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Specificity of isokinetic assessment in noncontact knee injury prevention screening: a novel assessment procedure with relationships between variables in amateur adult agility-sport athletes.

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Ethical statement

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None.

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Specificity of isokinetic assessment in noncontact knee injury prevention screening: a novel assessment procedure with relationships between variables in amateur adult agility-sport athletes.

ABSTRACT

Objectives: To present a new knee isokinetic assessment procedure linked to noncontact knee injury mechanisms and examine correlations between variables relevant to noncontact knee injury prevention screening (peak torque [PT, Nm], time-to-peak torque [TTPT, ms], angle-of-peak torque [APT, °], mean PT [MPT, Nm]).

Design: Cross-sectional.

Setting: Sports medicine laboratory.

Participants: Thirty-four agility-sport athletes (male/female n=18/16, age 24.1±3.5yr, height 171.8±9.6cm, mass 70.6±12kg).

Main Outcome Measures: Pearson's/Spearman's correlation (r/r_s), coefficient of determination (r^2/r_s^2).

Results: Most correlations were statistically non-significant or statistically-significant with only weak-to-moderate coefficients. For both knee extension and flexion, PT and MPT were significantly and strongly correlated (r=0.99, r^2=0.98, p=0.001). Graphical analyses revealed two datapoint clusters for knee flexion TTPT and APT. One cluster indicated some participants could generate knee flexor PT rapidly (<150ms) at low knee flexion angles (<45°) and the other cluster indicated that other participants could not (>200ms, >50°).

Conclusions: In this study, most isokinetic variables represented distinct knee neuromuscular characteristics. For both knee extension and flexion, only PT or MPT need be used to represent isokinetic maximal strength. Knee flexion TTPT and APT may have utility in noncontact knee injury prevention screening with amateur adult agility-sport athletes.

KEYWORDS

Knee, injury prevention, isokinetic, screening

INTRODUCTION

Team sports such as football, basketball, and netball are played by millions of amateur adult male and female athletes worldwide (1-3). Such sports require athletes to execute agility skills as they manoeuvre within playing boundaries, avoid interception by opponents, and score points by depositing a ball in the opposition's goal (4). Given the agility nature of many team sports, noncontact knee injuries (e.g., anterior cruciate ligament sprain) are common (5-8). Noncontact knee injuries account for over two-thirds of knee trauma in team sports (9, 10), are defined as those happening without any contact with an opponent (11), and typically occur in situations involving single-limb stance-phase loading during agility-running and landing tasks (12-14). Knee injuries result in profound consequences, including physical disability (15), substantial healthcare costs (16), post-trauma osteoarthritis (17), and depression (18). Because of profound personal and socioeconomic consequences, injury prevention interventions are needed to help mitigate the burden of knee injuries for athletes and society and promote athletes' safe agility-sport participation.

Injury prevention refers to preventing first-time (primary) injury and includes all countermeasures to eliminate or minimise its occurrence (19). Primary injury prevention includes assessment and intervention procedures that combine to decrease the probability of first-time injury (19, 20). Assessment (screening) in primary injury prevention is a process to identify characteristics (risk factors) that increase athletes' predisposition for injury (21, 22). Skeletal muscle shields joint tissues from excessive loads (23), and isokinetic assessment of knee muscle performance has been used to profile athletes when considering predisposition for noncontact knee injury (24-26). When using isokinetic assessments of muscle performance, the specificity principle should be acknowledged relative to a sport's athletic tasks (27-29). The specificity principle requires that an isokinetic assessment procedure resembles the 'functional' movement pattern of interest and includes consideration for the range-of-motion through which a joint moves and the velocity-of-motion at which a joint moves (27-29).

In knee injury prevention, the specificity principle of assessment can also be considered relative to the mechanism of noncontact knee injuries (Figure 1; modified from (30)). The direction of knee joint motion during noncontact knee injury can be identified from video analyses of real-world injury events (Figure 1). Common mechanisms of noncontact knee injury include single-limb stance-phase loading with knee abduction (valgus), tibial internal rotation (IR), and anterior tibial displacement (ATD), all within a knee flexion range-of-motion of 0-60° (12, 13). It is not possible to voluntarily perform all planes and directions of knee motion observed during noncontact knee injury events on an isokinetic dynamometer (e.g., frontal plane, abduction/adduction); therefore, researchers can only study the planes/directions of knee motion that are possible to perform voluntarily (e.g., sagittal plane, flexion/extension) (Figure 1). When simulating real-world injury events in the laboratory, researchers can employ representative athletic tasks; these tasks contain biomechanical features similar or identical to those observed during real-world noncontact knee injury events (e.g., single-limb, stance-phase, high-velocity loading) (Figure 1). Biomechanical studies of athletic tasks involving stance-phase loading report uninjured participants can perform tasks with peak knee abduction velocities >169°·sec^{-1} (31) and >240°·sec^{-1} (32, 33). Therefore, for noncontact knee injury prevention screening that considers the common mechanism of injury in agility-sports, it is logical to include knee muscle performance assessments in a knee flexion-extension range-of-motion of 0-60° at velocities near 240°·sec^{-1}. When the mechanism of injury, range-of-motion, and velocity-of-motion are determined, relevant muscle performance variables can be considered (Figure 1).

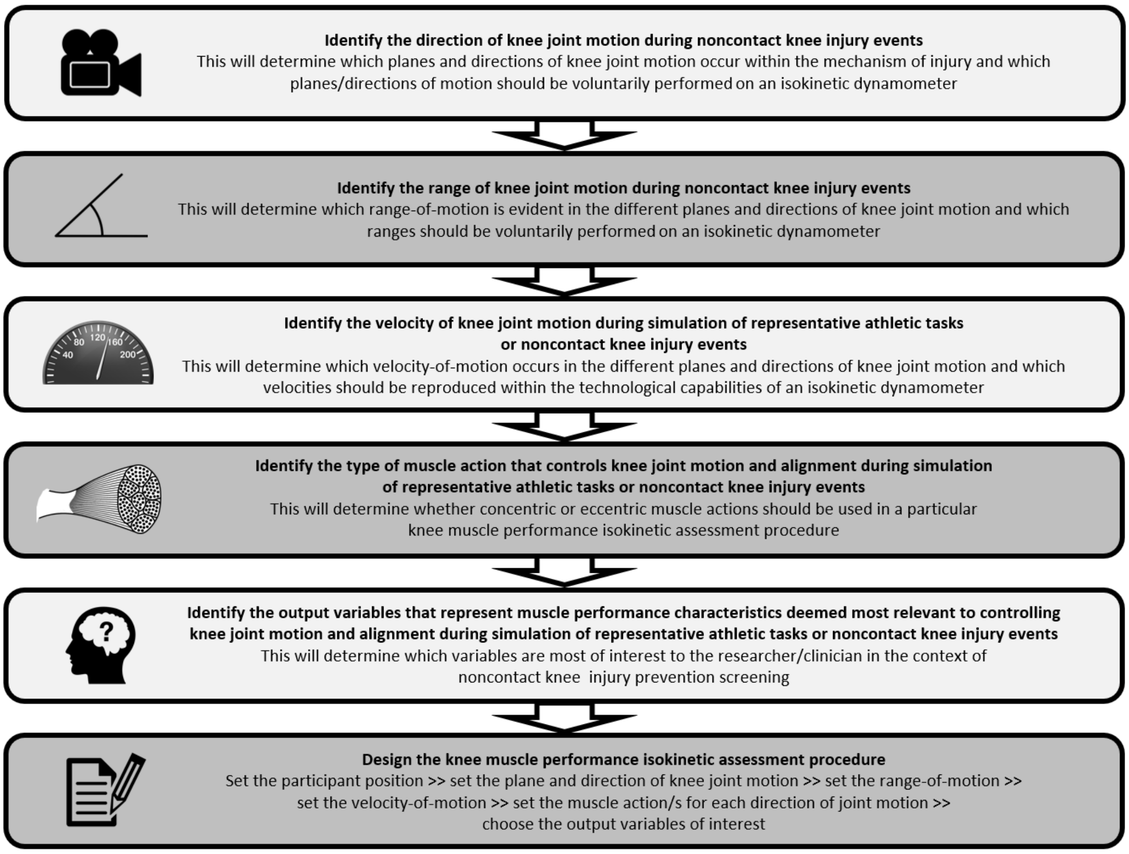

Figure 1. Suggested steps for considering the specificity principle in the design of knee isokinetic muscle performance assessments.

Isokinetic dynamometry is a valid procedure for collecting joint position, velocity, and torque data (34). Many muscle performance variables are output from isokinetic dynamometers. For example, peak torque (PT), time-to-peak torque (TTPT), and mean peak torque (MPT) (28, 29). Some criticise the term ‘torque’ because it implies torsion around the longitudinal axis of a bone (35). The term ‘moment’ is argued as preferable for isokinetic assessments because it is a force that tends to cause rotation of a bone around a joint axis (35). Whether ‘torque’ or ‘moment’ is used in the name of a variable, an isokinetic variable is an output that *indirectly represents* a distinct neuromuscular characteristic and its underlying physiological processes expressed through the lever system of the skeleton (28, 29, 35). For example, PT refers to the highest value from a set number of isokinetic repetitions (28, 29) and represents the maximal force-generating capacity of the neuromuscular system (i.e. maximal strength) (35). Time-to-peak torque refers to the time required to generate peak torque (28, 29) and represents the ability of the neuromuscular system to generate force rapidly (28). Therefore, it is essential to understand different isokinetic variables and the neuromuscular characteristics they represent to clinically-reason why a specific variable might be important in noncontact knee injury prevention contexts. It is also essential to understand the relationship between isokinetic variables in order to consider whether different variables sample similar or distinct neuromuscular characteristics; this will further inform clinical reasoning processes that underpin the design and specificity of knee isokinetic assessment procedures.

Several research groups have assessed knee isokinetic muscle performance in noncontact knee injury prevention contexts. Researchers consistently assess knee isokinetic muscle performance in 0-90° flexion-extension ranges-of-motion (25, 26, 36). Assessments are performed at angular velocities of 60°·sec^{-1} (25, 37, 38), 90°·sec^{-1} (36), 180°·sec^{-1} (25, 38, 39), 240°·sec^{-1} (38, 40), and 300°·sec^{-1} (25, 26, 41). Low to medium-velocity knee isokinetic assessments appear most common where low/slow, medium/moderate, and high/fast velocity are defined as 60°·sec^{-1}, 180°·sec^{-1}, and 300°·sec^{-1}, respectively (41, 42). No research group has published a knee isokinetic assessment procedure that considers the flexion-extension range-of-motion and abduction velocity-of-motion linked to the mechanism of noncontact knee injury. Few researchers have examined the relationship between different variables extracted from a single knee isokinetic assessment procedure. Correlations between PT and TTPT have been examined for knee isokinetic assessments in a 0-90° range-of-motion at 60°·sec^{-1}, 180°·sec^{-1}, and 300°·sec^{-1} (43, 44). Correlations between PT and angle-of-peak torque (APT) have also been examined for knee isokinetic assessments in a 0-90° range-of-motion at 60°·sec^{-1} and 180°·sec^{-1} (42, 45). No research group appears to have published correlations between more than two output variables from one isokinetic assessment procedure.

The purpose of this study was to examine the correlation between knee extension-flexion variables (PT, TTPT, APT, MPT) extracted from a novel isokinetic assessment procedure linked to the mechanism of noncontact knee injury. Peak torque was selected because as knee muscle strength increases, more favourable knee kinematics are displayed during athletic tasks (46, 47). Time-to-peak torque was selected because rapid force generation by the knee muscles is critical for restraining excessive knee joint displacements and restoring knee joint alignment following perturbation (37, 48, 49). Angle-of-peak torque was selected because the ability of the hamstrings and quadriceps to resist an external force causing knee joint perturbation changes according to knee flexion angle (50-52). Mean peak torque was selected because it is a variable commonly used in knee injury control research (53-55). It was hypothesised there would be no statistically-significant strong correlation between variables. The hypothesis was set to align with previous researchers' views that each isokinetic variable represents a distinct neuromuscular characteristic and its underlying physiological processes (28, 29, 35). Data were collected as part of a larger noncontact knee injury control project. This study is original because no previous work has examined relationships between PT, TTPT, APT, and MPT extracted from a knee isokinetic assessment procedure designed to consider the specific mechanism of noncontact knee injury. The findings from this study will be practically significant and offer real-world impact because they will inform the specificity of future isokinetic assessments in noncontact knee injury prevention screening with amateur adult agility-sport athletes.

MATERIALS AND METHODS

Study design, sample size calculation

This was a cross-sectional study. A power analysis was performed using G*Power (56). To detect a correlation of 0.75 with a power of 0.80 and an alpha of 0.05, 37 participants were required.

Ethical approval, participant recruitment, informed consent

Institution ethics approval was obtained (IRBPRO13030035). Participants were recruited from the local community (university campus, university sports medicine centre, health/fitness facilities, sports teams) using flyers posted on official noticeboards. Informed consent was obtained from all participants.

Participants

Inclusion criteria were: males/females aged 18-40 years participating in Level I-II sports according to the knee Sports Activity Rating Scale (SARS) (57). Exclusion criteria were: current lower-quadrant pain or time-loss injury in the previous two months (i.e. injury requiring withdrawal from one or more training/matches), diagnosed knee ligament deficiency or cartilage lesion, history of knee surgery, and any current condition affecting sensorimotor processing. Thirty-four athletes volunteered (male *n*=18, female *n*=16, Table 1).

Table 1. Participant descriptive statistics (*n* =34)

	Age (yr)	Height (cm)	Mass (kg)	SARS
Minimum	19.0	153.0	48.9	80.0
Maximum	32.0	194.0	91.4	100.0
Median	23.0	173.0	70.5	95.0
Mean	24.1	171.8	70.6	90.9
SD	3.5	9.6	12.2	7.3

yr = years; cm = centimetres; kg = kilograms
SARS = Sports Activity Rating Scale
SD = standard deviation

Procedures

Data collection occurred in a sports medicine laboratory in one session. Athletes were instructed to avoid fatiguing exercise/sports for 48 hours beforehand. The dominant limb was assessed and defined by the preferred kicking limb (58). Participants wore their preferred athletic attire.

Data were collected with a Biodex System 3 isokinetic dynamometer (Biodex, Shirley, New York) at 100Hz. The dynamometer was calibrated before each data collection session according to the manufacturer's procedures. Participants were seated on the dynamometer, the popliteal fossa approximately 5cm off the edge of the chair, the lateral epicondyle of the dominant limb's knee aligned with the lever-arm axis-of-rotation, the nondominant limb hanging freely (Figure 2). The torso, pelvis, and dominant limb were secured using the dynamometer's straps (Figure 2). The dynamometer's knee attachment was adjusted so the lower edge of the shank strap was just above the proximal margin of the medial malleolus (Figure 2).

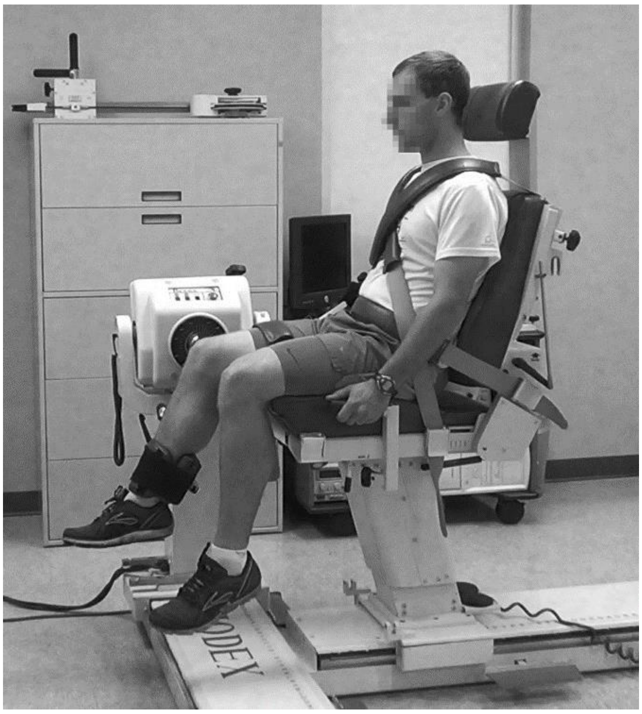

Figure 2. Participant-dynamometer configuration

Sagittal plane range-of-motion limits were set to start with the knee flexed and allow a 60-0° extension-flexion range-of-motion. Extension-flexion movements were assessed because these can be voluntarily performed on an isokinetic dynamometer (Figure 1), because the quadriceps are dynamic restraints to knee abduction (50, 59, 60), and because the hamstrings are dynamic restraints to knee abduction, tibial IR, and ATD (50, 59, 60). A 60-0° extension-flexion range-of-motion was used because it is the range-of-motion in which noncontact knee injuries occur (12, 13, 61). Because the dynamometer is positioned adjacent to the lateral aspect of the knee (Figure 2), it is not possible to access the lateral bony landmarks required for knee goniometry and measurement of knee angles. Therefore, the knee's 0° position (anatomical position) and extension range-of-motion limit was determined with visual estimation, which is reliable for experienced practitioners (62) and not significantly different from goniometric measurement (63). Next, the 60° flexion range-of-motion limit was set using the dynamometer's digital goniometer. The limb was weighed, and participants instructed to extend and flex the knee with no resistance to ensure correct participant-dynamometer configuration under dynamic conditions. At the same time, thigh strap (Figure 2) tension was checked to ensure it was not restricting quadriceps girth expansion during knee extension. Velocity of assessment was set at $240°\cdot sec^{-1}$. A velocity of $240°\cdot sec^{-1}$ was used because it corresponds to the upper limits of knee abduction velocities published for single-limb loading athletic tasks (32, 33). We also reviewed unpublished participant data (*n*=30) from 3D motion-analysis of single-limb athletic tasks used in our laboratory (46) and calculated a stance-phase mean peak knee abduction velocity of $244.5\pm83.3°\cdot sec^{-1}$. Reciprocal extension-flexion concentric-concentric muscle actions were used because concentric muscle actions restore joint alignment following perturbation by pulling bones in the direction opposite to that of the initial displacement (40, 64, 65).

Participants performed five sub-maximal warm-up trials at 50% perceived maximum voluntary velocity (MVV) immediately followed by five warm-up trials at 100% MVV. Participants were provided with 60-seconds rest, given a "3, 2, 1, Go!" countdown, and instructed to perform five reciprocal extension-flexion measured trials at 100% MVV. Participants were permitted to hold the dynamometer handles (Figure 2), and strong verbal instructions included "Kick out as fast as you can! Pull back as fast as you can!" (66).

Data was gravity corrected automatically by the dynamometer's software (Biodex Advantage Software v.3.0, Biodex, Shirley, New York). Immediately after the measured trials, two data quality-control procedures were performed using the dynamometer's software and computer display. First, the graphical output of the isokinetic curve was visually inspected for any aberrancy (67, 68). Second, the text file output was reviewed to verify that participants achieved a minimum range-of-motion of 55-5° and a maximum velocity of at least 235°·sec^{-1} for each extension-flexion cycle. If graphical or text file outputs were unsatisfactory, the assessment procedure was discarded, the participant given adequate rest, and a new assessment procedure performed. For PT (Newton-metres (Nm)), data were windowed to ensure PT values were extracted from constant-velocity portions of an assessment (29, 69). For TTPT (milliseconds (ms)), data included the entire acceleration period for the limb/dynamometer lever-arm system. For APT (°), data were for the angular position of the knee rather than the dynamometer lever-arm. For MPT (Nm), data were for the average peak torque across the five measured trials. Pilot work with male and female agility-sport athletes established the intra-rater, between-day, test-retest reliability for all variables (Table 2).

Table 2. Intra-rater, between-day, test-retest reliability for all isokinetic variables (*n* =12)

	Knee Extension				**Knee Flexion**			
	PT	TTPT	APT	MPT	PT	TTPT	APT	MPT
ICC	0.98	0.90	0.70	0.98	0.97	0.99	0.99	0.98
SEM	6.0Nm	4.5ms	1.0°	5.6Nm	6.0Nm	7.4ms	1.6°	3.7Nm
MDD	16.7Nm	12.5ms	2.7°	15.4Nm	13.9Nm	20.6ms	4.4°	10.2Nm

PT = peak torque; TTPT = time-to-peak torque; APT = angle of peak torque; MPT = mean peak torque
ICC = intraclass correlation coefficient: ICC (2,1) for PT, TTPT, and APT, and ICC (2,*k*) for MPT
SEM = standard error of measurement; Nm = Newton-metres; ms = milliseconds; ° = degrees
MDD = minimum detectable difference

Statistical Analyses

There were no missing data. Summary statistics were calculated, including 95% confidence intervals. Normality of data was assessed using histogram inspection and Shapiro-Wilk tests.

Inter-variable relationships were assessed with scatterplot inspection, Pearson's correlation (*r*) for normally distributed *y* variables, and Spearman's correlation (r_s) for non-normally distributed *y* variables. Sensitivity analyses were guided by the graphical appearance of data to examine the potential influence of outliers and datapoint clusters on statistical outputs (70). Correlations were defined as weak-to-moderate (0.25-0.50), moderate-to-strong (0.50-0.75), and strong-to-very strong (0.75-1.00) (71). The proportion (%) of variance shared between variables was assessed with the coefficient of determination (r^2/r_s^2) (72). An $r^2/r_s^2 \geq 0.60$ was employed as a threshold for defining a large proportion of shared variance between variables (72, 73). For all analyses, alpha was set *a priori* at 0.05.

RESULTS

All participants were right limb dominant. No participant experienced pain during data collection. There were no adverse events. Summary statistics are presented in Table 3.

Table 3. Summary statistics (*n* =34)

	Knee Extension				Knee Flexion			
	PT (Nm)	TTPT (ms)	APT (°)	MPT (Nm)	PT (Nm)	TTPT (ms)	APT (°)	MPT (Nm)
Minimum	53.3	90.0	36.0	48.5	44.1	90.0	17.0	40.7
Maximum	183.0	140.0	45.0	170.7	149.0	310.0	56.0	144.8
Median	95.6	110.0	41.0	87.0	83.2	230.0	55.0	76.4
95% CI	87.3, 109.0	106.3, 114.9	39.8, 41.1	80.8, 101.7	75.1, 92.6	168.3, 226.4	33.6, 45.8	70.0, 86.3
Mean	98.2	110.6	40.1	91.2	83.6	197.4	39.7	78.3
SD	31.2	12.3	2.0	30	25.1	83.4	17.5	23.3

PT = peak torque; TTPT = time-to-peak torque; APT = angle of peak torque; MPT = mean peak torque
Nm = Newton-metres; ms = milliseconds; ° = degrees
95% CI = 95% confidence interval (lower bound, upper bound); SD = standard deviation

Knee extension PT, APT, and MPT and knee flexion PT and MPT were normally distributed ($p \geq 0.12$). Knee extension TTPT and knee flexion TTPT and APT were not normally distributed ($p \leq 0.04$). Knee flexion TTPT (Figure 3a) and APT (Figure 3b) demonstrated a binomial distribution. Datapoints were reviewed, verified, and retained. There was no pattern for either left or right sides of the knee flexion TTPT or APT histograms. For both histograms, males and females were present on both sides and with comparable ages and SARS levels. For both histograms, more females were present in the right side (*n*=11) than the left side (*n*=5).

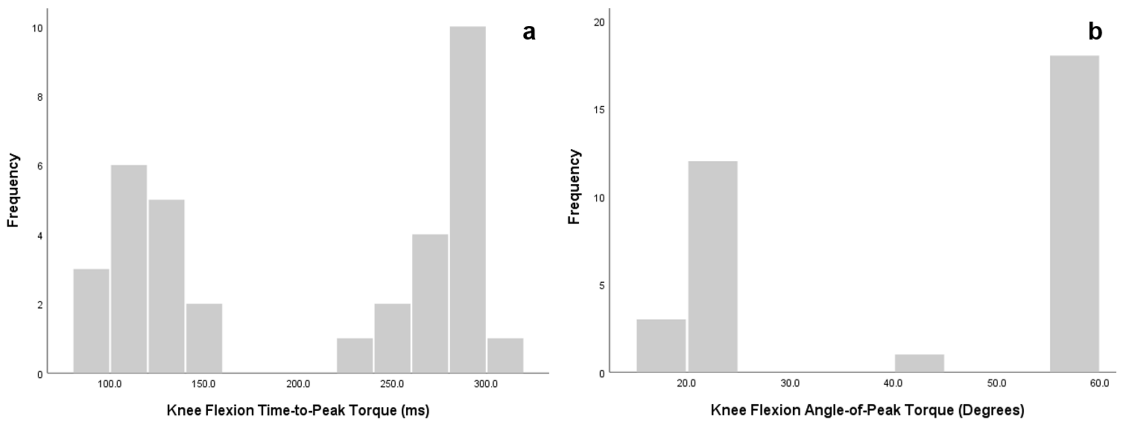

Figure 3. Frequency distribution histograms for knee flexion time-to-peak torque and angle-of-peak torque variables.

ms = milliseconds

Between-variable scatterplots are presented for knee extension in Figure 4 (a-d) and knee flexion in Figure 5 (a-d). Correlation matrices are presented in Table 4 and 5. For most knee extension relationships, correlations were significant, negative, and moderate-to-strong (Table 4). One correlation, between MPT and PT, was significant, positive, and very strong. The proportion of variance for the three significant negative correlations ranged 27-45% and for the significant positive correlation was 98%. For most knee flexion relationships, correlations were non-significant (Table 5). Two correlations were significant, positive, and strong-to-very strong. The proportion of variance for the two significant correlations ranged from 61-98%.

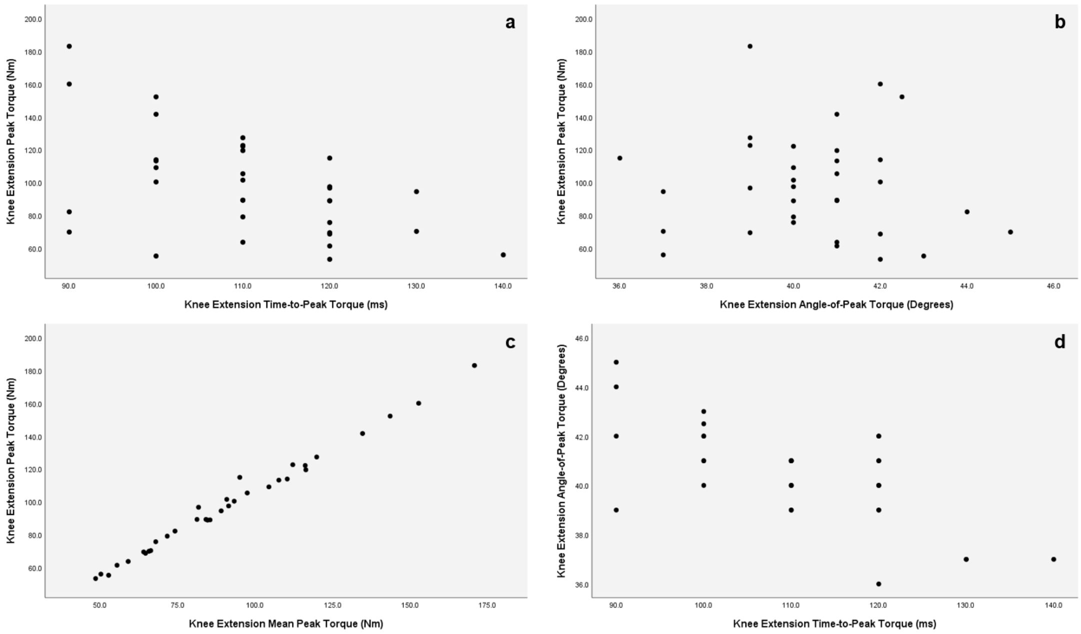

Figure 4. Scatterplots for knee extension isokinetic variables (*n*=34)

ms = milliseconds; Nm = Newton-metres

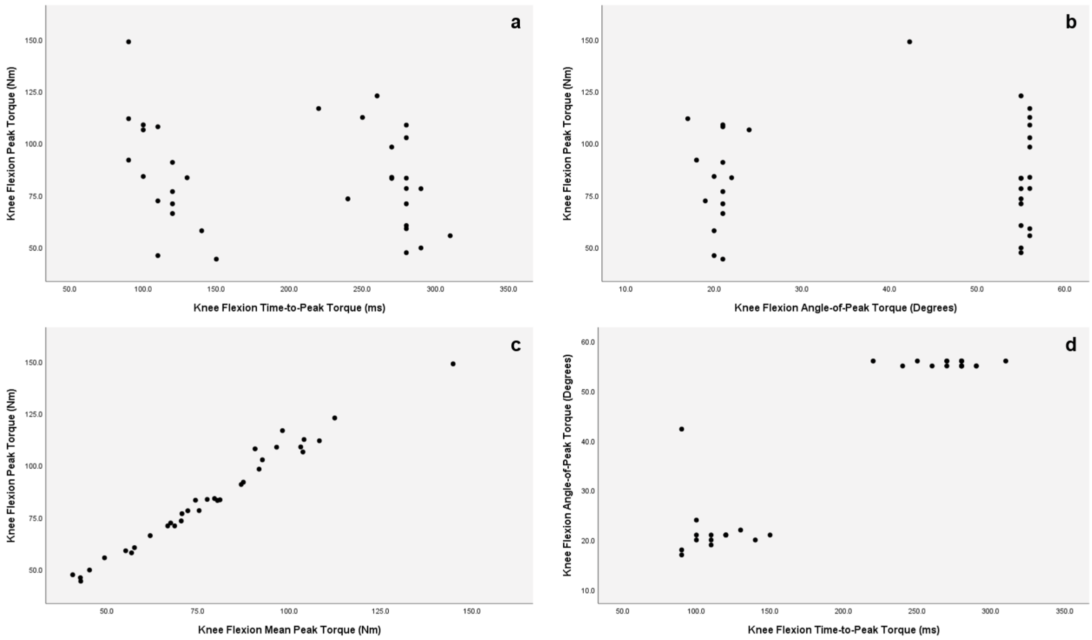

Figure 5. Scatterplots for knee flexion isokinetic variables (*n*=34)

ms = milliseconds; Nm = Newton-metres

Table 4. Knee extension correlation matrix (*n* =34)*

	PT	TTPT	APT	MPT
PT	1.00, 1.00			
TTPT	**-0.52, 0.27 (0.002)**	1.00, 1.00		
APT	-0.08, 0.00 (0.671)	**-0.67, 0.45 (0.001)**	1.00, 1.00	
MPT	**0.99, 0.98 (0.001)**	**-0.54, 0.29 (0.001)**	-0.03, 0.00 (0.867)	1.00, 1.00

PT = peak torque; TTPT = time-to-peak torque; APT = angle of peak torque
MPT = mean peak torque
*cells contain Pearson's correlation coefficient, coefficient of determination (p value)
Significant correlations are in bold text

Table 5. Knee flexion correlation matrix (*n* =34)*

	PT	TTPT	APT	MPT
PT	1.00, 1.00			
TTPT	-0.21, 0.04 (0.242)	1.00, 1.00		
APT	0.04, 0.00 (0.823)	**0.78, 0.61 (0.001)**	1.00, 1.00	
MPT	**0.99, 0.98 (0.001)**	-0.25, 0.06 (0.150)	-0.08, 0.01 (0.671)	1.00, 1.00

PT = peak torque; TTPT = time-to-peak torque; APT = angle of peak torque
MPT = mean peak torque
*cells contain Pearson's correlation coefficient (without underline), coefficient of determination (p value)
*cells contain Spearman's correlation coefficient (with underline), coefficient of determination (p value)
Significant correlations are in bold text

Four sensitivity analyses were conducted for the knee flexion TTPT versus PT data (Figure 5a). First, for the entire left-side cluster alone, a significant statistic was returned (r=−0.73, r^2=0.53, p=0.001). Second, for the left-side cluster without the single outlier above, a significant statistic was returned (r=−0.70, r^2=0.49, p=0.004). Third, for the entire right-side cluster alone, a significant statistic was returned (r=−0.59, r^2=0.35, p=0.001). Fourth, for the right-side cluster without the two outliers to the left, a significant statistic was returned (r=−0.67, r^2=0.45, p=0.004). Therefore, sensitivity analyses returned very different statistical outputs to that for the complete knee flexion TTPT versus PT data (Table 5).

DISCUSSION

The purpose of this study was to examine the correlation between knee extension-flexion variables extracted from a novel isokinetic assessment procedure linked to the mechanism of noncontact knee injury. It was hypothesised there would be no statistically-significant strong correlation between variables. Findings partially support the hypothesis because there was no statistically-significant strong correlation between the majority of knee extension (Table 4) or flexion (Table 5) isokinetic variables. However, there were statistically-significant strong-to-very strong correlations between knee extension MPT and PT (Table 4), knee flexion MPT and PT (Table 5), and knee flexion TTPT and APT (Table 5). Sensitivity analyses revealed the initial statistically non-significant weak correlation between knee flexion TTPT and PT (Table 5) was altered to statistically-significant moderate-to-strong correlations when separate datapoint clusters were considered and outliers were removed.

Direct comparison of the present knee extension and flexion values (Table 3) to other work is not possible because no other group has reported data using the knee isokinetic assessment procedure described here. The alternative, therefore, is to compare the present mean data to that reported for other knee isokinetic studies at $240°\cdot sec^{-1}$ with different participants and different ranges-of-motion (Table 6) (38, 40, 74-80). Compared to the knee extension and flexion PT values in Table 6, the current values are generally similar or higher, respectively (Table 3). The present knee extension and flexion mean TTPT values (Table 3) are shorter than or within the ranges of other work, respectively (Table 6). The present knee extension and flexion mean APT values (Table 3) appear lower than or similar to other work, respectively (Table 6). Compared to the knee extension and flexion MPT values in Table 6, the current values are generally similar or higher, respectively (Table 3).

Table 6. Selected output variables from knee isokinetic studies performed at 240°·sec^{-1}

Knee Extension

Authors	Participants	ROM (°)	PT (Nm)	TTPT (ms)	APT (°)	MPT (Nm)
Bračič et al., 2011	Professional male athletes	5-90	–	120.0-155.0	53.0-64.0	–
Dibrezzo et al., 1988	Healthy females	Unspecified	–	–	–	71.0-72.2
Greenberger & Paterno 1995	Healthy males and females	Unspecified	–	–	–	97.4-97.8
Huston & Wojtys 1996	Elite male and female athletes	Unspecified	–	153.0-158.0	–	–
Maciel et al., 2020	Sports students	30-90	–	160.4-168.9	–	–
Thompson et al., 1989	Healthy males and females	Unspecified	–	–	43.0-69.3	–
Xaverova et al., 2015	Elite female athletes	10-90	109.6-109.9	–	–	–
Yilmaz & Kabadayi 2019	Amateur male athletes	Unspecified	80.3-88.7	–	–	–
Yilmaz & Kabadayi 2020	Amateur male athletes	0-90	111.3-119.8	–	–	–

Knee Flexion

Authors	Participants	ROM (°)	PT (Nm)	TTPT (ms)	APT (°)	MPT (Nm)
Bračič et al., 2011	Professional male athletes	5-90	–	320.0-350.0	75.0-77.5	–
Dibrezzo et al., 1988	Healthy females	Unspecified	–	–	–	45.0-47.2
Huston & Wojtys 1996	Elite male and female athletes	Unspecified	–	150.0-169.0	–	–
Maciel et al., 2020	Sports students	30-90	–	197.1-227.3	–	–
Thompson et al., 1989	Healthy males and females	Unspecified	–	–	34.4-37.0	–
Xaverova et al., 2015	Elite female athletes	10-90	70.3-71.6	–	–	–
Yilmaz & Kabadayi 2019	Amateur male athletes	Unspecified	49.4-56.4	–	–	–
Yilmaz & Kabadayi 2020	Amateur male athletes	0-90	63.2-65.8	–	–	–

ROM = range-of-motion in which the isokinetic procedure was performed (0° represents 0° knee extension)
PT = peak torque; TTPT = time-to-peak torque; APT = angle of peak torque; MPT = mean peak torque
° = degrees; Nm = Newton-metres; ms = milliseconds

Direct comparison of the present knee extension and flexion inter-variable correlations (Table 4 and 5) to other work is also not possible because no other group has performed such correlations using the knee isokinetic assessment configuration described here. The alternative, therefore, is also to compare the present inter-variable correlations to other knee isokinetic studies with different participants, ranges-of-motion, and velocities. For knee extension PT and TTPT, statistically-significant correlations of r=−0.50 (9-10 year old boys, 0-90°, 180°·sec^{-1}) (43) and r=−0.54 (university male/female athletes, 0-90°, 180°·sec^{-1}) (44) have been reported. For knee flexion PT and TTPT, no statistically-significant inter-variable correlations are evident (43). For knee extension PT and APT, no statistically-significant inter-variable correlations are evident (42). For knee flexion PT and APT, statistically-significant correlations of r=−0.24-−0.47 (healthy males/females, 0-90°, 60°·sec^{-1}) (42) and r=−0.23-−0.39 (healthy males/females, 0-90°, 180°·sec^{-1}) (42) have been reported. As for the present findings (Table 4 and 5), the studies just cited and the inter-variable correlations therein are consistently statistically non-significant or statistically-significant with only weak-to-moderate relationships.

Interpretation of the size and relevance of correlation coefficients can alter according to a study's context and the coefficient of determination is useful for indicating the proportion (%) of variance in one variable shared by another variable (71, 72). Together, correlation and the coefficient of determination are used to examine whether one variable captures similar or different aspects of neuromuscular performance compared to another variable (73, 81). Of the knee extension statistically-significant correlations (Table 4), only MPT and PT shared a large proportion of variance (98%). The present data indicate that knee extension MPT and PT capture highly similar aspects of neuromuscular performance, and only one need be used to represent knee extension isokinetic maximal strength. Of the knee flexion statistically-significant correlations (Table 5), MPT versus PT and TTPT versus APT shared large proportions of variance (98% and 61%, respectively). Knee flexion MPT and PT also capture highly similar aspects of neuromuscular performance, and only one need be used to represent knee flexion isokinetic maximal strength. Knee flexion TTPT and APT appear to capture similar aspects of neuromuscular performance, and researchers can clinically-reason which is preferred for a specific study context. The majority of knee extension and flexion inter-variable correlations examined in this study were either statistically non-significant or statistically-significant with only weak-to-moderate relationships (Table 4 and 5). Therefore, the majority of variables appear to represent distinct knee neuromuscular characteristics. Researchers should clinically-reason meticulously why a particular variable might be important in noncontact knee injury prevention screening.

Unexpected findings included two separate datapoint clusters for the knee flexion data (Figure 5a/5b/5d). Sensitivity analyses for the knee flexion TTPT versus PT data (Figure 5a) revealed statistically-significant, negative, moderate-to-strong correlations; for both clusters, as the time required to generate peak torque increased, peak torque (maximal strength) decreased. For knee flexion TTPT versus APT (Figure 5d), a statistically-significant, positive, strong-to-very strong correlation existed (Table 5); this is logical given higher angles-of-peak torque require longer timeframes for the knee to acquire such angles from the 0° starting position. The two datapoint clusters (Figure 5a, 5d) indicate some participants were capable of generating knee flexion PT rapidly (<150ms, Figure 5a, left-side cluster) at low knee flexion angles (<45°, Figure 5d, left-side cluster), but others were not (Figure 5a, 5d, right-side cluster). Such findings are clinically-important because rapid force generation by the knee muscles is critical for restoring knee joint alignment following external perturbations (37, 48, 49), because the knee flexors become effective at resisting knee abduction, IR, and ATD perturbations between 0-45° knee flexion (50-52), and because the angle at which noncontact knee injury occurs is commonly <50° knee flexion (12, 13, 61). Therefore, it is plausible that athletes who require longer timeframes to generate knee flexor PT at higher knee flexion angles (e.g., Figure 5a/5d, right-side cluster) may be more predisposed to noncontact knee injury.

Potential limitations include not performing analyses also using the nondominant limb. Such analyses were not performed because there is no statistically-significant between-limb difference for dominant and nondominant knee isokinetic muscle performance (82). Potential limitations also include not performing analyses using data collected using eccentric muscle actions. Eccentric muscle actions were not employed here because previous work reported knee isokinetic eccentric muscle performance assessments demonstrate poor reliability and substantial measurement error, particularly at medium-to-high velocities (83, 84). The findings of this study are only generaliseable to amateur adult agility-sport athletes participating in Level I-II sports (57). Future research should replicate this study's design with professional adult agility-sport athletes. Future research should also employ the novel knee isokinetic assessment procedure described here within prospective studies designed to examine the utility of injury prevention screening procedures for identifying athletes' predisposition for noncontact knee injury. Emphasis could include the role of knee flexion TTPT and APT variables.

CONCLUSION

The novel knee isokinetic assessment procedure used in this study was safely employed with amateur adult agility-sport athletes. The majority of inter-variable correlations were either statistically non-significant or statistically-significant with weak-to-moderate relationships. For both knee extension and flexion, MPT and PT were significantly and strongly correlated. For both knee extension and knee flexion, only MPT or PT need be used to represent isokinetic maximal strength. Graphical analyses revealed two datapoint clusters for knee flexion TTPT and APT. One cluster indicated some participants could generate knee flexor PT rapidly at low knee flexion angles, the other cluster indicated that other participants could not. Sensitivity analyses for TTPT versus PT revealed statistically-significant moderate-to-strong correlations for each cluster, although the proportion of shared variance was not high for either cluster. Findings indicate that most isokinetic variables used in this study represent distinct knee neuromuscular characteristics. Knee flexion TTPT and APT may have utility to help discriminate between athletes with and without an increased predisposition for noncontact knee ligament injury. The new findings from this study will inform researchers' clinical-reasoning regarding the specificity of knee isokinetic assessments. The findings will also support researchers' choices for isokinetic variables used in prospective studies examining noncontact knee injury prevention screening with amateur adult agility-sport athletes.

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