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Effect of Physical Fatigue on the King-Devick Concussion Assessment

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Abstract

The King-Devick (K-D) test is an oculomotor assessment that is currently being used for the acute (i.e., sideline) assessment of SRC. Despite psychometric studies, there are a lack of studies examining the potential influence that the confounding variable of physical fatigue may have on this measure. The purpose of this study was to investigate the effect of physical fatigue on the King-Devick concussion assessment. Based on the deleterious of effects of physical fatigue on cognition and attention, an assumption was made that increased physical fatigue would negatively affect K-D performance. A prospective, repeated measures design was used to compare K-D times from baseline to post-exertion in high school basketball athletes. A total of 18 athletes (mean age 15.4 ± 1.1 years) were equipped with heart rate monitors and accelerometers and administered K-D at different time intervals during a noncontact practice. Participants were randomly chosen to be pulled to the sideline for testing. K-D was administered and heart rate, RPE, and PCSS were recorded. Pearson correlation between fatigue variables (heart rate, RPE, $\%HR_{max}$, and vector magnitude) and post-exertion K-D time was analyzed to determine a significant association between physical fatigue and slower K-D time. Additionally, a Chi-square test was used to analyze an association between higher physical activity intensity and slower-than-baseline K-D time. The primary finding was 11 of the 17 athletes included in data analyses obtained a slower K-D time compared to baseline, but there were no significant results among Pearson correlations or the Chi-square test indicating an association between physical fatigue and slower K-D time. The results from this study suggest that, while physical fatigue is unable to be tied to diminished K-D performance, perhaps the K-D is an inaccurate tool in detecting SRC.

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Introduction

Between 1.6 to 3.8 million recreation and sport-related concussions occur each year in the United States (Langlois, Rutland-Brown, & Wald, 2006). The identification of sport-related concussion (SRC) with a subsequent removal from play may help expedite recovery time (Elbin et al., 2016). Approximately 53% of SRC in high school athletes go unreported due to desires to stay in the game, unawareness, or minimizing the severity of the injury (McCrea, Hammeke, Olsen, Leo, & Guskiewicz, 2004). Sideline management of SRC includes brief assessments that evaluate concussion symptoms (e.g., headache, disorientation, dizziness) and impairments (e.g., visual disturbances). If a concussion is suspected the athlete should be immediately removed from play until concussion-like symptoms have resolved (McCrory et al., 2013). Therefore, it is critical that sports medicine professionals use sideline assessments that are valid and reliable in their ability to detect SRC.

There are several different assessments recommended for the on-field/sideline evaluation of SRC. The Sport Concussion Assessment Tool (SCAT3) is currently endorsed by consensus statements and assesses cognition and balance (McCrory et al., 2013). Recent findings from clinical research on SRC have outlined the importance of assessing the visual system following SRC, a component missing in the SCAT3 (Capo-Aponte, Urosevich, Temme, Tarbett, & Sanghera, 2012). The King-Devick test (K-D) is a rapid-number naming test that assesses saccadic eye movements and was originally designed to detect learning disabilities and is a popular sideline assessment for SRC. Several studies have investigated the utility of the K-D test and report that it is an effective tool in detecting SRC (Galetta et al., 2011a; Galetta et al., 2011b; Smolyansky, Morettin, Hitzman, & Beckerman, 2016). A worsening of scores from baseline to post-concussion demonstrates the negative effect of

SRC on eye movements (Galetta et al., 2011b). Other studies have shown that fatigue exhibits these similar results causing the deterioration of ocular abilities (Di Stasi et al., 2013).

Functions of the oculomotor system such as smooth pursuit, saccades, vergence eye movements, vestibulo-ocular reflex, and fixation of the eye are negatively impacted by fatigue (Strupp et al., 2014). Fatigue can be defined as the sensation of feeling tired in association with diminishing physical performance and function (Lambert, St Clair Gibson, & Noakes, 2005; Green, 1997; Kay & Marino, 2000). However, termination of muscle output is reached at the point of exhaustion, not fatigue (Kay & Marino, 2001; Kay & Marino, 2000). Saccadic velocities diminish with the association of fatigue, which could potentially negatively affect K-D scores. In a previous military study, eye movements were recorded throughout a two-hour flight and saccadic velocities significantly decreased as a result of fatigue from pre-flight to post-flight (Diaz-Piedra et al., 2016). Studies have shown increased saccadic drift and ocular instability as a result of fatigue in healthy adults (Di Stasi et al., 2013; Bahill & Stark, 1975).

Several physiological mechanisms are proposed in the literature to account for the relationship between fatigue and oculomotor performance. Muscle contractions associated with physical exercise deplete energy stores throughout the body and direct the use of energy toward muscular contractions (Ament & Verkerke, 2009). This depletion of energy in other areas such as the brain could weaken the excitatory nerves connecting the frontal cortex to the reticular formation, which is responsible for receiving neural input from the superior colliculus (Munoz & Everling, 2004). Playing a large role in the direction of eye movements, this impact on the superior colliculus could deteriorate oculomotor function.

The superior colliculus could also potentially be affected by the inhibitory actions of sleep-regulating centers of the brain that are triggered in response to fatigue (Optican, 2008). In addition to the emerging evidence supporting the use of the K-D test for the sideline evaluation of SRC, the potential confounding effect that physical fatigue may have on K-D performance is unknown.

The influence of physical fatigue on the sensitivity and specificity of SRC assessments should be a consideration for the sports medicine professional. The deleterious effects that physical fatigue has on cognition (Covassin, Weiss, Powell, & Womack, 2007), attention (Boksem, Meijman, & Lorist, 2005), and balance (Wilkins, McLeod, Perrin, & Gansneder, 2004) is well documented in the literature. Studies examining the relationship between fatigue and neurocognitive scores have shown diminished cognitive performance following a maximal exertion test (Covassin, Weiss, Powell, & Womack, 2007). Other researchers report that postural stability is worse following exertion (Wilkins, McLeod, Perrin, & Gansneder, 2004). The effect of physical fatigue on K-D performance has yet to be thoroughly investigated and is warranted given the deleterious effects of fatigue on oculomotor function (Di Stasi et al., 2013; Bahill & Stark, 1975; Diaz-Piedra et al., 2016).

The literature examining the influence of fatigue on the K-D test is scant. Leong et al. (2015) administered the K-D test to female basketball players at pre-season and following an intense sprint workout and reported faster K-D times following exercise. These results were consistent with a previous study of amateur boxers pre-fight and post-fight, also concluding faster K-D times following physical exercise (Leong, Balcer, Galetta, Liu, & Master, 2014). Dhawan et al. (2015) tested hockey players during pre-season and post-game, concluding no significant difference in K-D times following in-game fatigue. However, no measures of fatigue were assessed to determine if the subjects' K-D times were truly influenced by physical fatigue, which is a methodological weakness of these studies. Therefore, a more thorough investigation of the effects of physical fatigue on K-D performance is warranted and future research should quantify fatigue. **The purpose of this study is to investigate the effects of physical fatigue on the King-Devick concussion test.**

Hypothesis

H1: Increased physical fatigue will negatively affect K-D time in high school athletes.

Review of Literature

A concussion is a subset of mild traumatic brain injury (mTBI) defined as a linear or rotational acceleration of the brain due to a direct or indirect force applied to the skull (McCrory et al., 2013). Accelerations within the skull generate force and pressure on brain tissue, causing cognitive, vestibular, and oculomotor impairments (Leong et al., 2015; Collins, Kontos, Reynolds, Murawski, & Fu, 2014). A potential long-term effect of SRC is Chronic Traumatic Encephalopathy (CTE), a neurodegenerative disease. CTE shares clinical similarities with Parkinson's Disease and Alzheimer's but is unable to be diagnosed until post-mortem examination (Feden, 2016). A concussion is of high concern to healthcare professionals because of the detrimental effects and specificity among individuals, requiring specialized diagnosis and treatment for the complex injury.

Prevalence of Sport-Related Concussion

An estimated 1.6 to 3.8 million sport-related concussions occur annually in the United States. This underestimated statistic does not include SRCs that have gone unreported or diagnosed in non-emergent settings (Langlois, Rutland-Brown, & Wald, 2006; Sussman, Ho, Pendharkar, & Ghajar, 2016). A study by Gessel, Fields, Collins, Dick, & Comstock (2007) examined the prevalence of concussion among nine high school and collegiate sports and found that concussions primarily occurred in football followed by girls' soccer, boys' soccer, girls' basketball, and wrestling. Certain risk factors such as LD, ADHD (Elbin et al., 2013), history of concussion (Schatz, Moser, Covassin, & Karpf, 2011), sex, and age (Covassin, Elbin, Harris, Parker, & Kontos, 2012) increase an athlete's vulnerability to obtain a concussion. The number of concussions obtained is expected to grow as sport participation increases.

Biomechanics of Sport-Related Concussion

Following a linear or rotational acceleration of the brain a series of physiological events occur that lead to an energy crisis capable of manifesting signs and symptoms of a concussion. This series of events is known as a neurometabolic cascade involving axonal stretching, random release of neurotransmitters, and alteration of Potassium and Calcium levels (Stussman, Pendharkar, & Ghajar, 2016; Giza & Hovda, 2001). As a result, the sodium-potassium pump has to work harder to maintain the neuronal membrane potential, requiring increased amount of ATP (Giza & Hovda, 2001). This sudden jump in ATP triggers an increase in glucose metabolism, also considered hypermetabolism, ultimately creating a cellular energy crisis (Giza & Hovda, 2001). As neurometabolic cascade occurs, the brain becomes increasingly vulnerable to a second injury that could possibly cause longer-lasting impairments (Giza & Hovda, 2001).

Signs and Symptoms

A concussion is a heterogeneous injury with symptoms varying from athlete to athlete, but some of the most common symptoms include headache, dizziness, confusion, or difficulty concentrating among other cognitive, vestibular, and oculomotor impairments (Collins et al., 2014). Symptoms can be categorized into four different clusters: cognitive (i.e. headache, dizziness), emotional (i.e. sadness, anxious), physical (i.e. nausea, neck pain), and sleep (i.e. trouble falling asleep)(Pardini et al., 2004). Using a Post-Concussion Symptom Scale (PCSS), athletes can provide a subjective measure of these symptoms.

Objective measures are also necessary to better assess the status of a concussed athlete. A comprehensive multi-model assessment approach has become a standard of care in concussion management. This approach involves a clinical exam/interview, symptom reporting, neurocognitive testing, balance assessments, and vestibular-oculomotor assessments (Collins et al., 2014).

Management and Recovery

Immediate management of an SRC involves addressing any first aid issues then using sideline assessment tools to assess the concussion. Further evaluation should be conducted using a multi-model approach. Once the athlete is diagnosed with an SRC, they should not be allowed to return to play the same day of the injury. The athlete is not to be left alone and monitoring for deterioration is crucial over the first few hours (McCrory et al., 2017). Traditionally, rest has been a widely used intervention in the management of concussion with the intention of easing discomfort and reducing symptoms. Recent consensus statements have agreed that rest during the first 24-48 hours is necessary but athletes may gradually become more active following the acute stage (McCrory et al., 2017). Graduated return to sport (RTS) protocol may begin after the acute stage (McCrory et al., 2017). Stage one of the RTS protocol enables symptom-limited activity. During stage two the athlete may begin light aerobic exercise such as walking or stationary cycling. During stage three the athlete may begin sport-specific exercise such as running or skating drills but none with potential head impact. During stage four the athlete may begin non-contact training drills such as passing drills as well as progressive resistance training. During stage five, the athlete may begin full contact practice and, following medical clearance, may begin normal resistance training. Finally, stage six allows the athlete to return to sport and normal game play. Each stage should last a minimum of 24 hours and, if symptoms worsen, the athlete should return to the previous stage (McCrory et al., 2017).

Past studies have concluded that the majority of concussed athletes recover within the first 10 days (McCrory et al., 2005). While this may be generally true among group findings, there is potentially great variability between individual athletes. Recent studies have found that recovery may last much longer than 10 days but the majority of athletes recover within the first month from a clinical perspective (McCrory et al., 2017).

Assessments for Sport-Related Concussion

Common assessments that are used in the management of a concussion include the Sport Concussion Assessment Tool (SCAT3), Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT), Vestibular/Ocular Motor Screening (VOMS), and the King-Devick Test (K-D). The SCAT3 evaluates symptoms, cognition, and balance using the Balance Error Scoring System (BESS) (McCrory et al., 2013). ImPACT is a computer based neurocognitive assessment that generates composite scores for visual and verbal memory, processing speed, and reaction time (Elbin et al., 2016). VOMS assesses vestibular impairment by provoking symptoms in concussed athletes (Yorke, Smith, Babcock, & Alsalaheen, 2016). Finally, K-D is used in assessing oculomotor function (Galetta et al., 2011b). All of these tools are commonly used in evaluating the state of the injured athlete throughout the recovery process.

The King-Devick Test

The King-Devick (K-D) is a rapid number naming assessment that evaluates saccadic eye movement and requires the athlete to read aloud a series of numbers from left to right on three test cards. Athletes are asked to read the numbers as quickly as possible without making errors. The cumulative time it takes to complete the three test cards constitutes the summary score for the entire test. The K-D has demonstrated high test-retest reliability and is considered an accurate tool in the determination of SRC (Galetta et al., 2011a; Galetta et al., 2011b; Leong, Balcer, Galetta, Liu, & Master, 2014). This test requires a baseline assessment to be completed by the athlete prior to the start of the season. At baseline, the K-D is administered twice and the better time of the two is considered to be the athlete's baseline. Following a suspected concussion, K-D is only administered once and, if the time to complete the test is slower than the athlete's baseline, or if any errors are made, the athlete is to be removed from play (Galetta et al., 2011b).

The K-D has been studied in a variety of contact sports such as boxing, MMA, football, and basketball. Similar results were found across each sport in that the K-D is a valid tool for detecting SRC (Galetta et al., 2011a; Leong et al., 2015). In non-concussed athletes, K-D time typically improves compared to baseline due to a learning effect associated with the test (Galetta et al., 2011a). Therefore, any worsening in K-D time indicates a suspected concussion. Average worsening in K-D time in concussed athletes is 5-7 seconds but tends to vary among individuals (Galetta et al., 2011a; Galetta et al., 2011b; Leong et al., 2015). Slower K-D time post-concussion represents the negative effect of SRC on eye movements.

Physical Fatigue and the King-Devick

Studies have shown that fatigue exhibits similar deterioration of ocular abilities such as smooth pursuit, saccades, vergence eye movements, vestibulo-ocular reflex, and eye fixation (Di Stasi et al., 2013; Strupp et al., 2014). Diaz-Pedra et al. (2016) examined saccadic velocities among military pilots from pre-flight to post-flight and found significant decrease in saccadic velocity. The deleterious effects of physical fatigue on attention (Boksem, Meijman, & Lorist, 2005) and cognition (Covassin, Weiss, Powell, & Womack, 2007) are well documented in the literature. However, the potential confounding effect of physical fatigue on K-D performance has not been thoroughly investigated. Leong et al. (2015) administered the K-D to female basketball players prior to the start of the season and following an intense sprint workout and reported faster K-D times following exertion. Leong et al. (2014) found similar results among boxers that were tested pre-fight and post-fight, also concluding faster K-D time post-exertion. Dhawan et al. (2015) examined K-D times in hockey players pre-season to post-game and reported no significant difference in change in K-D time. Galetta et al. (2011a) also reported faster K-D times from pre-fight to post-fight among MMA fighters. However, no measures of fatigue were used to determine if the subjects' K-D times were truly influenced by physical fatigue.

Methods

Participants

Eighteen high school (age 14-18) basketball athletes were recruited to participate in the study. Participants with LD, ADD, ADHD, or having sustained a concussion six months prior to testing were excluded from participation.

Instrumentation/Measures

Demographics: Demographic data was obtained from participants including age, sex, corrective lenses, ADHD, LD, and concussion history.

The King-Devick Test: The King-Devick (K-D) test evaluates saccadic eye movements while the subject reads aloud a series of numbers from left to right on three test cards. Each test administration takes approximately 2 minutes. Athletes are asked to read the numbers on each card as quickly as possible, without making any errors. The cumulative of the three test card time scores constitutes the summary score for the entire test. The K-D has been shown to be sensitive for sideline diagnosis of concussion (Leong, Balcer, Galetta, Liu, & Master, 2014). Its portability, ease of administration and brevity makes this tool convenient for quick concussion screening (Galetta et al., 2011a; Galetta et al., 2011b; Leong et al., 2015). The K-D has demonstrated high test-retest reliability and is considered an accurate tool in the determination of SRC (Galetta et al., 2011a; Galetta et al., 2011b; Leong, Balcer, Galetta, Liu, & Master, 2014).

Post-Concussion Symptom Scale (PCSS): The subjective Post-Concussion Symptom Scale is a 22-item inventory that evaluates typical cognitive and non-cognitive symptoms of concussion. Athletes are asked to rank symptoms on a scale of 0 (asymptomatic) to 6 (maximum severity). Overall PCSS scores range from 0 to 132 (Brown et al., 2014). Previous studies have determined the reliability and normative data of the PCSS among high school and collegiate athletes (Lovell et al., 2006).

Physical fatigue: Physical fatigue was measured using a combination of data collected from an ActiGraph, rating of perceived exertion (RPE), and a Polar heart rate monitor. The ActiGraph is a validated 3-axis accelerometer (McVeigh et al., 2016). When measures from the ActiGraph, Polar heart rate monitor, and RPE are combined they serve to give an objective and subjective snapshot of an individual's exertion (McVeigh et al., 2016; Jakicic, Donnelly, Pronk, Jawad, & Jacobsen, 1995). All athletes were fitted with the hip-worn Actigraph GT9x, and a Polar heart rate monitor. Heart rate was analyzed using a percent of the individual's predicted heart rate maximum ($\%HR_{max}$) in association with physical activity intensity. According to the American College of Sports Medicine (2014), very light to light intensity is defined as a $\%HR_{max} < 64\%$ and moderate to vigorous intensity is defined as $\%HR_{max} \geq 64\%$. The GT9x was programmed to record raw data at a frequency of 30 Hz and used to calculate vertical movement counts every 60s. The Actigraph accelerometer has indicated strong validity in its ability to assess physical exertion among children and adolescents (De Vries, Bakker, Hopman-Rock, Hirasing, & Mechelen, 2006).

Procedure: Institutional Review Board approval and informed consent from all participants and their parents was obtained before study participation. Sports medicine professionals and coaches at local high schools that are currently involved in an on-going sport concussion surveillance program were contacted about study participation of their athletes. Participants who agreed to participate were administered a baseline K-D test prior to the beginning of their competitive season. Prior to one basketball practice, athletes completed the PCSS and their resting heart rate was recorded by a researcher. During a designated noncontact practice conducted by coaches, eighteen athletes were assigned to wear the ActiGraph accelerometer and Polar heart rate monitor. Once scrimmaging began, athletes were pulled to the sideline for testing at varying intervals dependent on the length of the scrimmage. All athletes were randomly selected by researchers for testing. Once athletes were pulled for testing, heart rate and RPE were recorded immediately. K-D was administered followed by a second measure of heart rate and RPE. Then athletes completed the PCSS and returned to practice.

Participating athletes were told prior to testing that they would receive full compensation only if they beat their baseline K-D time. At the conclusion of the study all participants were informed of the deception to elicit their best effort and all athletes that completed the entire protocol were compensated.

Data Analysis

Statistical analyses were conducted with SPSS (IBM Corp., 2012). Mean and standard deviation were calculated for ages of all participants as well as female and male group averages. Mean and standard deviation were also calculated for pre-test and post-exertion measures including baseline K-D time, post-exertion K-D time, resting heart rate, post-exertion heart rate, RPE, and total PCSS symptom scores. A paired-sample t-test was conducted to examine changes in K-D scores from baseline to post-exertion. Fatigue variables used to analyze a Pearson correlation between physical fatigue and slower K-D time include post-exertion heart rate, percent of heart rate max ($\%HR_{max}$), RPE, and average vector magnitude. Difference in K-D time from baseline to post-exertion was calculated for each participant to determine a “slower than baseline” group and a “faster than baseline” group. A Chi-square test (with Yates Continuity Correction) was used to determine a significant association between slower K-D time and moderate to vigorous physical activity intensity, defined by $\%HR_{max} \geq 64\%$. Independent variables were time (intervals that athletes were removed). Male participants were pulled at 7 minute intervals throughout a 25 minute practice. Female participants were pulled at 15 minute intervals throughout a 60 minute practice, except for one pulled at 5 minutes. Dependent variables were post-exertion K-D time. The level of statistical significance was $p \leq .05$.

Results

Demographics

A total of 17 (8 male and 9 female, mean age 15.4 ± 1.1 years, range 14-17 years) high school basketball athletes were included in the study. One participant was excluded from the study due to medication causing inaccuracy in heart rate measures. Six participants reported a history of concussion but none occurred within six months prior to testing. Average ages among female participants and male participants were 15.1 ± 1.2 years and 15.6 ± 1.1 years, respectively. Among all participants, only one reported requiring and wearing corrective lenses while taking the K-D assessment at both baseline and post-exertion measures.

Pre-Test Measures

All participants had a K-D baseline assessment on file. The mean K-D time for the total sample was 43.50 ± 9.2 seconds. The mean resting heart rate for the sample was 87.1 ± 11.2 mmHg prior to the start of practice and the total PCSS symptom score was .53 ± .94.

Post-Exertion Measures

Participants were randomly selected to be pulled from practice at varying intervals presented in Table 1. Heart rate measures recorded immediately when pulled reported a mean value of 127.41 ± 21.68 mmHg. Average RPE reported by all participants when pulled from practice was 13.06 ± 2.36, ranging from 8-17 (on a scale of 6-20). Total symptom scores taken from post-exertion PCSS reported an average score of 3.24 ± 4.80**.** Average time taken to complete the K-D assessment post-exertion was 45.27 ± 8.75 seconds. There was no significant change ($p = .11$) from average baseline K-D time to average post-exertion K-D time. Post-exertion measures for individual participants are presented in Table 1 as well as change in K-D time from baseline to post-exertion, a positive value representing a slower time following exertion.

Table 1.

Individual results of K-D and post-exertion measures in ascending order of time pulled from practice

Athlete	Sex	Baseline K-D Time	Time Pulled (min)	Heart Rate	RPE	K-D Post-Exertion	K-D Post-Exertion Errors	Change in K-D time
1	F	47.22	63	136	15	50.53	0	3.31
2	F	50.22	72	105	13	48.20	0	-2.02
3	F	34.69	72	100	9	40.32	0	5.63
4	M	59.00	73	101	13	54.25	0	-4.75
5	M	33.75	73	125	12	32.85	0	-0.90
6	M	39.27	74	135	12	36.50	0	-2.77
7	M	39.99	80	141	15	49.56	0	9.57
8	M	35.48	80	141	17	40.69	0	5.21
9	M	59.62	81	151	12	53.79	0	-5.83
10	M	36.56	86	140	15	33.02	0	3.42
11	F	45.71	87	152	15	45.84	0	0.13
12	F	36.03	87	161	13	35.67	0	-0.89
13	M	36.53	88	124	12	40.12	0	3.59
14	F	45.40	101	85	11	52.59	0	7.19
15	F	48.39	102	140	8	49.72	0	1.33
16	F	40.28	115	102	15	41.18	0	0.90
17	F	57.83	115	127	15	64.81	0	6.98

Examining the Relationship Between Fatigue and K-D Scores

The results from a series of Pearson correlations for post-exertion heart rate, RPE, %HRmax, and average vector magnitude yielded no significant relationships between these variables (See Table 2).

Table 2.

Pearson correlations between fatigue variables and post-exertion K-D time

Variables	1	2	3	4	5
Post-exertion K-D time	-				
Heart rate when pulled from practice	-.186	-			
RPE when pulled from practice	.027	.278	-		
$\%HR_{max}$ when pulled from practice	-.187	1.000**	.289	-	
Vector magnitude	-.327	.293	.200	.298	-

** $p \leq .05$*
*** $p \leq .01$*

Athletes were categorized into an intensity group based on $\%HR_{max}$ measures. Participants with a $\%HR_{max} < 64\%$ were considered the very light to light intensity group while participants with a $\%HR_{max} \geq 64\%$ were considered the moderate to vigorous intensity group. Athletes were also categorized into a slower/faster than baseline group based on post-exertion K-D times. Cross tabulation of intensity groups and slower/faster than baseline groups are presented in Table 3. The Chi-square test for independence (with Yates Continuity Correction) indicated no significant association between physical activity intensity and post-exertion K-D times (p = 1.00).

Table 3.

Cross tabulation of $\%HR_{max}$ and post-exertion K-D times slower or faster than baseline (n=17)

	Slower than baseline	Faster than baseline
$\%HR_{max} < 64\%$	5 (45.5%)	3 (50%)
$\%HR_{max} \geq 64\%$	6 (54.5%)	3 (50%)

$\chi^2 = .00$, df = 1. Numbers in parentheses indicate column percentages.
** $p \leq .05$*

Discussion

General Discussion of Results

This study examined the potentially negative effect of physical fatigue on the King-Devick (K-D) concussion assessment among non-concussed high school basketball athletes. The primary finding of this study was that physical fatigue is not significantly associated with a worsening in K-D time. However, it is important to note that 11 out of 17 athletes experienced a worsening in K-D time following exertion. This worsening in time would typically indicate a suspected concussion and removal from play for more than half of the athletes. This finding suggests that, although physical fatigue may not directly affect K-D times, the K-D assessment may not be a reliable tool for detecting concussion.

Previous literature has found contrasting results in that K-D times following exertion improved among non-concussed athletes. Dhawan et al. (2015) reported hockey players having an average K-D time of 43.4 seconds and 42.0 seconds from pre-game to post-game. Leong et al. (2014) and Leong et al. (2015) reported an average change in K-D time to be 41.0 versus 39.3 seconds from baseline to post-fight among boxers and 34.5 versus 31.8 seconds from baseline to post-workout among high school basketball players. Galetta et al. (2011a) also reported average K-D times of 42.7 versus 41.5 seconds from pre-fight to post-fight among MMA fighters. These studies did not ensure the athletes were physically fatigued and did not use variables to quantify exertion, which was the goal of this study. While the slower K-D times following exertion were unable to be explained statistically by the effect of fatigue, the results indicate there may be some inaccuracy using K-D post-exertion.

Discussion of Hypothesis

H1: Increased physical fatigue will negatively impact K-D time in high school athletes. Based on the main finding of this study, Hypothesis 1 was not supported. Due to the insignificant association between increased physical fatigue and slower K-D time, the post-exertion decrease in K-D time among 11 athletes could be due to other various factors. Possible explanations for slower K-D time could be distraction caused by the practice, lack of effort knowing a concussion was not potentially obtained, or nervousness taking the test.

Limitations

There were several limitations to this study, the main one being a small sample size. Such a small sample inhibits the accuracy of correlation between physical fatigue and slower K-D time. The practice conducted by the coaches also limited the degree to which each athlete was fatigued. Many athletes were not physically active continuously until they were pulled for testing and some were pulled directly from the sideline. This limited the ability to examine increasing physical fatigue associated with the time athletes were pulled from practice. Finally, baseline K-D was administered as part of a surveillance program apart from this study. A more recent measure, just before the start of practice, may have been a more accurate baseline K-D time to compare with post-exertion K-D time.

Future Research

Further research should be conducted to investigate the effects of physical fatigue on the King-Devick assessment. A larger sample size could provide more accurate analyses of the data and find potential correlation between physical fatigue and slower K-D time. It may also be beneficial to conduct an independent practice that would allow athletes to play continuously until tested. This would provide better measures of physical fatigue and ensure increasing physical fatigue over the course of the practice.

Conclusion

The results of this study did not support the hypothesis that physical fatigue would negatively impact K-D time in high school athletes. There were slower K-D times following exertion among 11 of the athletes but no significant correlation was found between physical fatigue and slower K-D time. The results of this study suggest potential inaccuracy associated with administering K-D to detect concussion and further investigation into the effects of physical fatigue on the King-Devick assessment is warranted.

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