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QUANTIFICATION OF ECCENTRIC HAMSTRINGS STRENGTH IN ELITE ACADEMY FOOTBALLERS: CONSIDERATIONS FOR ASSESSMENT

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Abstract Quantification of eccentric hamstring strength within elite youth sporting populations is a contemporary issue within practice. The aim of the study was to identify the reliability of eccentric strength metrics obtained via isokinetic dynamometry (IKD) and the NordBord in an elite youth football population. Furthermore, relationships between the strength metrics exhibited by the two devices were observed, to ascertain whether level of performance on one device can indicate how athletes will perform on the other. Twenty-one elite academy footballers completed two measures of eccentric hamstring strength on each device ($60°\cdot s^{-1}$ and $180°\cdot s^{-1}$). Test-retest reliability was determined through Pearson correlation analysis. Relationships between strength metrics (IKD: PT, AvT and oPT at $60°\cdot s^{-1}$ and $180°\cdot s^{-1}$; NordBord: PF, AvF, PT, AvT, ϴ) obtained on both devices were identified for analysis. Test-retest of both devices identified significant correlations for all eccentric strength metrics ($P = \leq 0.05$). Significant unilateral (L) relationships between PT, AvT (IKD $60°\cdot s^{-1}$; $180°\cdot s^{-1}$), break angle (ϴ) (NordBord) angle peak torque (oPT) at $60°\cdot s^{-1}$ and ϴ were identified ($P = \leq 0.05$). Eccentric hamstring strength analysis on both the IKD and NordBord provide reliable information for practitioners, justifying their inclusion as one factor that may inform readiness to train and injury risk, within elite youth footballers. Although, careful consideration in relation to individual metrics must be given when informing decision making processes. Practitioners require clarity on the objectives of the assessment, what the strength metrics represent and how they provide insight into performance and injury risk.

Keywords screening, injury risk, performance, muscle assessment

Introduction

Quantification of eccentric hamstring strength (Ham_{ecc}) is an ongoing contemporary debate between academics and practitioners, due to the influence of the hamstring on knee function and the incidence of hamstring injuries within the modern game (Rhodes et al., 2020a; Chebbi, Chamari, Van Dyk, Gabbett, Tabben, 2020). Hamstring strain injuries (HSI) account for 12% of all injuries documented in professional football and represented 37% of all muscle injuries sustained (Ekstrand, Hägglund, Walden, 2011). On average 21.8% of all players sustain at least one hamstring injury during a given season with a football team with 25 players typically suffering 5–7 HSI each season, equivalent to between 80–90 days lost due to injury (Ekstrand, Walden, Hägglund, 2016). Representing a significant financial loss for clubs and potentially a large impact on team performance (Hägglund, Walden, Ekstrand, 2013). These patterns of injury are consistent across elite academy footballers, inhibiting player development (Read, Oliver, Croix, Myer, Lloyd, 2017). Interestingly, literature reports that approximately one-third of HSI recur; with the highest risk for injury recurrence being within the first two weeks of return to sport (Sherry, Best, 2004; Dalton, Kerr, Dompier, 2015). This high recurrence rate could potentially be attributed to how practitioners quantify injury risk, an athlete's progression through rehabilitation or a premature return to sport. The consequences of recurrence are high with recurrent hamstring strains being shown to result in significantly more time lost than the first incidence (Erickson, Sherry, 2017).

Reduced eccentric strength has been shown to correlate with an increased risk of injury with significant strength reductions post injury (Vicens-Bordas et al., 2020). It is widely accepted that eccentric training should be incorporated in an uninjured footballer's schedule, to develop eccentric strength of the hamstrings and to reduce HSI risk (Grieg, 2008; Opar, Piatkowski, Williams, Shield, 2013; Rhodes, McNaughton, Greig, 2018). This extends to the integration of its use within rehabilitation programmes post injury in footballers (Tyler, Schmitt, Nicholas, McHugh, 2017). Contemporary debate exists between sports performance practitioners within elite sport settings as to which metrics should be used to quantify functional strength and the optimum technology to obtain such information.

Eccentric strength is often quantified in practice through; peak force (PF), average force (AvF), peak torque (PT), average torque (AvT), angle of PT (°PT) and break angle (⊖) with variations described across literature (Rhodes et al., 2018; Rhodes, Alexander, Greig, 2020b). These metrics are utilised to inform practitioners and athletes of the functional strength profile of the musculature, also providing insight into muscle architecture (Opar et al., 2013; Rhodes et al., 2020b). Thus, informing injury risk reduction strategies, conditioning, and periodisation of training. Isokinetic and NordBord testing can both be used to quantify these metrics, with literature citing isokinetics as the gold standard (Hazdic, Sattler, Markovic, Veselko, Dervisevic, 2010). Although, the high cost, lack of portability and time-consuming assessment process in a time pressured environment causes barriers to its widespread use, for example when quantifying functional strength measures to inform readiness to train/play (Hazdic et al., 2010; Opar et al., 2013). The NordBord (Vald Performance) as an alternative is a portable, quick assessment tool that allows analysis of large groups, quickly and efficiently providing information on the same functional strength parameters (Timmins et al., 2015). That said, questions have been raised with regards the functionality of the contemporary assessment tools available on the market, querying the testing position (Aagaard et al., 1998; Croisier et al., 2002; Brockett et al., 2004). Traditionally the hamstrings assessment in the IKD is performed in a seated hip flexion position in comparison to the kneeling hip neutral position of the NordBord test. Importantly, the knee position in both devices presents similarity. Ensuring range through which the hamstrings are loaded remains consistent in both tests. Literature currently fails to examine any relationships between metrics exhibited on each device, nor does it provide any indication that a level of performance on one device, equates to the same on another.

Consideration should not be focussed on the nature of the test, but information the test provides, with the aim to provide an accurate insight into function (Greig, 2008). Consensus throughout literature highlights the importance of eccentric strength and its reduction in injury occurrence, injury risk and increased performance (Greig, 2008; Opar et al., 2013; Rhodes et al., 2018). Highlighting the importance of quantification. Consequently, there is a lack of research in elite youth populations in relation to isokinetic and eccentric hamstring strength assessment utilising both the IKD and NordBord. Although, both devices are heavily utilised in elite performance environments, the reliability of these devices in elite youth populations is not well described (Wiesinger, Gressenbauer, Kösters, Schardinger, Müller, 2020). Clarity is required with regards any similarity of the range of metrics obtained between the two devices, reliability of measures in an elite academy setting, relevance of the speed of testing and interpretation of this information in practice. Literature assessing the similarities between both pieces of equipment is limited to one known study (Wiesinger et al., 2020). They describe the similarities between measures and resultant surface electromyography (sEMG) activity when performing the tests of the hamstrings and surrounding musculature. Concluding weak relationships between PT measures on the Isokinetic Dynamometer (IKD) and NordBord (Vald Performance), greater muscle activity on the IKD and hip angle influencing the PT output or °PT when performing testing on either device (Wiesinger et al., 2020). Indicating a need to standardise hip position within both tests. Limitations of this work were attributed to its sole focus on two strength parameters (PT and °PT) alongside sEMG measures, restricting the practical interpretation of the results and link to injury mechanisms (Rhodes et al., 2018). In addition to this the discussion regarding the variation in speed of test and its significance was not acknowledged. Previous literature has failed to consider variation in testing speed and isolated to a single testing velocity, limiting the interpretation of data in relation to injury mechanisms (Dvir, 1991; Ayala, De Ste Croix, Sainz de Baranda, Santonja, 2012). Recent evidence however has shown significant effects of testing speed particularly within elite sporting populations advocating its use (Greig, 2008; Rhodes et al., 2018; Rhodes et al., 2020b).

Clarity of the mechanical output quantifying the functional eccentric strength of the hamstrings via the IKD and NordBord is required. Whereby similar metrics are obtainable on both devices, direct comparison is beneficial and required to inform practitioners of their use in an elite environment. Further, highlighting how an athlete performs on one device will not equate to the same level of performance on the other. Providing insight into these measures on both devices will guide injury risk reduction strategies and their use in quantifying progression within rehabilitation. The aim of the present study is to determine the reliability the measures obtained on the IKD and NordBord in elite academy footballers and establish any relationships between these metrics to indicate whether measures are transferrable guiding their use in an applied environment.

Material and Methods

Participants

Twenty-one elite youth footballers from a Premier League Category 1 Academy completed the present study, age 17.63 ±0.76 years; height 180.2 ±6.1 cm; body mass 72.5 ±9.9 kg. All players were in full training, free from injury and available for competitive selection. Any player who had returned from injury within two months leading to the study were not included. All participants provided written informed consent in accordance with department and faculty research ethics committees (STEMH), and in accordance with the Helsinki Declaration.

Experimental Design

Participants were required to complete familiarisation trials consistent with the testing procedure on the Biodex IKD (System 3, Biodex Medical Systems, Shirley, NY, USA) and NordBord (VALD Performance, Newstead, Queensland Australia) seven days prior to testing to negate potential learning effects (Hinman, 2000). All participants involved in the studies completed all testing between 13:00 and 17:00 hrs to account for the effects of circadian rhythm (Sedliak, Haverinen, Hakkinen, 2011) and in accordance with regular training and competition times. Participants performed an identical warm up protocol before testing on each piece of equipment. This was led by the clubs Sports Science staff and consisted of a 10-minute of supervised stationary cycling 1.5 W kg^{-1}, cadence of 60 rpm on a cycle ergometer (Wattbike Ltd, Nottingham, UK). Followed by 10 full weight bearing bilateral squats, 10 unilateral left and right lunges, finishing with a dynamic hamstring stretching routine.

All players completed the strength testing across the two devices over 4 testing sessions, with 72 hrs between each bout of testing session, alternating between the NordBord and IKD respectively.

Eccentric Hamstring Strength

Data collection on the IKD (System 3, Biodex Medical Systems, Shirley, NY, USA) consisted of 2 × 3 repetitions of Ham_{ecc} work, which was followed by passive movement back into knee flexion guided by the IKD at $10°·s^{-1}$. Each subject completed a unilateral isokinetic eccentric protocol on each limb, where dominant leg as defined as preferred kicking leg (van Melick et al., 2017) was carried out first. Gravity-corrected PT, AvT and ^{o}PT of the knee flexors were assessed at $60°·s^{-1}$ and $180°·s^{-1}$. Gravity correction was taken by weighing the athlete's limb weight on the IKD. Three repetitions were performed on each limb at each speed allowing 10 seconds recovery between efforts and a 2-minute recovery between sets (Greig, 2008). The IKD setup was modified to be subject specific following the manufacturer's guidelines and maintained throughout the exercise protocol. Participants were secured in a seated position consistent with previous approaches (Askling, Karlsson, Thorstensson, 2003; Greig, 2008; Rhodes et al., 2018). Restraints were applied across the thigh, proximal to the knee joint so as not to restrict movement, shoulders and chest (Rhodes et al., 2018). The crank axis was aligned with the axis of rotation of the knee joint, and the cuff of the IKD lever arm was secured at the ankle, proximal to the malleoli. Range of motion (ROM) was pre-set from full knee extension to a 95° range of knee flexion (Greig, 2008). The order of speeds performed was in line with recommendations that IKD protocols should be progress from slower to faster speeds (Wilhite et al., 1992). Verbal encouragement was provided consistently throughout the testing process as this replicated the encouragement they traditionally receive during performance (Knicker, Renshaw, Oldham, Cairns, 2011; Wiesinger et al., 2020).

Each subject performed three trials of NHE lowers on the NordBord. Each trial was recorded from the sagittal plane using a Canon XA35 camera at 50 Hz. The camera was placed on a fixed stand set 3 m away and 0.5 m from the floor (Rhodes et al., 2020a). Each participants' ϴ (lowest, closest to the floor) was calculated by using reflective markers placed on the skin of the anatomical landmarks previously set with the best repetition used for the purpose of the research (Rhodes et al., 2020a), which included; right greater trochanter, lateral femoral condyle, and lateral malleolus (Lee, Mok, Chan, Yung, Chan, 2017). Minimal clothing was recommended to avoid movement of markers. Participants were positioned on the NordBord replicating previous study protocols (Timmins et al., 2015; Bourne et al., 2017). Participants knelt on the padded section of the NordBord with each ankle secured superior to the lateral malleolus by individual braces. Participants were instructed to gradually lean forward at the slowest possible speed, from the upright position (90° knee flexion) maximally resisting this movement with both limbs, while holding their trunk and hips in a neutral position throughout, with their hands across their chest (Buchheit et al., 2016). Performance of the Nordic exercise was completed at –20 to –40°·s^{-1} in line with previous work (Opar et al., 2013; Wiesinger et al., 2020). Failure to perform at this speed resulted in repeated trials. Individual's knee position on the NordBord was recorded using the integrated knee position guides with the ankle restraints at 90°, 2 cm superior to the lateral malleolus to ensure the body position remain consistent between tests. The NHE completed on the NordBord was analysed using a variation of the motion analysis protocol adopted from previous studies (Rhodes et al., 2020a). Video clips were digitized and transformed into a two-dimensional space using motion analysis application software (IOS Nordics Application). Ө was ascertained by utilising the break point frame in the application. The three markers were placed on the reflective markers on the anatomical landmarks of 1) lateral malleolus; 2) lateral femoral condyle and 3) greater trochanter.

Data Analysis

IKD gravity corrected torque-angle curve was analysed for both testing speeds, with analysis restricted to the isokinetic phase. The repetition eliciting the highest peak torque was identified for subsequent analysis. Peak torque (PT), the corresponding angle (°PT), and the average torque across the isokinetic phase (AvT) were identified for each player, at each testing speed (Greig, 2008; Rhodes et al., 2018). NordBord strength metrics of peak force (PF), average force (AvF), peak torque (PT) and average torque (AvT) were determined utilising Vald Performance LTD IOS Application NordBord Hamstring Testing System ver. 1.1.2. Break angle (Ө) was determined by identifying the largest angle produced within the 3 repetitions individually for each player.

Statistical Analysis

Data is presented as mean ± SD and 95% confidence limits. Statistical significance was set at $P \leq 0.05$. Statistical analysis was performed using SPSS (V26, SPSS Inc, Chicago, IL). Pearson's correlation coefficients (r) were calculated to quantify the test-retest relationship and the linear relationship between IKD and NordBord profiles. Further correlation coefficient (r) analysis was completed to quantify the linear relationship between strength metrics from the IKD at both testing speeds (60°·s^{-1} and 180°·s^{-1}) and NordBord strength parameters. Coefficient of correlation (r) and respective level of significance (p value) describes total variance. The following criteria quantified magnitude of the correlation <0.1, trivial; >0.1 to 0.3, small; >0.3 to 0.5, moderate; >0.5 to 0.7, large; >0.7 to 0.9, very large; and >0.9 to 1.0, almost perfect (Mukaka, 2012).

Results

Tables 1 and 2 summarise the mean ± standard deviation scores achieved for the test-retest of the IKD and NordBord respectively, representing a plethora of strength metrics observed on each device.

Table 1. Displaying mean and standard deviation scores for test-retest of IKD strength metrics at 60 o/s^{-1} and 180 o/s^{-1}

Speed °/s^{-1}	Week 1						Week 2					
	PT (L)	PT (R)	AvT (L)	AvT (R)	°PT (L)	°PT (R)	PT (L)	PT (R)	AvT (L)	AvT (R)	°PT (L)	°PT (R)
60	153.01 ±15.10	158.69 ±14.37	116.57 ±15.13	120.20 ±14.63	48.07 ±10.46	45.86 ±11.51	155.30 ±14.05	160.36 ±19.90	119.28 ±14.13	118.83 ±11.81	48.09 ±10.27	45.27 ±11.56
180	126.61 ±21.91	129.23 ±19.885	109.85 ±15.71	106.36 ±18.50	55.83 ±13.26	61.03 ±11.20	128.34 ±20.05	127.54 ±19.579	110.85 ±18.93	106.01 ±17.13	54.54 ±13.15	57.50 ±14.17

Table 2. Displaying mean and standard deviation scores for test-retest of NordBord strength metrics

	Week 1									Week 2								
	PT (L)	PT (R)	AvT (L)	AvT (R)	PF (L)	PF (R)	AvF (L)	AvF (R)	Break Angle	PT (L)	PT (R)	AvT (L)	AvT (R)	PF (L)	PF (R)	AvF (L)	AvF (R)	Break Angle
N	150.4 ±33.36	157.98 ±35.45	141.77 ±35.49	147.4 ±36.23	380.4 ±53.65	400.2 ±59.31	356.5 ±60.34	371.3 ±63.20	38.5 ±8.87	149.55 ±34.53	155.57 ±33.93	134.74 ±31.58	142.74 ±32.44	377.1 ±62.91	397.6 ±57.50	344.1 ±63.04	366.8 ±63.39	38.18 ±8.28

Statistically significant correlation coefficients were displayed for all metrics on both the IKD and NordBord. *IKD*: PT (L) 60°·s^{-1}: r = 0.878, p = 0.000, CI = 0.724–0.943; PT (R) 60°·s^{-1}; r = 0.923, p = ≤0.001, CI = 0.839–0.972; PT (L) 180°·s^{-1}: r = 0.881, p = ≤0.001, CI = 0.650–0.976; PT (R) 180°·s^{-1}: 0.880, p ≤ 0.001, CI = 0.763–0.955; AvT (L) 60°·s^{-1}: r = 0.878, p = ≤0.001, CI = 0.724–0.943; AvT (R) 60°·s^{-1}: r = 0.911, p = ≤0.001, CI = 0.729–0.973; AvT (L) 180°·s^{-1}: r = 0.874, p = ≤0.001, CI = 0.652–0.970; AvT (R) 180°·s^{-1}: r = 0.881, p = ≤0.001, CI = 0.746–0.970; °PT (L) 60°·s^{-1}: r = 0.878, p = ≤0.001, CI = 0.724–0.943; °PT (R) 60°·s^{-1}: r = 0.914, p ≤ 0.001, CI = 0.836–0.974; °PT (L) 180°·s^{-1}: r = 0.899, p = ≤0.001, CI = 0.797–0.967; °PT (R) 180°·s^{-1}: r = 0.896, p = ≤0.001, CI = 0.745–0.962. NordBord: PF (L): r = 0.906, p = ≤0.001, CI = 0.798–0.962; PF (R): r = 0.792, p = ≤0.001, CI = 0.571–0.924; PT (L): r = 0.763, p = ≤0.001, CI = 0.510–0.946; PT (R): r = 0.603, p = ≤0.001, CI = 0.285–0.876; AvF (L): r = 0.891, p = ≤0.001, CI = 0.762–0.957; AvF (R): r = 0.852, p = ≤0.001, CI = 0.688–0.938; AvT (L): r = 0.575, p = 0.013, CI = 0.246–0.839; AvT (R): r = 0.557, p = 0.016, CI = 0.220–0.820; ϴ – r = 0.922, p = ≤0.001, CI = 0.820–0.953.

Further correlation coefficient analysis of the NordBord and IKD metrics to examine relationships between the two devices predominantly displayed no significant correlations between any of the strength metrics taken (p > 0.05).

Table 3. Displaying Correlations for all Eccentric Strength Metrics Obtained on the NordBord against the IKD

Specification	PF (L)	PF (R)	PT (L)	PT (R)	AvF (L)	AvF (R)	AvT (L)	AvT (R)	Break Angle
1	2	3	4	5	6	7	8	9	10
PT (L) 60°·s^{-1}	r = 0.256, p = 0.338, CI = –0.247–0.702	r = 0.079, p = 0.773, CI = –0.438–0.562	r = –0.006, p = 0.982, CI = –0.541–0.626	r = –0.150, p = 0.580, CI = –0.629–0.486	r = 0.055, p = 0.838, CI = –0.521–0.638	r = –0.013, p = 0.961, CI = –0.566–0.528	r = –0.102, p = 0.707, CI = –0.625–0.586	r = –0.169, p = 0.531, CI = –0.684–0.516	r = –0.555, p = 0.026, CI = –0.790–0.260*
PT (R) 60°·s^{-1}	r = 0.260, p = 0.331, CI = –0.177–0.674	r = 0.237, p = 0.377, CI = –0.172–0.572	r = 0.168, p = 0.533, CI = –0.319–0.712	r = 0.143, p = 0.598, CI = –0.306–0.579	r = 0.153, p = 0.571, CI = –0.265–0.627	r = 0.143, p = 0.597, CI = –0.232–0.544	r = 0.127, p = 0.638, CI = –0.334–0.687	r = 0.073, p = 0.787, CI = –0.360–0.581	r = –0.418, p = 0.107, CI = –0.811–0.071
AvT (L) 60°·s^{-1}	r = 0.291, p = 0.271, CI = –0.193–0.718	r = 0.083, p = 0.761, CI = –0.386–0.551	r = 0.059, p = 0.827, CI = –0.483–0.712	r = –0.110, p = 0.684, CI = –0.583–0.535	r = 0.106, p = 0.696, CI = –0.440–0.691	r = 0.007, p = 0.981, CI = –0.495–0.535	r = –0.028, p = 0.919, CI = –0.543–0.703	r = –0.130, p = 0.632, CI = –0.633–0.565	r = –0.551, p = 0.027, CI = –0.808–(–0.242)*
AvT (R) 60°·s^{-1}	r = 0.400, p = 0.125, CI = 0.062–0.748	r = 0.379, p = 0.148, CI = 0.038–0.641	r = 0.295, p = 0.267, CI = –0.116–0.716	r = 0.269, p = 0.314, CI = –0.161–0.614	r = 0.329, p = 0.214, CI = –0.003–0.708	r = 0.312, p = 0.240, CI = –0.022–0.604	r = 0.279, p = 0.295, CI = –0.124–0.727	r = 0.220, p = 0.412, CI = –0.232–0.607	r = –0.214, p = 0.426, CI = –0.777–0.329
PT (L) 180°·s^{-1}	r = 0.242, p = 0.367, CI = –0.219–0.652	r = 0.110, p = 0.686, CI = –0.386–0.630	r = 0.055, p = 0.841, CI = –0.517–0.706	r = –0.036, p = 0.896, CI = –0.613–0.737	r = 0.102, p = 0.707, CI = –0.426–0.652	r = 0.071, p = 0.793, CI = –0.481–0.637	r = –0.004, p = 0.987, CI = –0.589–0.713	r = –0.021, p = 0.939, CI = –0.633–0.756	r = –0.593, p = 0.016, CI = –0.817–(–0.286)*

1	2	3	4	5	6	7	8	9	10
PT (R) 180°·s^{-1}	r = 0.278, p = 0.298, CI = –0.258–0.758	r = 0.123, p = 0.650, CI = –0.352–0.681	r = 0.178, p = 0.510, CI = –0.361–0.659	r = 0.034, p = 0.901, CI = –0.425–0.558	r = 0.099, p = 0.716, CI = –0.464–0.600	r = –0.018, p = 0.949, CI = –0.477–0.509	r = 0.062, p = 0.819, CI = –0.447–0.582	r = –0.029, p = 0.916, CI = –0.480–0.479	r = –0.278, p = 0.297, CI = –0.682–0.207
AvT (L) 180°·s^{-1}	r = 0.333, p = 0.208, CI = –0.150–0.739	r = 0.186, p = 0.491, CI = –0.288–0.658	r = 0.214, p = 0.425, CI = –0.433–0.772	r = 0.096, p = 0.724, CI = –0.526–0.745	r = 0.212, p = 0.432, CI = –0.335–0.757	r = 0.167, p = 0.536, CI = –0.386–0.679	r = 0.151, p = 0.577, CI = –0.490–0.770	r = 0.119, p = 0661, CI = –0.509–0.762	r = –0.616, p = 0.011, CI = –0.833–(–0.300)*
AvT (R) 180°·s^{-1}	r = 0.391, p = 0.134, CI = –0.135–0.821	r = 0.284, p = 0.286, CI = –0.192–0.787	r = 0.371, p = 0.157, CI = –0.158–0.776	r = 0.249, p = 0.352, CI = –0.249–0.711	r = 0.249, p = 0.353, CI = –0.324–0.706	r = 0.176, p = 0.514, CI = –0.322–0.681	r = 0.265, p = 0.321, CI = –0.302–0.712	r = 0.200, p = 0.457, CI = –0.295–0.664	r = –0.346, p = 0.190, CI = –0.702–0.179
°PT (L) 60°·s^{-1}	r = –0.235, p = 0.382, CI = –0.699–0.311	r = –0.145, p = 0.591, CI = –0.569–0.296	r = –0.094, p = 0.728, CI = –0.600–0.382	r = 0.008, p = 0.978, CI = –0.427–0.391	r = –0.075, p = 0.783, CI = –0.560–0.460	r = –0.040, p = 0.882, CI = –0.465–0.420	r = 0.012, p = 0.964, CI = –0.498–0.462	r = 0.059, p = 0.828, CI = –0.422–0.461	r = 0.504, p = 0.047, CI = 0.018–0.867*
°PT (R) 60°·s^{-1}	r = –0.375, p = 0.152, CI = –0.755–0.171	r = –0.335, p = 0.205, CI = –0.659–0.150	r = –0.402, p = 0.123, CI = –0.772–(–0.003)	r = –0.354, p = 0.178, CI = –0.665–0.039	r = –0.384, p = 0.142, CI = –0.731–0.019	r = –0.350, p = 0.184, CI = –0.644–0.025	r = –0.433, p = 0.094, CI = –0.755–(–0.092)	r = –0.398, p = 0.127, CI = –0.672–(–0.047)	r = 0.546, p = 0.029, CI = 0.095–0.828*
°PT (L) 180°·s^{-1}	r = –0.343, p = 0.194, CI = –0.754–0.172	r = –0.313, p = 0.238, CI = –0.694–0.227	r = –0.159, p = 0.556, CI = –0.603–0.298	r = –0.132, p = 0.627, CI = –0.555–0.342	r = –0.227, p = 0.398, CI = –0.643–0.294	r = –0.225, p = 0.402, CI = –0.584–0.220	r = –0.114, p = 0.675, CI = –0.548–0.337	r = –0.118, p = 0.663, CI = –0.544–0.353	r = –0.485, p = 0.06, CI = 0.006–0.814
°PT (R) 180°·s^{-1}	r = –0.222, p = 0.409, CI = –0.802–0.487	r = –0.052, p = 0.847, CI = –0.578–0.474	r = –0.045, p = 0.868, CI = –0.605–0.540	r = 0.099, p = 0.716, CI = –0.385–0.535	r = –0.125, p = 0.645, CI = –0.688–0.513	r = –0.004, p = 0.989, CI = –0.507–0.503	r = –0.014, p = 0.958, CI = –0.555–0.529	r = 0.086, p = 0.751, CI = –0.402–0.525	r = –0.327, p = 0.217, CI = –0.161–0.723

* Denotes significance 0.05 level.
Confidence Intervals at 95%.

Statistically significant correlations were identified for NordBord ϴ and PT (L) 60°·s^{-1}: r = –0.555, p = 0.026, CI = –0.790–0.260; NordBord ϴ and AvT (L) 60°·s^{-1}: r = –0.551, p = 0.027, CI = –0.808–(–0.242); Nordbord ϴ and PT (L) 180°·s^{-1}: r = –0.593, p = 0.016, CI = –0.817–(–0.286); AvT (L) 180°·s^{-1}: r = –0.616, p = 0.011 CI = –0.833–(–0.300); NordBord ϴ and °PT (L) 60°·s^{-1}: r = 0.504, p = 0.047, CI = 0.018–0.867; NordBord ϴ and °PT (R) 60°·s^{-1}: r = 0.546, p = 0.029, CI = 0.095–0.828.

Discussion

The aim of the study was to establish the reliability of quantifying Ham_{ecc} in elite youth footballers using the IKD and NordBord. Although the reliability of eccentric strength measures on both devices have been ascertained in an adult sporting population, it is not represented in elite academy footballers, despite the widespread use of these metrics in a practical setting (Greig, 2008; Opar et al., 2013). Additionally, the recent work by Wiesinger et al. (2020) does not consider PF, AvF and ϴ for comparison. This work is also completed in a non-sporting adult population. Further highlighting the need for the present study. The present study analyses the relationships between multiple metrics of PF, PT, AvF, AvT, °PT and ϴ between the IKD and NordBord were quantified. A limitation exhibited in the present work was both testing devices were completed in their traditional positions. However, the focus of the work was to load the hamstrings through similar knee ranges, with replicable start and end ranges in both pieces of testing equipment. The findings in the present study identified that the IKD was shown to have very large to almost perfect correlations across all parameters for the two testing speeds utilised (0.87–0.91). These results are contradictory to previous research, which both reported poor correlations (Dvir, 1991; Ayala et al., 2012) and thus advocate the use of a variety of testing speeds within this population to allow greater association to be made between function and injury mechanisms (Greig, 2008; Rhodes et al., 2018). In contrast, the variation of coefficient of correlation measures obtained for the NordBord in the current study displayed greater variance, contradicting previous research completed in senior elite sports populations reporting large to perfect correlations in PF and AvF values (Opar et al., 2013). Specifically, PF and AvF exhibited large to almost perfect relationships (0.79–0.91), moderate to large correlations (0.56–0.76) and ϴ showing almost perfect correlations (0.92). Interestingly, greater variance in metrics were seen on the right limb for PF and PT, this was also displayed in AvF and AvT, albeit the difference between right and left being smaller. Reasons for this are unclear, however, it is suggested this could potentially be associated with the bilateral nature of the exercise (Opar et al., 2013; Timmins et al., 2015) and the larger group of muscle recruitment required to perform the exercise (Wiesinger et al., 2020). This may highlight deficiencies in elite youth footballers that could contribute to sustaining lower limb injury (Rhodes et al., 2020a). Practitioners and future research should consider electromyographic analysis of the musculature during performance of the test to identify asymmetry.

Correlation analysis of the functional strength metrics across both devices identified significant moderate correlations for °PT (L) and (R) $60°\cdot s^{-1}$ and ϴ (r = 0.50–0.55). Interestingly (L) sided measures of PT and AvT at $60°\cdot s^{-1}$ and $180°\cdot s^{-1}$ highlighted significant negative correlation with ϴ. Suggesting players with greater (L) PT/AvT values at both speeds presented with lower ϴ scores, highlighting a greater range under eccentric tension when performing the NHE. In addition to this, significant moderate correlations were found between °PT (L) and (R) $60°\cdot s^{-1}$ and ϴ. It is important to note that the lower angles attained from measures of °PT and ϴ, both represented values where the knee was in a greater degree of extension, making it more relatable to hamstrings mechanism of injury. The faster speed of $180°\cdot s^{-1}$ did not show any significant relationship between °PT and ϴ, suggesting that strength response changes in response to faster speed exposure. This provides considerations for practitioners when conditioning athletes in relation to specific game play demands and may contribute to the discussion of maximum velocity exposure (Mendiguchia et al., 2020). Caution must be taken with regards the interpretation of these findings. Although, significant correlations were found, in line with previous research (Sconce, Jones, Turner, Comfort, Graham-Smith, 2015), it is important to note these were moderate and further work should consider a larger population of elite youth athletes. Break angle on the NordBord was calculated bilaterally and future work should consider analysis of the relationship between break point angle and the sum (or average) of the left or right limb on the NordBord and IKD. Interpretation of these findings and translation to practice is important. Within this elite youth population, either device could be utilised to determine an individual's functional strength and gain some insight into the muscle architecture. This said, thought must be given to the specific metrics utilised to quantify functional strength, what they represent and how they relate to injury mechanisms and functional performance. Lastly, future work should consider the youth players maturation status, as this may affect physical or predicted outputs in relation to strength assessments.

PF represents the maximum force exerted when performing the NHE, with AvF representing the average force output through range. Research has indicated that PF and AvF are relative to body mass (Buchheit et al., 2016), although higher values of PF and AvF reduce the chance of sustaining hamstring injury (Timmins et al., 2015; Roe et al., 2018). Consequently, any quantification of PF or AvF utilising the NordBord should consider body mass assessment of the athlete (Bucheit et al., 2016). There is limited literature that exists discussing PT and AvT within

NordBord testing. Significantly, IKD research focusses heavily on these two metrics (Greig, 2008; Ayala et al., 2012; Rhodes et al., 2018). PT representing the peak output achieved through range at a given speed and AvT representing a measure of the average exerted in relation to testing speed (Small, McNaughton, Greig, Lovell, 2009). Within the present study, reliability findings associated with the NordBord indicate that reliance on these strength metrics may be questioned. Perhaps providing an insight in to why they are not heavily utilised within literature. It is suggested that these metrics obtained via NordBord testing should not be considered for use in practice within an elite youth sports population. ϴ and °PT provide insight into the muscle architecture of the hamstrings. Detailing muscle length in relation to when it can no longer sustain the force applied or at which point the muscle is exerting its maximal force through the repetition (Greig, 2008), both devices exhibit almost perfect reliability. Thought should be given to the bilateral nature of the NHE, as ϴ represents both (L) and (R) limbs. Alternatively, the IKD provides a unilateral analysis of °PT. Within athletes where asymmetry in function is suspected, for example post injury, practitioners should consider IKD analysis due to its unilateral nature.

Questions in practice have been raised in relation to the functionality of both devices, with literature highlighting the variance of testing speed on the IKD increases its relevance to injury mechanism and performance (Dvir, 1991; Ayala et al., 2012). The importance of the slow and controlled eccentric function of the hamstring during deceleration within performance could provide evidence of the functional relevance of the NordBord device. This exercise is completed in a controlled manner, with the athlete dictating speed of control. PF and AvF may provide greater awareness into an athlete's preparedness for this load during performance. During deceleration movements within performance the musculature has been shown to be under the most force increasing injury risk (Harper, Kiely, 2018). PF potentially provides insight into why greater functional strength outputs are related to lower limb injury occurrence (Timmins et al., 2015). To ensure the functionality of the PF output this must be considered along with ϴ, as it will provide information to where the PF is exerted in relation and links to injury mechanism can be made by practitioners.

It is important to note a singular metric on either device is not enough to draw conclusions on an athlete's functional strength in relation to performance and injury risk. Practical considerations in relation to the reliability of metrics utilised and the time allocated to assess players function must be considered. It is suggested that either device can provide Sports Medicine or Performance practitioners with a clear insight into the athlete's functional strength, when metrics analysed are considered carefully. Practitioners should consider the reliability of metrics within their population, before considering their use.

Relationships between NordBord and IKD strength metrics are limited, with only significant moderate correlations identified between PT and ϴ at $60°·s^{-1}$ and (L) AvT/PT and ϴ at both testing speeds. Eccentric hamstring strength analysis on both the IKD and NordBord provides reliable information for practitioners to evaluate readiness to train and injury risk, within elite youth footballers. Although, careful consideration must be given to the metrics utilised to guide decision making. IKD metrics were identified as being reliable bilaterally across all metrics (PT, AvT and °PT). The unilateral nature of the IKD may be advantageous in practice to draw definitive conclusions into the performance of the isolated limb. Completion of Norbord testing represents a bilateral exercise, where the performance of one limb may affect the output of the contralateral side. This said, NordBord measures of PF and break angle were highlighted as being highly reliable. Consideration must be given to what the strength metrics represent and how this provides insight into performance and injury risk. Eccentric strength analysis and subsequent conclusions drawn should not be made on information provided by isolated metrics. In practical settings it is important to consider reliability measures with the specific population prior to implementing testing protocols.

Practical Implications

1. Utilisation of a range of testing speeds on the IKD are beneficial to assess the functionality of the hamstring and provide the practitioner with valuable information to inform rehabilitation programming and injury risk reduction strategies.

2. °PT ($60°\cdot s^{-1}$) and ϴ display moderate correlations, indicating practitioners can cautiously interpret that young athletes produce similar outputs on each device in relation to these strength metrics. These similarities may be seen due to the slow nature that each of these tests are performed. The reasons for only a moderate correlation, however, may be due to adapted technique performed during a Nordic hamstring curl, that may engage other musculature.

3. The variation of coefficient of correlation measures obtained for youth footballers on the NordBord displayed greater variance. Contradicting previous research completed in senior elite sports populations reporting large to perfect correlations in PF and AvF values.

4. Levels of performance on the IKD do not equate to the same levels of performance on the NordBord. Careful consideration must be given by practitioners to the utilisation of each device in the field, what the device measures and why the test is being performed.

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