Assessing isometric kicking force and post-match responses using the Kicker test

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ABSTRACT

This study examined the inter-session reliability of force output from a novel isometric strength assessment protocol (the Kicker); and the Kicker's suitability to monitor soccer player's combined hip flexion and knee extension force capacity over 72-hours post-competitive matches. Reliability (Part-A) testing was completed over three sessions on 20 individuals participating in various sports at a recreational level or higher. Post-match strength response (Part-B) data were collected for 72 hours (h) after a game (24 h (+24), 48 h (+48) and 72 h (+72) post-match) in 17 male academy soccer players. After familiarisation, Kicker force for each limb showed high inter-session reliability (intraclass correlation coefficients (ICC) >0.95; typical error (TE) <14 Newtons (N) (coefficient of variation (CV) <6%); minimum detectable change at a 95% confidence interval (MDC95%) <40N). Across the 72 hour post-match period, Kicker force for each limb was suppressed compared to baseline (force loss range = -5.8% to -12.5%; effect sizes (Cohen's *d*) range = -0.26 to -0.43) at all time points. The Kicker assessment protocol measures combined isometric hip flexor and knee extensor force capacity with high inter-session reliability. The proof of concept, that the protocol can be used as a monitoring tool was evidenced by sustained suppression of baseline force capacity in both kicking limbs for 72 hours post soccer matches.

Keywords: muscle strength, measurement, muscle injury, quadricep

INTRODUCTION

Field sports that involve kicking, such as soccer, carry a risk of strain injury to the quadriceps, with the rectus femoris most commonly afflicted.[1] A recent 16 year follow up study of professional adult soccer players showed that although the frequency of quadricep strain injury (5.7% of all injuries) is less than hamstring strain injury (17.4% of all injuries), quadricep strain injuries result in a longer time to return to play (19.5 days in quadriceps versus 18 days in hamstrings) and an equally high recurrence rate (15.6% in quadriceps versus 17.5% in hamstrings). As there is a high burden and recurrence rate of quadriceps strain injury, the prevention of these injuries is of paramount importance for practitioners.[1] In addition, injury data from more than 40 elite youth soccer academies in the United Kingdom showed the quadriceps to be the most frequent site of muscle strain injury,[2,3] which suggest this injury is of even greater prominence in this cohort.

Kicking is the most common mechanism for rectus femoris strain injury in soccer[4] and is also the primary injury mechanism in 8-13% of all injuries in high-level male youth soccer.[5] The kicking action involves a combination of hip flexion and knee extension during the leg acceleration phase to ball contact, although the extent of this varies depending on kick type.[6] As these two actions are the primary functions of the biarticular rectus femoris, it is unsurprising that the action of kicking and injury to the rectus femoris are closely linked.[4]

Elite sport settings often include periodic maximal strength testing to identify fluctuations in this capacity as a form of secondary injury prevention.[7] This form of screening is increasingly incorporated to identify acute reductions in maximal strength (e.g., 48-72 hours post-competition) which may indicate sub-clinical signs of pathology and a potential increased risk of future injury to the assessed muscle.[8,9] The test outcomes can provide information that may guide secondary prevention strategies, such as training load modification (e.g., volume of goal shooting or sprinting) until strength scores return to baseline.[10,11] This approach has been reported recently for the adductors and knee flexors in similar cohorts of elite youth male soccer players.[10,11]

To assist with these secondary injury prevention strategies, practitioners require reliable tests for easy and reproducible assessment of muscle strength.[10] Reliable force tests for the separate isolated actions of the kick exist (i.e., knee extension using hand-held dynamometry (HHD) and isokinetic dynamometry[12] and hip flexion using HHD[13]), however, these isolated actions do not replicate the unique combination of joint actions during the kick (ball contact phase) that place a high demand on the biarticular rectus femoris.[14] Furthermore, although isokinetic dynamometry remains the gold standard for strength testing of knee extension force[15], it is expensive and time consuming[16]. Additionally, the reliance on the skill and strength of the tester when using HHD, counteracts the benefits of cost and time efficiency.[17] As a result, studies examining the force production of kicking is likely limited by the lack of an appropriate and feasible test of this action. More research is required to understand the specific strength demands of the muscles involved in kicking and their recovery following a match.

A simple and practical field-based strength test of combined hip flexion and knee extension is required to examine kicking related function/strength. Due to the combination of those joint actions, this test will likely provide a surrogate measure to monitor the status of rectus femoris. An appropriate test could be incorporated as a serial monitoring tool to determine the temporal function of rectus femoris following match-play. Therefore, the aims of this study were to: a) describe a novel test to assess isometric strength during a task that closely resembles the action of a kick (referred to as the Kicker); b) determine the inter-session reliability of Kicker force; and c) evaluate the effect of competitive match-play on Kicker force for a subsequent 72 hour period in academy soccer players, given their elevated risk of quadriceps strain injury.

MATERIALS AND METHODS

Thirty-seven participants were recruited for this study that consisted of two parts. Part A examined the inter-session reliability of the Kicker test on 20 participants (13 male, 7 female) partaking in various sports at a recreational level or higher (age: 27.4 ± 4.3 years; height: 175.2 ± 7.8cm). For Part B, post-match strength response data were collected on 17 male academy soccer players (age: 18.0 ± 0.8 y; height: 181.6 ± 8.4 cm; weight: 70.9 ± 9.5 kg). Analysis was then completed on 16 data points at +24 and 14 data points at +48 for both preferred and non-preferred limbs, and 10 and 11 data points at +72 for the preferred and non-preferred limbs respectively**.** All academy soccer players were contracted to one professional sporting team at the time of assessment, of which there were two goal-keepers, five defenders, six mid-fielders and four forwards. The decision was made to conduct Part A and B in different cohorts for several reasons. Firstly, to assess inter-session reliability of measures, it was imperative that all participants presented to the lab in a standardized condition. To disrupt the professional academy coaches and players' schedules to ensure they were in a rested state was considered unnecessary and therefore unethical. Secondly, it was expected that the recreational athletes would be less skilled at a kicking action compared to the academy soccer players and, therefore, the inter-session error detected in the recreational athletes would provide a conservative (or larger) indication of the error in the Kicker that could be utilized for further interpretation in Part B. This approach also allowed for Part A to inform the design of Part B, with Part A providing guidance around the need and extent for familiarization to the test prior to conducting data collection in Part B.

Participants in both Part A and B had no significant lower limb injury (i.e., no injury that resulted in greater than six weeks of convalesces until return to given sport) in the previous six months. Informed consent (including guardian consent and minor assent for participants under 18 years of age) and institutional ethics approval were obtained (ACU HREC: 2017-245H). Participants were informed of the benefits and risks of the investigation prior to signing the institutionally approved informed consent document to participate in the study.

Reliability testing was performed at the School of Behavioural and Health Sciences, Australian Catholic University in Melbourne. Post-match strength response data were collected at the Melbourne Victory Football Club training facilities. All testing was completed by the lead investigator, who is a physiotherapist with six years of clinical experience.

The Kicker test involved participants standing on the ForceFrame Strength Testing System (Vald Performance, Albion, Queensland, Australia) with their stance leg heel in contact with the device handle and the kicking leg (dorsum of foot) in contact with the device load cell (Figure 1). Participants held onto the device bars and started with their kicking leg in a neutral hip position (0 degrees). The bar height remained the same for each participant at the maximum height. The load cell height was customized for each participant to ensure adequate foot clearance and optimal foot contact. Following a verbal cue, participants completed a warm-up comprising a 50% and 75% maximum effort. After a 30 second rest, participants performed three consecutive maximum repetitions, pushing through the dorsum of their foot for three to five seconds. Participants were verbally encouraged during the contraction to ensure maximum effort with a consistent command of “Kick, Kick, Kick”. Participants then had a 10 second rest and repeated the test. In total, three efforts were completed for each limb. Less than 5 minutes was required to administer the Kicker per participant. The single highest force (N) measure from any of the three trials individually for the preferred and non-preferred limbs was determined as Kicker force. This testing protocol was identical for both Part A and Part B of this study.

(Insert Figure 1 here)

Reliability data were collected between November 2017 and February 2018. Participants completed testing on the same day and at the same time of day, for three consecutive weeks (3 testing sessions in total, spanning 14 days). Post-match strength data were collected over four consecutive weeks between

July and August 2018 with the first of the four weeks (i.e., three testing sessions) completed as a familiarisation week. Data collected from players who did not play ≥ 60 minutes (determined from publicly available data) in the previous weekend's match were not used for the corresponding week's analysis. Testing was always conducted within the 60 minutes prior to the commencement of training sessions to minimise the impact of any acute fatigue. Testing time points were chosen to capture the first 72 h after a game and to correspond with the club's typical weekly system of player monitoring. Testing time points coincided with a recovery day 24 h ± 2 h (+24) post-match, upper body gym session 48 h ± 2 h (+48) post-match, and a main skills training sessions 72 h ± 2 h (+72) post-match. As a result, testing for a given week was concluded prior to the main skills training session for that week.

Data from the inter-session reliability testing were uploaded to the device manufacturers cloud-based repository. Normal distribution of the data was assessed in JMP® Pro version 14.2 (SAS Institute Inc., Cary, NC, USA) using a Shapiro-Wilks test. Data was then exported into a customized Microsoft Excel spreadsheet[18] designed to assess inter-session reliability. Mean differences (and associated 95% confidence intervals), effect sizes (Cohen's *d*), intraclass correlation coefficient (ICC 3,1),[19] typical error (TE), and TE as a coefficient of variation (%CV) were calculated to assess the extent of variation between the first to second, and the second to third testing sessions.[19] Based on Weir,[19] it was determined that an ICC >0.90 was high, between 0.80 and 0.89 was moderate, and <0.79 was poor.[19] Minimum detectable change at a 95% confidence interval (MDC95) was calculated as TE X 1.96 X√2.[20]

Post-match strength data were analysed using RStudio (Version 1.1.463) running the R programming language (Version 4.0.5, *Shake and Throw*, The R Foundation for Statistical Computing). A linear mixed effect model was used with player ID incorporated as a random intercept, which assessed the difference post-match, in Kicker force across three time points and each limb (fixed effects) using the *lmerTest* package in R. Where significant effects were seen, post hoc analysis was performed using estimated marginal means, with significance set at $p < 0.05$. The time points, +24, +48, +72, were chosen as they represent time points explored in previous studies looking at recovery of both isometric knee extension and flexion force in soccer and Australian Football athletes respectively.[21, 22] Furthermore, testing time points were chosen to capture the first 72 h after a game and to correspond with the club's typical weekly system of player monitoring. A rolling baseline was adopted for this component of the study. During familiarization the highest Kicker force was recorded across three sessions as the baseline score. If Kicker force in a subsequent week was higher than the previously defined baseline, a new baseline was defined as this higher score, accordingly. We recorded the highest value for each time point (+24, +48, +72) where we measured kicker force across the 3 weeks. To determine the size of the differences at each time point, and to account for the dependency of repeated measurements, Cohen's d_z was calculated with 95% confidence interval were calculated. Using the *effectsize* package, the t value from the linear mixed model was divided by the square root of the degrees of freedom error from the same model and interpreted as *trivial*, <0.20; *small*, 0.20-0.49, *moderate*, 0.50-0.79, and *large*, ≥0.80.[23,24]

RESULTS

Of the 20 participants in Part A, 17 reported their right leg as their preferred kicking leg. All data was normally distributed. Kicker force scores (N) across the three sessions were: 253±69, 258±64, 265±62 and 253±59, 259±56, 263±60 for the preferred and non-preferred limbs respectively. The ICCs ranged from 0.91-0.98 and %CVs were below 10.3% for all sessions (Table 1). Effect sizes (Cohen's *d*) ranged from 0.07-0.10 for all sessions (Table 1). Minimal detectable change scores at a 95% confidence interval were below 49.3 N for all sessions (Table 1).

(Insert Table 1 here)

Seventeen participants were tested over three weeks in Part B. Of the 17 participants, 16 reported their right leg as their preferred kicking leg. Twenty one data points were excluded from the analysis due to incomplete data (due to injury, absence from training, or <60 minutes game time) leaving a total of 81 data points included in the analysis. This includes a single participant for which all testing data was excluded. Testing did not interfere with players' regular training schedule and no participants were injured during testing of the Kicker or reported any soreness on the testing day or in subsequent days.

There was a main effect reported for both time ($p<0.001$) and limb ($p<0.01$), but no interaction effect ($p= 0.52$) was observed. Following match-play, Kicker force remained suppressed compared to baseline in both limbs at all time points ($p<0.01$). Loss in force capacity were -10.7% at +24 ($p< 0.01$; $d= -0.39$), -12.5% at +48 ($p<0.01$; $d= -0.43$) and -5.8% at +72 ($p<0.01$; $d= -0.26$) for the preferred limb and -9.2% at +24 ($p<0.01$; $d= -0.35$), -9.8% at +48 ($p<0.01$; $d= -0.34$) and -7.8% at +72 ($p<0.01$; $d= -0.33$) for the non-preferred limb (see Table 2 & Figure 2).

(Insert Table 2 here)

(Insert Figure 2 here)

DISCUSSION

This is the first study to explore the reliability of a combined hip flexion and knee extension isometric strength test (the Kicker), and to examine the recovery of Kicker force output for 72 hours post-match in academy soccer athletes. The major findings of this study were: a) the force outputs obtained from the Kicker protocol display high levels of inter-session reliability; b) compared to baseline data, Kicker force was suppressed post-match in both limbs at 24, 48 and 72 hours post-match; and c) there was no evidence that Kicker force had returned to baseline levels at (72 hours post-match) the time typically expected sufficient for full recovery and, according to weekly tactical periodization models, when soccer players are exposed to stimulating training intensities.

This study demonstrates that the Kicker is a reliable assessment to measure combined hip flexion and knee extension force. Furthermore, measurement error tended to lessen following the initial exposure to the Kicker protocol (TE reduced from 17.6 N to 9.5 N and 17.8 N to 13.6 N for the preferred and non-preferred limbs, respectively). This infers that a learning effect may exist and familiarisation to the test may be important prior to collecting data intended to be used for further analysis.

The Kicker's ICC of 0.91-0.98 compares well to the reliability of an isokinetic dynamometer-based isometric test of knee extension (ICC 0.93-0.96).[25] The reliability of isometric knee extension measured using HHD suggests that it is a repeatable test (ICC 0.92-0.99),[26,27] while HHD measures of isometric hip flexion (ICC 0.86) tend to be somewhat less stable.[17] The isometric protocol of the Kicker compares favourably to dynamometer-based testing procedures due to being an externally fixed test (which is superior to HHD) that is simple and easy to use in practice (which is superior to isokinetic dynamometry). Furthermore, being able to combine the assessment of knee extension and hip flexion lends itself to a more functionally relevant and time efficient (<5 minutes per participant) assessment of kicking function, as opposed to independent, isolated movements.

The results of the reliability component (Part A) of this study allowed for inferences to be made regarding post-match responses (Part B) in relation to the smallest detectable change of the test. As the reliability data indicated a reduction in error with additional testing sessions, the post-match response portion of the current work included a week of familiarization to minimize the impact of a learning effect. Therefore, the reliability data comparing session 2 to session 3 (CV% = 3.7 to 5.3; MDC95% = 26 to 38 N) should be used to guide the interpretation of the post-match response study.

Kicker force suppression was observed at all post-match testing time points (-10.7% at +24, -12.5% at +48 and -5.8% at +72 [$p < 0.01$; *d* range -0.26 to -0.43]) for the preferred limb (-9.2% at +24, -9.8% at +48 and -7.8% at +72 [$p < 0.01$; *d* range -0.33 to -0.35]) and for the non-preferred limb. There were some outlier responses observed at some time points that would affect the amount of change observed. There didn't appear to be anything obvious (e.g. player motivation etc.) that could explain these outliers. Suppressed force capacity has been reported previously. Draganidis and colleagues[28] found that isometric, concentric and eccentric knee extension strength and peak torque all did not return to baseline by 60 hours post a soccer match and Thomas and colleagues[21] found that isometric knee extension did not return to baseline by 72 hours post simulated match play. Additionally, a recent systematic review and meta-analysis showed that muscle force capacity (hamstring muscle group) and other fatigue related markers (e.g., creatine kinase levels) remained substantially impaired 72 hours following actual and simulated soccer match play.[30] What was different to previous reports however, was that based on those findings knee extension and flexion strength and peak torque was anticipated to be lowest at 12 to 24 hours post-match.[28,30] There was no clear pattern in the current profiles across the 72 hours of post-match testing. Understanding the shape and timeframe for recovery of Kicker force following matches has important implications for its potential utility in soccer academies.

Armed with this novel assessment protocol, clinicians may be able to identify those with continued suppressed force capacity. This may be useful from a secondary injury prevention perspective as a test to help guide secondary prevention for quadriceps strain injuries. For example, monitoring the post-match response to determine meaningful deviations (based on the MDC95% of 26 to 38 N) in Kicker force could be used to inform modifications to training (e.g., shooting, sprinting) in the 72 hours post-match, as has been recently described for the hamstrings.[11]

While the current study aimed to establish the reliability and potential utility of the Kicker test from a secondary injury prevention perspective, it may also have further applications that can be explored in future work. For example, during rehabilitation from rectus femoris strain injury, a graded reintroduction of kicking loads that replicates the demands required for match play is crucial for a safe return to play.[32] Clinical guidelines for return to kicking activities have been detailed in the literature,[32] but do not provide criteria for progression with respect to hip flexion and knee extension force and the subsequent progressions through the kicking program. Monitoring Kicker force may provide an objective tool and valuable outcome measure for monitoring kicking progressions over time and could be incorporated within clinical guidelines to inform rehabilitation and more specifically kicking progressions following rectus femoris strain injury, however, more work is needed in this area.

The current study was used as a proof of concept and therefore has some limitations that need to be considered in this context. First, an absence of testing beyond 72 hours meant that the time course for full restoration of Kicker force could not be determined. A 72-hour window of data collection post-match play was utilized based on similar previous literature that deemed this sufficient to observe full restoration[30] and was also considered in light of contemporary coaching practice (i.e., weekly tactical periodization models widely used in soccer). Furthermore, the absence of external load monitoring (e.g., running distance and speeds etc.) and most importantly the number and type of kicks in a match/training meant that no associations could be made between the impact of external loads to post-match Kicker responses. It cannot be precluded that individual athlete external loads as well as other factors including motivation or some athlete's pre-clinical pathology would influence some individual data points. It also should be acknowledged that Part B utilized a convenience sample and investigation with a larger number of participants would increase our confidence in these findings. Finally, as previously, reliability of the Kicker was established in a different cohort of older recreationally active participants and not the academy soccer players who were used for the post-match response component of the study. Differences between the two cohorts (i.e. age disparity, distribution of gender, type and level of sport exposure, kicking skill) should be considered when interpreting results. It is likely that the academy soccer players who produced greater force outputs are more skilled at the kicking action and therefore the error in the Kicker reported in the recreational athletes would overestimate the error in a soccer playing cohort.

In conclusion, the Kicker provides reliable data for the assessment of combined isometric hip flexor and knee extensor force in recreationally active or higher participants from various sports. Kicker force is still suppressed 72 hours after match play in both the preferred and non-preferred limbs in academy soccer players. The Kicker provides a reliable and clinically feasible test that can be used to monitor combined hip flexion and knee extension strength. This information may, in future, be used in conjunction with return to kicking programs to help guide return to play following kicking related injuries.

PRACTICAL APPLICATIONS

Practitioners require reliable tests for easy, timely and reproducible assessment of muscle strength.[10] There has previously been no simple and practical field-based strength test that measures the unique combination of joint actions (combined hip flexion and knee extension) during the kick. The Kicker is a reliable, quick to implement (<5 minutes) and safe to use (during the competitive season) test that can be used to measure combined hip flexion and knee extension force. This test will likely provide a surrogate measure to monitor the status of rectus femoris, as the action of kicking and injury to the rectus femoris are closely linked.[4] A familiarization session is important when utilizing the Kicker test to minimize systematic error caused by possible learning effects. After familiarization, practitioners may interpret Kicker force changes that exceed the CV% of 5.3% as real. Objective data from such a test may be useful for practitioners during the rehabilitation of rectus femoris injuries in sports that involve kicking to provide guidance for kicking progressions.

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DECLARATION OF INTEREST STATEMENT

Dr David Opar is listed as a co-inventor on a patent filed for a field-testing device of eccentric hamstring strength (PCT/AU2012/001041.2012). The patent was filed by Queensland University of Technology (QUT) and Dr Opar has received revenue distributions from QUT based on revenue the university has generated from his intellectual property.

Dr Opar is a minority shareholder in Vald Performance Pty Ltd, the company responsible for commercialising the device. Vald Performance has also commercialised the device utilised in the current manuscript.

Dr Opar has received research funding from Vald Performance, for work unrelated to the current manuscript. Dr Opar is the Chair of the Vald Performance Research Committee, a role that is unpaid. Some of Dr Opar's family members are minor shareholders and/or employees of Vald Performance.

Dr Morgan Williams is a member of the Vald Research Committee. Dr Morgan Williams has been provided donations of equipment, and funds for travel and subsidence by Vald Performance to conduct research unrelated to this project. Dr Morgan Williams has received payment for reports for Vald Performance unrelated to this and any research study.

The ForceFrame was provided to the research team free of charge.

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Tables

Table 1: Inter-session reliability of force data (N) for the Kicker test comparing session 1 to 2, and 2 to 3 respectively.

Test	**Side**	**Mean difference (95% CI)**	**Cohen's d**	**ICC (95% CI)**	**TE (95% CI)**	**%CV (95% CI)**	**MDC95 (N)**
2-1	**Preferred Leg**	5.2 (-6.46 to 16.9)	0.08	0.94 (0.85 to 0.97)	17.6 (13.4 to 25.7)	10.3 (7.7 to 15.3)	49
	Non-preferred Leg	6.0 (-5.8 to 17.8)	0.10	0.91 (0.80 to 0.97)	17.8 (13.6 to 26.1)	9.2 (6.9 to 13.8)	49
3-2	**Preferred Leg**	6.3 (-0.01 to 12.5)	0.10	0.98 (0.95 to 0.99)	9.5 (7.2 to 13.8)	3.7 (2.8 to 5.4)	26
	Non-preferred Leg	4.0 (-5.0 to 13.0)	0.07	0.95 (0.88 to 0.98)	13.6 (10.3 to 19.9)	5.3 (4.0 to 7.9)	38

ICC: intraclass correlation coefficient; CI: confidence interval; TE: typical error; %CV: typical error as a coefficient of variation; MDC95: Minimum detectable change; N: Newtons.

Table 2: Within- group data and effect size (95%CI) of changes in Kicker force 24, 48 and 72 hours following competitive match play compared to baseline.

Time	Mean ± SD (N)	P Value	Effect size estimate (95% CI)
Preferred Leg			
Baseline	343 ± 39	-	-
+24 (n=16)	306 ± 53	<0.01	-0.39 (-0.53 to -0.26)
+48 (n=14)	300 ± 56	<0.01	-0.43 (-0.57 to -0.29)
+72 (n=10)	323 ± 44	<0.01	-0.26 (-0.39 to -0.13)
Non-preferred Leg			
Baseline	351 ± 43	-	-
+24 (n=16)	319 ± 43	<0.01	-0.35 (-0.48 to -0.21)
+48 (n=14)	317 ± 46	<0.01	-0.34 (-0.47 to -0.20)
+72 (n=11)	324 ± 39	<0.01	-0.33 (-0.46 to -0.19)

SD: standard deviation; CI: confidence interval; L: left; R: right; N: Newtons

Figure 1

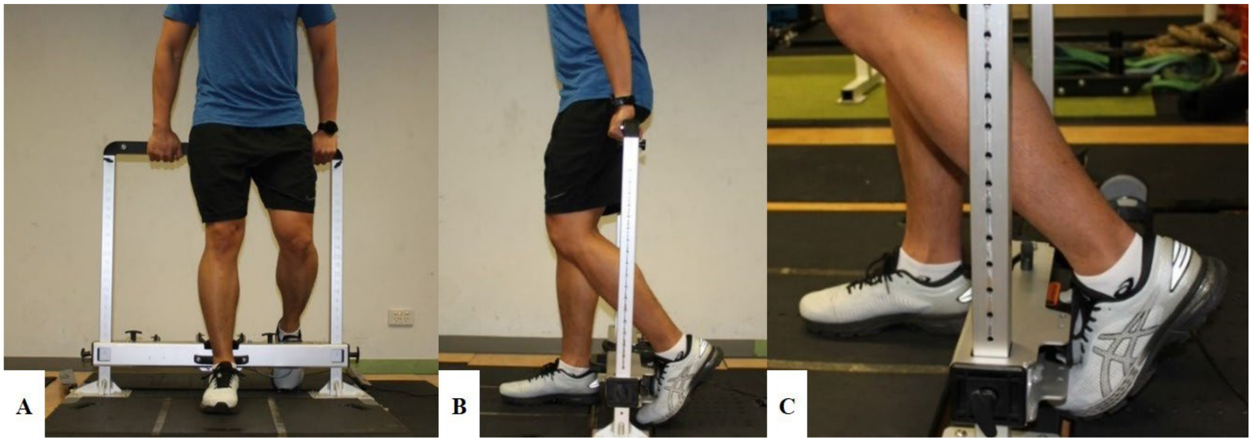

Figure 2

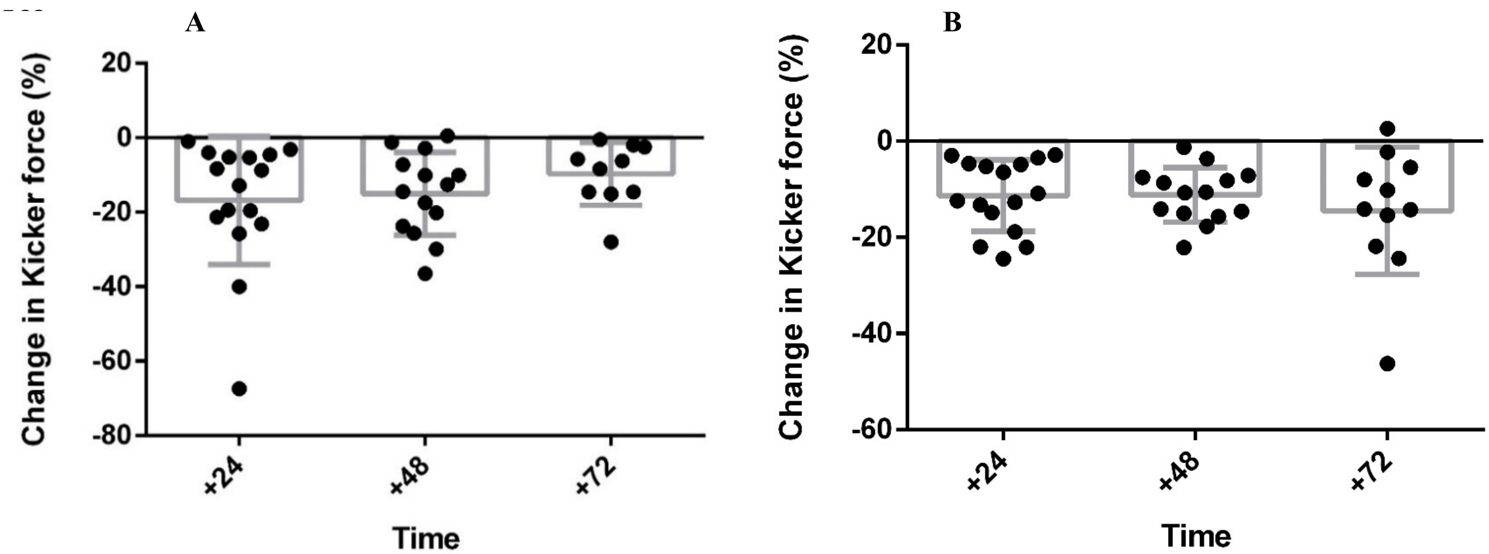
A
Change in Kicker force (%)
20
0
-20
-40
-60
-80
+24
+48
+72
Time
B
Change in Kicker force (%)
20
0
-20
-40
-60
+24
+48
+72
Time

Figure Captions

Figure 1: Kicker setup: A) Front on and B) side on view of participant standing on ForceFrame, holding onto the bar, with buttocks in contact with bar. Back of stance leg in contact with crossbar handle and kicking leg in contact with load cell. C) Dorsum of foot (participants defined best contact point) in contact with device load cell.

Figure 2: Percentage change in Kicker force, compared to baseline, for the: A) Preferred leg and B) Non-preferred leg 24, 48 and 72 hours following a competitive soccer match.