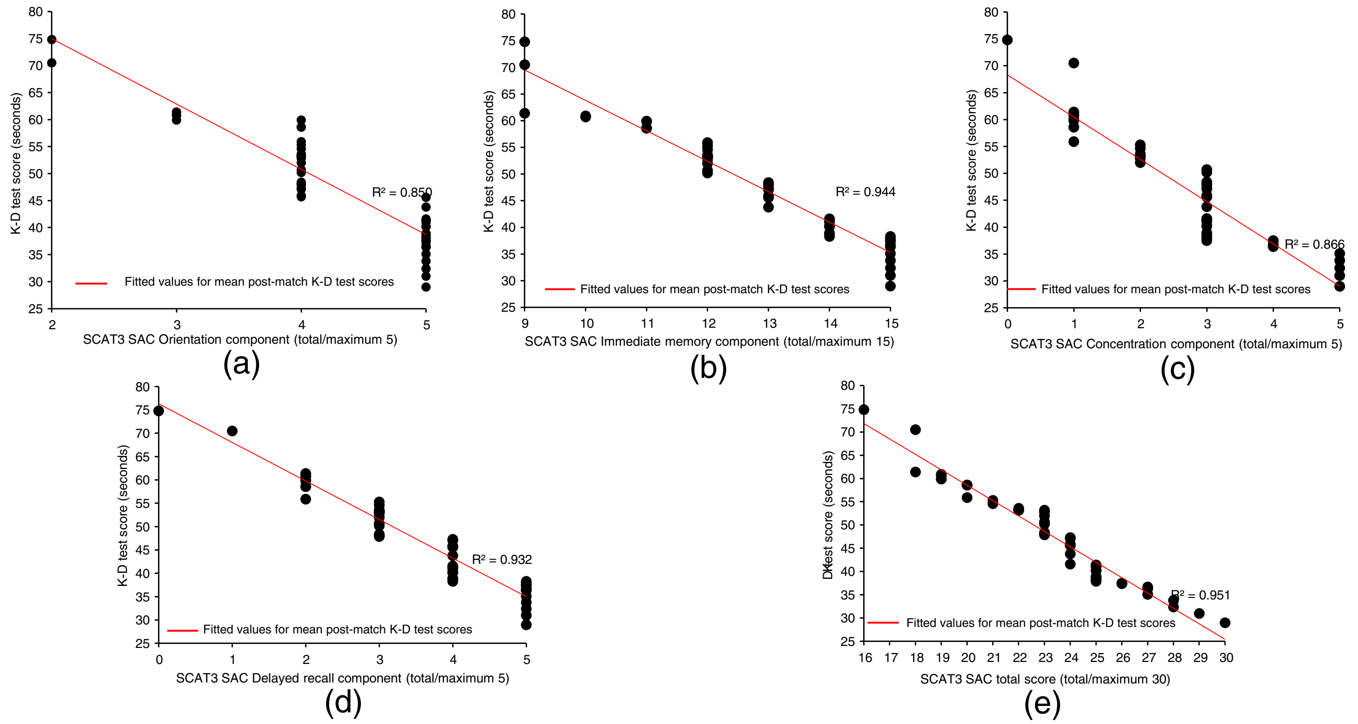

Fig. 1. Scatter plot and linear regression line showing the relation of post-match King–Devick (K–D) test time scores to Sport Concussion Assessment Tool 3 (SCAT3) Standardized Assessment of Concussion (SAC) components for orientation (a), immediate memory (b), concentration (c), delayed recall (d) and total SAC score (e). The regression line represents fitted values for the post-match K–D time score for each value of SCAT2 SAC total score. Lower (worse) total SAC scores were associated with higher (worse) K–D time scores at baseline; on average, for every 1-point reduction in component score, we found a corresponding increase (worsening) of K–D time.

circuits throughout the brain involving attention, motivation, visual–spatial integration, motor planning, and spatial organization [36]. The K–D test requires saccades to enable completion of the test and may also reflect concentration and language function [20]. Injuries to any of the areas involved in saccade production and regulation may explain the eye movement and memory related problems that can occur following a concussive injury [20].

Many concussion assessment tools are still undergoing research and development and these all have the potential for widespread clinical application [37]. Although no one concussion assessment tool can be definitive, the use of a continuum of assessment tools may provide a broader screening process available to the clinician assessing concussions [28]. The K–D test is available in either a moisture-proof 6 × 8 inch spiral bound physical test or as an application on an iPad platform and this makes the K–D test a readily portable, and easily adaptable, sideline administration tool for the assessment of concussive injuries [19]. The appeal of the K–D test is in the rapid, easy manner of its administration, and the reliable, objective results it provides to the administrator [1]. The K–D test has been shown to be sensitive to subtle changes that can occur with concussive injuries in high school football players without clinically-diagnosed concussion but with functionally-detected cognitive impairment [6].

Impacts to the head from participation in high school American football have resulted in some players exhibiting no clinically-observed symptoms associated with concussion but demonstrated measurable neurocognitive and neurophysiological impairments [6]. These players had decreased functional magnetic resonance imaging (fMRI) activation levels in areas strongly associated with working memory and significant reductions (score outside 99% confidence interval and flagged by ImPACT® as significantly decreased) in the VMS and/or VIS composite

Table 3
Post-match K–D test scores in seconds by median [25th to 75th interquartile range] for witnessed, unwitnessed and total concussions compared with baseline K–D test scores for post-match, days 3, 7, 14, 21 and 28 post-concussive injury and the association between these tests.

Testing phase	Witnessed concussions	Association		Unwitnessed concussions	Association		Total concussions	Association	
	s, median [IQR]	ICC	r=	s, median [IQR]	ICC	r=	s, median [IQR]	ICC	r=
Baseline K–D	43.6 [31.1 to 54.3][bcdef]			40.6 [34.2 to 48.6][bcdf]			41.4 [34.2 to 48.6][bcdef]		
Post-match K–D	48.0 [38.8 to 58.6][aef]	0.984	0.969	45.9 [38.1 to 53.3][acef]	0.986	0.974	46.5 [38.3 to 53.4][acef]	0.985	0.972
Difference from baseline	6.2 [4.0 to 8.8][‡]			4.6 [3.6 to 6.0][‡]			4.6 [3.8 to 6.7][‡]		
Post-day 3 K–D	51.9 [44.7 to 59.1][aef]	0.923	0.891	47.8 [38.6 to 57.6][abdef]	0.947	0.902	48.2 [40.0 to 57.5][abdef]	0.942	0.891
Difference from baseline	6.8 [6.4 to 10.1][‡]			6.1 [3.3 to 10.0][‡]			6.3 [4.2 to 10.0][‡]		
Post-day 7 K–D	49.8 [44.7 to 55.6][af]	0.894	0.829	46.8 [37.8 to 53.4][acef]	0.954	0.914	46.8 [38.6 to 53.8][acef]	0.944	0.893
Difference from baseline	4.3 [3.1 to 11.4][‡]			4.3 [1.7 to 7.3][‡]			4.2 [2.0 to 7.3][‡]		
Post-day 14 K–D	45.5 [36.1 to 57.5][abcf]	0.994	0.992	41.0 [34.1 to 48.1][bcdf]	0.989	0.979	42.1 [34.7 to 48.4][abcdf]	0.988	0.976
Difference from baseline	3.0 [1.6 to 10.1][‡]			−0.1 [−0.3 to 1.2][‡]			0.0 [−0.2 to 2.6][‡]		
Post-day 21 K–D	43.6 [34.5 to 56.0][abcde]	0.994	0.989	40.9 [33.9 to 47.3][abcde]	0.994	0.988	41.2 [34.0 to 48.0][abcde]	0.993	0.987
Difference from baseline	0.8 [0.0 to 2.7][‡]			−0.3 [−0.9 to −0.1]			−0.3 [−0.7 to 0.0]		

K–D = King–Devick test; CI = confidence interval; ICC = intraclass correlation coefficient; r = Pearson correlation coefficient; s = seconds; IQR = inter-quartile range; significant difference ($p < 0.05$) than (a) = baseline; (b) = post-match; (c) = day 3; (d) = day 7; (e) = day 14; (f) = day 21; ‡ = positive numbers for change in K–D score indicates longer (worsening) than baseline score.

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scores of the ImPACT® computerised concussion evaluation system [6]. The VMS component of ImPACT® has been shown to have the most reliable composite scores and is commonly utilised for determining visual-motor deficits [1]. The VMS, and other composite scores (RT and VIS), provide unique information incorporating visual processing, acuity and oculomotor speed and any deficits in these areas may reflect axonal damage to oculomotor neurons [1]. The finding [1] that the K–D test has a correlation with changes in the VMS ($r = -0.696$; $p < 0.0001$), RT ($r = 0.633$; $p < 0.0001$), and VIS ($r = -0.482$; $p < 0.0001$) components of ImPACT® indicates that the K–D test appears sensitive to revealing visual performance-related effects of concussion in players with no clinically-observed symptoms. The use of the K–D test as part of a continuum for the assessment and monitoring of players with a concussion can assist healthcare providers to evaluate adequate cognitive rest and informed clinical decisions regarding return-to-play and return-to-academic activities [1].

In the absence of concussion, the K–D test has been shown to have learning effects associated with repeat testing [19]. This is commonly associated with repeated performance measures, or timed testing [19] and can be seen by the median improvement of 3.4 s between the two tests undertaken to establish the individual player's baseline score. This is similar to previous studies reporting on the K–D in sport activities with improvements of 1.9 s to 3.1 s [18–23] 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 [38] such as previous exposure to similar tests. Although employing serial K–D assessments has a learning effect, which is not uncommon in timed test, [18] there should be an equalling of, or an improvement in, the score upon each subsequent test administration [38]. The iPad version of the K–D test (v.2.2.0) utilised in our study had two sets of demonstration and test cards with different numbers along the same pattern. The post-match K–D tests were varied weekly to eliminate any possibility of players learning the numbers. Although these were varied, players showed an improvement in the scores from their baseline. Any worsening of the scores is likely to be a reliable indicator that player should be evaluated further for a possible concussive event [19].

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 [22]. 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 [39]. This is reported to occur in the first 10 min from a concussive event and then a neuronal depression period occurs where cognitive dysfunction manifests [39]. Previous studies [18,19,21–23] have reported K–D test times of participants with a concussive injury 5 s slower (range 3.2 s to 18.0 s) than their baseline. Our study showed that players with a concussive injury had a similar slower than baseline K–D test score with a median of 5 s for players with a decrease in their post-match assessment, and a median of 6 s for players with a witnessed concussive injury identifying that these players needed further medical evaluation. All players with a worsening of their K–D test score were subsequently diagnosed with a concussion by their medical practitioner and underwent the required return-to-sport evaluations and clearances before they were allowed to participate in training and match activities.

Over the duration of the study there were three false positive cases of players who had slower post-match K–D test scores. None of these players had changes on the post-match SCAT3 and were cleared by their own health practitioner. Upon further investigation it was identified that these players were night-shift workers who had not had a sleep prior to commencing the match activities. It has been previously reported [15] that the K–D test is sensitive to the impact of sleep deprivation on cognitive functioning and this may have been the result of the false-positives detected post-match. Despite the three false-positive cases identified, the sensitivity (1.00), specificity (0.94) and kappa (0.98) of the K–D test show a high accuracy and near perfect agreement [32,33] for the detection of disruption of the pathways involved in saccades following an injury to these areas [20].

By using a return-to play monitoring process with the K–D test, the team medic was able to identify players that could commence graduated return-to-play activities while still monitoring the player's recovery. Improvements in the K–D test performance have been shown to be paralleled with improvements of the components of ImPACT® and appear effective in monitoring concussion recovery and symptom resolution. Although no player was allowed to return to full match activities until they equalled or improved their baseline score, several players were medically cleared by their own health practitioner before this occurred. All the witnessed concussed players were medically cleared by day 14 post-injury but were withheld from match activities until their K–D scores equalled or bettered their baseline score. For witnessed concussions one player (14%) returned to their baseline score at the 21 days post-match test while the other seven (86%) returned to their baseline at the day 28 post-match test which was similar to a previous study [21]. Most, but not all (n = 2; 4%), players with an unwitnessed concussion returned to their baseline K–D scores 14 days after the incident and, when medically cleared, were allowed to return to full training and match activities. This finding supports the need for the management of concussion on an individualized basis [5].

The use of multiple sideline tools such as the SCAT3 and the BESS examines a wide range of neurologic dysfunction and, while one tool may not identify a concussive injury, the other assessment tools may show abnormalities [24]. Including a visual dimension tool such as the K–D test may assist to increase the capacity for the identification of concussed players and decrease the likelihood of players with a concussive injury not reporting the symptoms and exposing themselves to further concussive events. The results of this study support the use of the K–D test and SCAT3 as sideline assessment tools for the identification of players with a suspected concussion, who should then be referred to a health practitioner for full clinical assessment and management of concussion.

A composite of rapid brief tests such as the K–D test, the SAC and the BESS are likely to provide a series of effective clinical tools to assess players on the sideline with a suspected concussive injury. Further longitudinal studies over different player cohorts will assist in the identification of a continuum approach to sports-related concussion.

4.1. Limitations

A limitation to this study was that not every player underwent the K–D test after every match they participated in. There were a few players who would try to avoid being tested post-match but these were assessed at the next training session and were required to complete the K–D test before undertaking any training activities or being named in the team for the ensuing weekend. Having a team medic on the sideline as the researcher also meant that other injuries were required to be tended to and some players did leave the changing rooms prior to being tested. To assist in reducing the possibility of a concussive injury remaining unnoticed the coach, manager and team medic identified players that were required to be assessed and these players were told to remain in the changing rooms until tested. Future studies involving the K–D as a sideline assessment tool for concussion may need to have more than one K–D administrator available so that all players can be tested post-match.

5. Conclusion

The K–D and SCAT3 tests helped identify cognitive impairment in players without clinically observable symptoms post-match. The rate of undetected concussion was higher than detected concussions by using the K–D test routinely following matches. By undertaking a

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return-to play monitoring process with the K–D test, the team medic was able to identify players that could commence graduated return-to-play activities while still monitoring the player's recovery. The inclusion of a visual dimension tool such as the K–D test may assist in increasing the capacity for the identification of concussed players and decrease the likelihood of players with a concussive injury not reporting the symptoms and exposing themselves to further concussive events. Using the K–D test as part of a continuum for the assessment and monitoring of players with a concussion can assist healthcare providers to evaluate adequate cognitive rest and informed clinical decisions regarding return-to-play and return-to-academic activities. A composite of rapid brief tests such as the K–D test, the SAC and the BESS are likely to provide a series of effective clinical tools to assess players on the sideline with a suspected concussive injury.

Conflict of interest

The authors declare that there are no competing interests associated with the research contained within this manuscript.

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