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Drop jump neuromuscular performance qualities associated with maximal horizontal deceleration ability in team sport athletes

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ABSTRACT

The purpose of this study was to investigate associations between, and within, drop jump (DJ) neuromuscular performance (NMP) qualities and maximal horizontal deceleration ability. We also compared DJ NMP qualities in "high" versus "low" horizontal deceleration ability athletes. Twenty-nine university athletes performed: (1) DJs on force plates from 20 (DJ20) and 40 cm (DJ40) heights and (2) maximal horizontal deceleration, measured using radar, following a 20 m acceleration. Maximal horizontal deceleration was evaluated using deceleration (HDEC; m·s^{-2}), across the entire deceleration phase and during early and late deceleration sub-phases. Of the DJ variables assessed, DJ20 and DJ40 reactive strength index (RSI) and concentric mean force had the largest correlations with HDEC ($r = -0.54$ to -0.61) and the largest differences between high and low HDEC groups ($d = 1.20$ to 1.40). These correlations were stronger with the early than late HDEC sub-phase ($r = -0.54$ to -0.66 vs. $r = -0.24$ to -0.40). Notably, eccentric mean force in DJ40 had large correlations with both DJ20 and DJ40 concentric mean force ($r = 0.67$ to 0.77), whereas at DJ20 these correlations were small ($r = 0.22$ to 0.40). Similarly, DJ40 eccentric mean force had a much larger difference between the high and low HDEC groups than DJ20 ($d = 1.11$ vs. 0.51). These findings suggest DJ RSI from either height may be used as a proxy for HDEC ability, while DJ kinetic analyses should use a higher height to distinguish those with a better capacity to generate eccentric braking forces under increased eccentric loading demands.

KEYWORDS
Braking; eccentric; concentric; reactive strength; force

HIGHLIGHTS

- Players with greater drop jump reactive strength index (RSI) demonstrated superior horizontal deceleration ability.
- Drop jump RSI had a greater association with the early compared to the late horizontal deceleration sub-phase.
- Of the drop jump kinetic variables examined, concentric mean force had the largest associations with horizontal deceleration ability.

Introduction

Rapid horizontal decelerations occur frequently in team sports competitive match play, and are crucial to successful performance outcomes when sudden changes in velocity are required to successfully evade or pursue opponents (Harper, Carling, & Kiely, 2019). Horizontal deceleration requires players to generate and attenuate large braking forces with each limb during short ground contact times in order to quickly reduce whole body momentum (Dos'Santos, Thomas, Jones, & Comfort, 2017). A larger magnitude of braking force may reduce the time needed to generate the requisite impulse to reduce momentum, in turn enabling horizontal deceleration to be achieved more rapidly. The braking ground reaction force profile associated with deceleration is distinct from that of other modes of running (i.e. horizontal acceleration and maximal velocity sprinting), imposing larger impact peaks and loading rates across very short time periods (Verheul et al., 2019). Consequently, in order to adequately prepare the swing limb for impact and to efficiently apply a high braking force, the neuromuscular system must appropriately coordinate the pre-activation and pre-tension of the ankle, knee and hip extensor musculature prior to ground contact (Colby et al., 2000). Indeed, deficiencies in the ability to rapidly pre-activate the ankle, knee and hip

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extensor muscles prior to ground contact can reduce total leg extensor force capability, thereby diminishing the ability to effectively orientate and apply the high braking impulse required to quickly decelerate whole body momentum (Tirosh & Sparrow, 2005).

The drop jump (DJ) is a movement used in both neuromuscular training and assessment that also requires quick and precise pre-activation of the leg extensors to counteract the impact forces generated during ground contact (Helm, Freyler, Waldvogel, Gollhofer, & Ritzmann, 2019). Furthermore, just as the intensity of horizontal deceleration is accentuated as running velocity increases (Nedergaard, Kersting, & Lake, 2014; Oliva-Lozano, Fortes, Krustrup, & Muyor, 2020), the deceleration demands of the DJ increase with greater drop height, significantly increasing demands for negative work and energy dissipation during the landing ("eccentric") phase of the jump (Kipp, Kiely, Giordanelli, Malloy, & Geiser, 2018; Peng, 2011). Accordingly, there is a greater demand for leg stiffness, which is generated via higher pre-activation of leg extensor muscles prior to ground contact. This pre-contact regulation of leg stiffness enhances reflex potentials and the ability of elastic tissue structures to mechanically "buffer" energy input to muscles and to positively contribute to the subsequent concentric (upward) phase of the DJ (Helm et al., 2019; Werkhausen et al., 2017). However, individuals with inadequate strength and/or neuromuscular skills to effectively attenuate higher impact forces, may adopt joint distribution strategies that result in greater negative work demands and a greater percentage of work being dissipated at the knee (McBride & Nimphius, 2020). Whilst such strategies may reduce exposure to excessive loads and attenuate the risk of injury, they also increase neuromuscular and energetic demands, in turn reducing DJ performance characterised by both reactive strength index (RSI) and leg stiffness (Helm et al., 2019; Kipp et al., 2018; McBride & Nimphius, 2020).

The RSI (jump height divided by ground contact time (GCT)) is a recognised measure of an individual's reactive strength and their ability to counteract high eccentric forces (Young, 1995). It is proposed that in addition to eccentric strength, power and dynamic stability, reactive strength is one of the major neuromuscular performance (NMP) qualities that underpin deceleration ability (Kovacs, Roetert, & Ellenbecker, 2008). Indeed, a speed and agility training programme, with enforced deceleration activities significantly improved RSI (measured during a 40 cm DJ), while this was not observed in a control group performing the same programme but without deceleration activities (Lockie, Schultz, Callaghan, & Jeffriess, 2014). Therefore, greater DJ performance, reflected in higher RSI, is potentially indicative of enhanced capacity to counteract both the high eccentric braking forces generated during the DJ, and also to those abilities associated with rapid horizontal deceleration. Maximal eccentric strength is strongly correlated with DJ RSI (Douglas, Pearson, Ross, & McGuigan, 2020) and has moderate-to-large correlations with horizontal deceleration ability (Graham-Smith, Rumpf, & Jones, 2018; Harper, Jordan, & Kiely, 2021). Accordingly, a better DJ performance might also be associated with superior horizontal deceleration ability. Furthermore, in team sport athletes DJ RSI was strongly associated with both vertical stiffness and maximum velocity during 50 m sprints (Douglas et al., 2020). Additionally, in the study by Douglas et al. (2020) leg stiffness and braking force in the DJ had large correlations with vertical stiffness measured during maximum velocity sprinting, providing evidence that these NMP qualities may also be important to generating and attenuating large ground reaction forces during short GCTs.

In comparison to other modes of running, horizontal decelerations create greater demands for energy absorption and depend less on the spring-like elastic functions typically used to amplify propulsive forces (Roberts & Azizi, 2011). Therefore, it is reasonable to speculate that kinetic variables, such as leg stiffness and eccentric force, which enhance performance during the eccentric (negative work) phase of the DJ (Douglas, Pearson, Ross, & McGuigan, 2018), may have larger associations with maximal horizontal deceleration ability than with commonly reported DJ performance outcomes, such as RSI. Furthermore, these mechanical qualities may be particularly important in team sport athletes capable of producing higher forward momentums (mass × velocity), and in order to decelerate rapidly must therefore also produce and attenuate higher eccentric braking forces.

Despite the apparent parallels between the neuromuscular demands of rapid horizontal deceleration and DJ movement tasks, associations between DJ kinetics and performance outcomes (such as DJ RSI) with horizontal deceleration ability have not been examined. Accordingly, the objectives of this study were to (1) explore potential correlations between DJ NMP variables and horizontal deceleration ability during the entire deceleration phase and during the early and late deceleration sub-phases, (2) compare DJ NMP qualities in athletes with high versus low horizontal deceleration ability, and (3) examine correlations within DJ and horizontal deceleration variables in team sport athletes. Based on previous findings (Douglas et al., 2020; Graham-Smith et al., 2018; Harper et al., 2021; Harper, Cohen, Carling, & Kiely, 2020), it was hypothesised that DJ RSI and concentric mean force would have the largest associations with horizontal deceleration ability, but that DJ concentric mean force would be largely correlated with DJ eccentric mean force, due to previously reported correlations between DJ eccentric phase muscle activity and concentric peak force (McBride, McCaulley, & Cormie, 2008).

Methods

Participants

Twenty-nine University athletes ($n = 23$ male, $n = 6$ female, age: 19.7 ± 1.8 years, height: 1.77 ± 0.09 m, body mass: 73.7 ± 16.4 kg) engaging primarily in team sports (soccer, rugby league, rugby union and netball) volunteered to participate. To be eligible for inclusion in the study all participants had to take part in regular (3 times per week) moderate to high intensity exercise and be familiar with change of direction (COD) movements that involve high intensity accelerations and decelerations. All participants participated in plyometric and resistance training as part of their weekly sports training. Participants were excluded from the study if they had suffered any kind of musculoskeletal injury that had prevented participation in sport or physical activity within the previous 3 months. All testing was conducted in December, which is mid-way through the University competitive sport season. The institutional ethics review committee at University of Central Lancashire granted ethical approval in accordance with the recommendations of the Declaration of Helsinki. All participants received a clear written and verbal explanation of the study, including the benefits and risks of participation, before providing voluntary, informed, written consent.

Experimental design

A cross-sectional research design was used to investigate the associations with DJ NMP and maximal horizontal deceleration ability in team sport athletes. All experimental procedures took place over a 2-week period, in which participants were required to complete 3 testing sessions separated by a recovery interval of at least 48 hours. Participants were asked to refrain from exercise in the 48 hours prior to testing. In the first session all participants had anthropometric measurements taken, completed a 20 m linear sprint, and were familiarised with the protocols of the maximal horizontal deceleration and DJ test protocols. In the second session participants completed the maximal horizontal deceleration test. In the final session participants completed DJ testing. All testing was completed on the same time of the day (9.00am to 12.00pm) on an indoor non-slip vinyl artificial sports surface. All participants wore their own indoor sports trainers during testing. Prior to testing all participants completed the same 15-minute standardised warm-up that included forward and backward jogging, dynamic stretching, and practice of test specific exercises (i.e. horizontal accelerations and decelerations, drop jumps) following a progressive increase in intensity.

Test procedures

Anthropometrics

Standing height was measured to the nearest cm using a stadiometer (Seca 217, Hamburg, Germany), and body mass to the nearest 0.1 kg using electronic weighing scales (Seca, Hamburg, Germany).

Maximal horizontal sprint test

Sprint times were recorded over 20 m distance using timing gates (Witty, Microgate, Bolzano, Italy) set to a height of 0.8 m (Cronin & Templeton, 2008). Times were recorded to the nearest 0.01 s. Each sprint commenced from a stationary split stance position with the front foot positioned 30 cm behind the timing gate to prevent a false trigger. Participants were instructed to initiate their own start with no backward step or "rocking motion" and to sprint as fast as possible. Each participant was allowed two trials interspersed by a passive recovery period of at least a 2-minutes duration. The best 20 m split was used as a "criterion" time in the maximal horizontal deceleration test.

Maximal horizontal deceleration test

Maximal horizontal deceleration ability was assessed using a maximal horizontal acceleration–deceleration ability (ADA) test as described by Harper, Morin, et al. (2020). Briefly, this involved participants sprinting maximally for 20 m before performing a maximal horizontal deceleration. Immediately following the end of the deceleration, players backpedalled to the 20 m line (Figure 1). To ensure the start of the deceleration commenced as close to the 20 m point as possible, any 20 m time that was 5% greater than the best 20 m split time achieved during the horizontal sprint test was considered as an unsuccessful trial. In such cases the participant were asked to repeat the test following a 3–5-minute recovery period. Participants were asked to perform a maximum of five trials, with the mean of the best two trials with the highest average deceleration used for analysis. Instantaneous horizontal velocity was measured throughout the maximal horizontal deceleration test using a radar device (Stalker ATS II, Applied Concepts, Inc., Dallas, TX, USA) sampling at 47 Hz. The

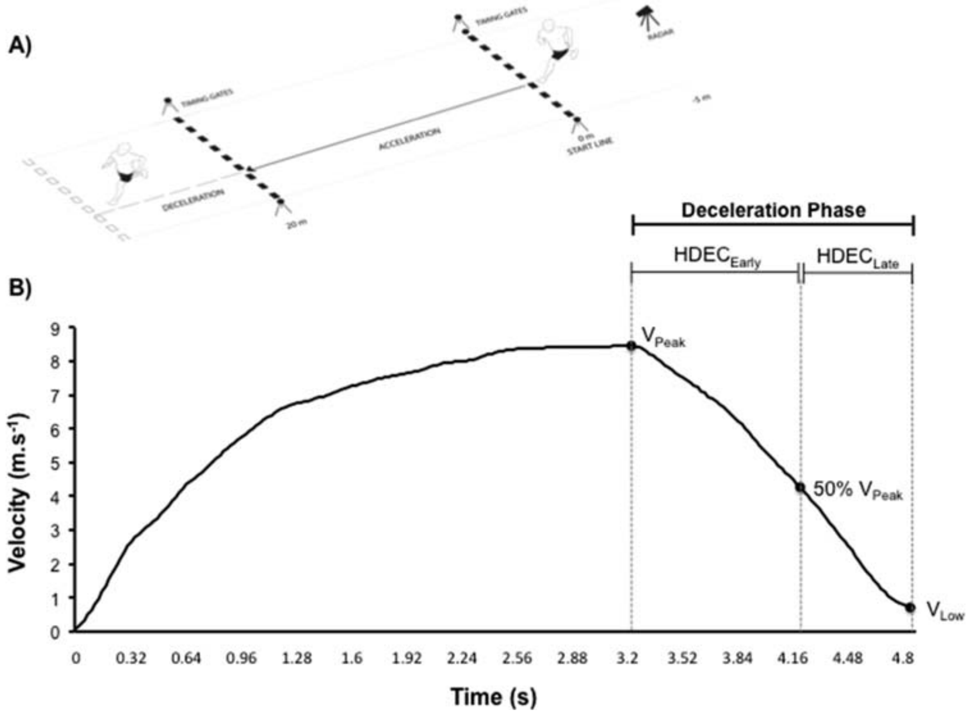

Figure 1. (a) Maximal horizontal deceleration test and (b) example of instantaneous velocity-time profile showing deceleration phase following manual processing with Stalker ATS™ system software. Note: V_{max} = maximum velocity defining start of deceleration phase; 50%V_{max} = 50% of maximal velocity separating early and late deceleration phases; V_{low} = lowest velocity defining end of deceleration phase; $HDEC_{Early}$ = early deceleration phase representing time between V_{max} and 50%V_{max}; $HDEC_{Late}$ = late deceleration phase representing time between 50%V_{max} and V_{low}.

radar device was mounted at a height of 1 m (approximate centre of mass) on a heavy-duty tripod, and positioned 5 m behind the start line.

Maximal horizontal deceleration: radar data analyses

Raw instantaneous velocity-time data captured with the radar was manually processed in the graph mode editor of the Stalker ATS system software (Version 5.0, Applied Concepts, Inc., Dallas, TX, USA) following procedures outlined by Simperingham, Cronin, Pearson, and Ross (2019). Instantaneous horizontal velocity, time and displacement was exported to Microsoft Excel (version 14.6.4, Microsoft, Redmond, DC, USA) for further analyses. The start of the deceleration phase was defined as the time point immediately following the peak velocity (V_{Peak}) achieved during the 20 m sprint. The end of the deceleration phase was defined as the lowest velocity (V_{Low}) following V_{Peak}. The entire deceleration phase was also further divided into early and late deceleration sub-phases using the time point associated with 50% V_{Peak} (Figure 1).

Horizontal deceleration (m·s^{-2}) was calculated using procedures previously outlined by Harper, Morin, et al. (2020) and averaged across the entire deceleration phase and during the early ($HDEC_{Early}$) and late ($HDEC_{Late}$) deceleration sub-phases. The peak instantaneous horizontal deceleration value ($HDEC_{Peak}$) observed across the entire deceleration phase was also obtained. The intra-session reliability for all horizontal deceleration variables was interpreted using criteria proposed by Koo and Li (2016) and McMahon, Suchomel, Lake, and Comfort (2021) and demonstrated good-to-excellent absolute (CV = 4.0–8.4%) and moderate-to-good relative (ICC = 0.60–0.87) reliability.

Drop jump test

Drop jumps were completed bilaterally from box heights of 20 and 40 cm (DJ20 and DJ40) with trials commencing at the lowest drop height. Participants were instructed to perform four maximal DJs interspersed with 30-seconds recovery between trials, and 3–5-minutes between heights. For all DJs participants were instructed to "keep hands on their hips, to step out from the box, and to jump as high and as fast as possible by minimising time on the ground" (Pedley, Lloyd, Read, Moore, & Oliver, 2017). All DJs were performed onto a pair of portable vertical axis force platforms (35 × 35 cm, PASPORT force plate, PS-2141; PASCO Scientific, Roseville CA) that simultaneously sampled at a rate of 1000 Hz. The platforms were positioned 10 cm away from the DJ boxes. To ensure safety of participants during the DJ landing phase, the force platforms were positioned within a heavy-duty foam surround. If participants did not land with both feet positioned on the force plates, or adhere to DJ technical requirements (i.e. there was a clear step down rather than step out), the DJ was ruled invalid, and participants were asked to perform an additional DJ at the end of the series.

Drop jump: force-platform analyses

DJ raw unfiltered vertical ground reaction force data was captured and analysed using commercially available software (Forcedecks, Vald Performance Pty Ltd, Australia). A vertical force threshold of 20N was used to delineate the start and end of ground contact, and the end of the flight phase. Eccentric and concentric phases of ground contact were determined from initial ground contact to zero velocity, and zero velocity to take off, respectively. The DJ NMP variables included: GCT, jump height (calculated using flight time), RSI calculated as jump height (m) divided by GCT (s), eccentric mean force, concentric mean force and leg stiffness calculated using the method by Dalleau, Belli, Viale, Lacour, and Bourdin (2004). Data from the two DJ trials with the highest RSI scores were averaged and used in the analyses. The intra-session reliability for all DJ variables was interpreted using criteria proposed by Koo and Li (2016) and McMahon et al. (2021) and demonstrated good-to-excellent absolute (CV: 2.8–6.2%) and relative (ICC: 0.76–0.97) reliability.

Statistical analysis

Normality of the data was checked using the Shapiro–Wilk's test. To examine relationships between horizontal deceleration abilities and DJ NMP variables, Pearson's (parametric data) or Spearman's (non-parametric data) correlations were calculated using SPSS for Mac (version 20.0; SPSS, Chicago, IL). Correlations were interpreted using the scale from Hopkins (2002) as: trivial (0.00–0.09), small (0.10–0.29), moderate (0.30–0.49), large (0.50–0.69), very large (0.7–0.89) and almost perfect (0.90–0.99).

To further examine differences in DJ NMP qualities, players were dichotomised into high and low HDEC ability groups using a median-split. Independent samples *t*-test (parametric) or Mann–Whitney *U* tests (non-parametric) were used to compare DJ NMP qualities of these two groups. Standardised mean differences (Cohen's *d* effect size) were calculated using an online statistical spreadsheet to evaluate the magnitude of differences between groups (Lakens, 2013), and were interpreted using the scale from Hopkins (2002) as: trivial (0.00–0.19), small (0.20–0.59), moderate (0.60–1.19), large (1.20–1.99), very large (2.0–4.0) and extremely large (>4.0). 90% confidence intervals (90% CI) were calculated for all correlations and effect sizes. Statistical significance was set at $P < .05$.

Results

Associations between horizontal deceleration ability variables

Table 1 reports descriptive statistics (mean ± SD) and correlations between all horizontal deceleration variables. HDEC had 86% shared variance with $HDEC_{Early}$, but only a 46% shared variance with $HDEC_{Late}$. $HDEC_{Late}$ also had a higher shared variance with $HDEC_{Peak}$ ($r^2 =$ 79%) than $HDEC_{Early}$ ($r^2 = 29\%$).

Associations between drop jump neuromuscular performance variables

Table 2 shows the descriptive statistics (mean ± SD) and correlations between all DJ NMP variables. The largest significant correlations with DJ20 and DJ40 RSI were DJ20 ($r = 0.84$) and DJ40 concentric mean force ($r =$ 0.80), respectively. Both DJ20 and DJ40 RSI had moderate correlations with DJ20 and DJ40 eccentric mean force ($r = 0.40$ and 0.46, respectively). DJ20 and DJ40 eccentric mean force had a low-shared variance ($r =$ 0.48, $r^2 = 23\%$). Notably, DJ40 eccentric mean force had a very large significant correlation with both DJ20 ($r =$

Table 1. Descriptive statistics (mean ± SD) and correlations (90% confidence intervals) between all horizontal deceleration variables.

Variable	Mean ± SD	$HDEC_{Peak}$	HDEC	$HDEC_{Early}$
$HDEC_{Peak}$ ($m \cdot s^{-2}$)	−8.54 ± 1.00			
HDEC ($m \cdot s^{-2}$)	−4.50 ± 0.58	**0.74* VL** (0.57; 0.85)		
$HDEC_{Early}$ ($m \cdot s^{-2}$)	−3.92 ± 0.60	**0.54* L** (0.27; 0.73)	**0.93* AP** (0.87; 0.96)	
$HDEC_{Late}$ ($m \cdot s^{-2}$)	−5.67 ± 0.70	**0.89* VL** (0.80; 0.94)	**0.68* L** (0.47; 0.82)	0.40 (0.10; 0.63)

Note: Abbreviations: $HDEC_{Peak}$ = peak horizontal deceleration, HDEC = average horizontal deceleration, $HDEC_{Early}$ = average early phase horizontal deceleration, $HDEC_{Late}$ = average late phase horizontal deceleration, L = large correlation, VL = very large correlation, AP = almost perfect correlation, * = $P < .01$.

Table 2. Descriptive statistics (mean ± SD) and correlation coefficients (± 90% confidence limits) between all drop jump neuromuscular performance variables.

		Drop Jump 20 cm						Drop Jump 40 cm				
Variables	Mean ± SD	CMF	EMF	GCT	JH	RSI	LS	CMF	EMF	GCT	JH	RSI
Drop jump 20 cm												
CMF ($N{\cdot}Kg^{-1}$)	26.33 ± 2.65											
EMF ($N{\cdot}Kg^{-1}$)	26.44 ± 3.55	0.40 (0.10; 0.63)										
GCT (s)	0.25 ± 0.03	**−0.71* VL** (0.25; 0.72)	**−0.70* VL** (0.50; 0.83)									
JH (m)	24.66 ± 5.68	**0.52* L** (0.25; 0.72)	−0.05 (−0.36; 0.27)	0.08 (−0.24; 0.38)								
RSI (m/s)	1.02 ± 0.25	**0.84* VL** (0.72; 0.91)	0.40 (0.10; 0.63)	−0.40 (0.10; 0.63)	**0.84* VL** (0.72; 0.91)							
LS ($kN^{-1}{\cdot}m{\cdot}kg^{-1}$)	0.48 ± 0.10	0.06 (−0.26; 0.37)	−0.36 (−0.60; −0.05)	**0.54* L** (0.27; 0.73)	**0.83* VL** (0.70; 0.91)	0.45 (0.16; 0.67)						
Drop jump 40 cm												
CMF ($N{\cdot}Kg^{-1}$)	27.06 ± 3.27	**0.85* VL** (0.73; 0.92)	0.22 (−0.10; 0.50)	**−0.58* L** (−0.76; −0.33)	0.39 (0.09; 0.63)	**0.66* L** (0.44; 0.81)	0.03 (−0.28; 0.34)					
EMF ($N{\cdot}Kg^{-1}$)	32.69 ± 3.74	**0.64* L** (0.41; 0.79)	0.48 (0.20; 0.69)	**−0.73* VL** (−0.85; −0.54)	−0.04 (−0.35; 0.28)	0.32 (0.01; 0.57)	−0.43 (−0.65; −0.14)	**0.77* VL** (0.60; 0.87)				
GCT (s)	0.24 ± 0.04	**−0.64* L** (0.41; 0.79)	−0.37 (0.07; 0.61)	**0.77* VL** (0.60; 0.87)	0.03 (−0.28; 0.34)	−0.31 (−0.57; 0.00)	0.45 (0.16; 0.67)	**−0.78* VL** (−0.88; −0.62)	**−0.93* AP** (−0.96; −0.87)			
JH (m)	26.95 ± 5.97	0.44 (0.15; 0.66)	−0.17 (−0.46; 0.15)	0.22 (−0.10; 0.50)	**0.85* VL** (0.73; 0.92)	**0.70* VL** (0.50; 0.83)	**0.80* VL** (0.65; 0.89)	0.29 (−0.02; 0.55)	−0.18 (−0.47; 0.14)	0.28 (−0.03; 0.54)		
RSI (m/s)	1.12 ± 0.26	**0.79* VL** (0.63; 0.88)	0.11 (−0.21; 0.41)	−0.33 (−0.58; −0.02)	**0.70* VL** (0.50; 0.83)	**0.81* VL** (0.67; 0.90)	0.37 (0.07; 0.61)	**0.80* VL** (0.65; 0.89)	0.46 (0.17; 0.68)	−0.41 (−0.64; −0.11)	**0.74* VL** (0.56; 0.85)	
LS ($kN^{-1}{\cdot}m{\cdot}kg^{-1}$)	0.51 ± 0.11	−0.03 (−0.34; 0.28)	−0.33 (−0.58; −0.02)	**0.62* L** (0.38; 0.78)	**0.66* L** (0.44; 0.81)	0.30 (−0.01; 0.56)	**0.85* VL** (0.73; 0.92)	−0.20 (−0.48; 0.12)	**−0.62* L** (−0.78; −0.38)	**0.73* VL** (0.54; 0.85)	**0.86* VL** (0.75; 0.92)	0.32 (0.01; 0.57)

Note: Abbreviations: CMF = concentric mean force, EMF = eccentric mean force, GCT = ground contact time, JH = jump height, RSI = reactive strength index, LS = leg stiffness, L = large correlation, VL = very large correlation, AP = almost perfect correlation, * = $P < .01$.

0.66) and DJ40 ($r = 0.77$) concentric mean force and a very large-to-almost perfect significant correlation with DJ20 ($r = -0.73$) and DJ40 GCT ($r = -0.93$).

Associations between approach velocity, approach momentum, drop jump and maximal horizontal deceleration ability variables

Table 3 shows the correlations between maximal approach velocity (V_{Peak}), approach momentum (MOM_{Peak}), DJ20 and DJ40, and maximal horizontal deceleration ability variables. V_{Peak} had a very large significant correlation with HDEC ($r = -0.76$), however MOM_{Peak} was only moderately correlated with HDEC ($r = -0.33$). As such players with greater V_{Peak} tended to display greater HDEC ability, but not higher MOM_{Peak}. DJ20 and DJ40 concentric mean force and RSI had significant large correlations with HDEC ($r = -0.54$ to -0.61, $P = <.01$) and $HDEC_{Early}$ ($r = -0.54$ to -0.66, $P = <.01$). DJ20 and DJ40 jump height also had significant large correlations with $HDEC_{Early}$ ($r = -0.52$, $P = <.01$).

Differences in drop jump neuromuscular performance variables between high and low horizontal deceleration ability groups

Table 3 shows descriptive statistics (mean ± SD) and effect size (Cohen's d) differences in DJ NMP variables between the high and low HDEC ability groups. DJ20 and DJ40 RSI and concentric mean force demonstrated the largest effect size differences between the high and low HDEC ability groups ($d = 1.20$ to 1.40, $P = <.01$). Both DJ eccentric mean force and GCT had larger differences between the high versus low HDEC ability groups at higher ($d = 0.87$ to 1.11) compared to lower ($d = 0.29$ to 0.51) drop heights. In contrast, DJ jump height showed only a significant large difference between high and low HDEC ($d = 1.29$, $P = <.01$) ability groups at the lower drop height (i.e. 20 cm).

Discussion

The aim of this study was to evaluate associations between, and within, DJ NMP variables and maximal horizontal deceleration ability in team sport athletes. A further objective was to compare differences in DJ NMP qualities between athletes characterised with high versus low HDEC ability. An important and novel finding was that both DJ20 and DJ40 RSI and concentric mean force had the largest correlations with HDEC ability and also had large differences between high and low HDEC ability groups. Another novel finding revealed through examining the early and late horizontal deceleration sub-phases, was that both DJ20 and DJ40 RSI and concentric mean force had larger correlations with the early compared to late HDEC sub-phase. Notably, DJ40 eccentric mean force had large-to-very large significant correlations with both DJ20 and DJ40 concentric mean force, whilst only small correlations were evident at the lower DJ20 height. Similarly, when comparing high versus low HDEC ability groups there was a much larger effect size difference in DJ eccentric mean force at the higher than lower DJ height. These findings broadly support our study hypotheses, but specifically highlight the importance of being able to generate and re-utilise high eccentric braking forces, particularly at higher DJ heights, for potential improvements in horizontal deceleration ability.

Although reactive strength has been proposed as a major NMP quality underpinning deceleration performance (Kovacs et al., 2008), this is the first study to report significant and large associations between reactive strength, characterised by DJ RSI, and maximal horizontal deceleration ability in team sport athletes. In addition to the significant correlations between DJ RSI and HDEC ability, dichotomising players into high and low HDEC ability revealed that those with high HDEC also had significantly higher RSI at both drop heights (DJ20; $d = 1.28$ and DJ40; $d = 1.20$). DJ RSI is considered to be representative of the "stretch-load" capacity of the muscle-tendon unit during short (<0.25 s), high force impacts with the ground, and is a widely adopted assessment used to measure athletes capacity to counteract high eccentric-braking forces (Young, 1995). The present results support this concept, as players with greater DJ RSI seem better able to generate higher eccentric-braking forces under increased eccentric loading demands, thereby enabling them to produce more rapid horizontal deceleration. Similarly, DJ RSI scores from greater DJ heights (~50 cm) also appear to contribute to higher maximal sprinting velocities in team sport athletes, likely, due to a greater ability to "strike the ground" with a stiffer leg spring (Douglas et al., 2020).

The very large correlation ($r = -0.76$) and shared variance (58%) between V_{Peak} and HDEC reported in the current study, suggests that these factors share common NMP qualities. Similar to during maximal velocity sprinting (Bezodis, Kerwin, & Salo, 2008), athletes need to rapidly attenuate and generate high impact forces (~6 times body mass) during very short time frames (~150 ms) when performing maximal horizontal decelerations (Verheul et al., 2019). Indeed, quadriceps muscle pre-activation prior to ground contact during horizontal decelerations, can exceed maximal voluntary

Table 3. Effect size (90% confidence intervals) differences between high and low horizontal deceleration ability groups and correlations (90% confidence intervals) between horizontal deceleration abilities and drop jump neuromuscular performance variables.

	High vs. Low Comparison				Correlations			
Variable	High (n = 15)	Low (n = 14)	Effect Size	Descriptor	$HDEC_{Peak}$	HDEC	$HDEC_{Early}$	$HDEC_{Late}$
Anthropometric								
Height (m)	1.79 ± 0.08	1.75 ± 0.10	0.46 (0.31; 0.61)	Small	−0.14 (−0.43; 0.18)	−0.28 (−0.54; 0.03)	−0.25 (−0.52; 0.07)	−0.13 (−0.42; 0.19)
Body Mass (kg)	73.5 ± 15.2	72.2 ± 17.8	0.08 (−0.03; 0.19)	Trivial	0.07 (−0.25; 0.37)	−0.12 (−0.42; 0.20)	−0.17 (−0.46; 0.15)	0.09 (−0.23; 0.39)
Approach demands								
V_{Peak} ($m{\cdot}s^{-1}$)	7.74 ± 0.43	6.98 ± 0.44	**1.81*** (1.40; 2.22)	**Large**	−0.40 (−0.10; −0.63)	**−0.76* VL** (−0.87; −0,59)	**−0.78* VL** (−0.88; −0.62)	−0.37 (−0.61; −0.07)
M_{Peak} ($kg{\cdot}m{\cdot}s^{-1}$)	568 ± 116	509 ± 150	0.46 (0.31; 0.61)	Small	−0.06 (−0.37; 0.26)	−0.33 (−0.58; −0.02)	−0.38 (−0.62; −0.08)	−0.15 (−0.44; 0.17)
Drop jump 20 cm								
CMF ($N{\cdot}Kg^{-1}$)	27.66 ± 2.26	24.95 ± 2.31	**1.23*** (0.94; 1.52)	**Large**	−0.29 (−0.55; 0.02)	**−0.61* L** (−0.77; −0.37)	**−0.66* L** (−0.81; −0.44)	−0.24 (−0.54; 0.08)
EMF ($N{\cdot}Kg^{-1}$)	27.45 ± 3.44	25.72 ± 3.55	0.51 (0.35; 0.67)	Small	−0.26 (−0.53; 0.06)	−0.35 (−0.60; −0.40)	−0.29 (−0.55; 0.02)	−0.34 (−0.59; −0.03)
GCT (s)	0.24 ± 0.04	0.25 ± 0.03	0.29 (0.16; 0.42)	Small	0.05 (−0.36; 0.27)	0.19 (−0.13; 0.47)	0.26 (−0.06; 0.53)	0.05 (−0.36; 0.27)
JH (m)	0.27 ± 0.06	0.22 ± 0.04	**1.29*** (0.99; 1.59)	**Large**	−0.34 (−0.59; −0.03)	−0.49 (−0.70; −0.21)	**−0.52* L** (−0.72; −0.25)	−0.32 (−0.57; −0.01)
RSI (m/s)	1.15 ± 0.22	0.89 ± 0.20	**1.28*** (0.98; 1.58)	**Large**	−0.45 (−0.67; 0.16)	**−0.61* L** (−0.77; −0.37)	**−0.62* L** (−0.78; −0.38)	−0.40 (−0.63; −0.10)
LS ($kN^{-1}{\cdot}m{\cdot}kg^{-1}$)	0.50 ± 0.12	0.46 ± 0.06	0.42 (0.27; 0.57)	Small	−0.27 (−0.54; 0.05)	−0.24 (−0.54; 0.08)	−0.20 (−0.48; 0.12)	−0.23 (−0.51; 0.09)
Drop jump 40 cm								
CMF ($N{\cdot}Kg^{-1}$)	28.92 ± 3.40	25.15 ± 1.93	**1.40*** (1.08; 1.72)	**Large**	−0.38 (−0.62; −0.08)	**−0.54* L** (−0.73; −0.27)	**−0.54* L** (−0.73; −0.27)	−0.36 (−0.60; −0.05)
EMF ($N{\cdot}Kg^{-1}$)	34.57 ± 3.76	30.93 ± 2.94	1.11 (0.84; 1.38)	Moderate	−0.30 (−0.01; 0.56)	−0.39 (−0.63; −0.09)	−0.36 (−0.60; −0.05)	−0.33 (−0.58; −0.02)
GCT (s)	0.23 ± 0.04	0.26 ± 0.03	0.87 (0.65; 1.09)	Moderate	0.16 (−0.16; 0.45)	0.24 (−0.08; 0.51)	0.22 (−0.10; 0.50)	0.19 (−0.13; 0.47)
JH (m)	27.73 ± 6.23	25.10 ± 4.04	0.51 (0.35; 0.67)	Small	−0.28 (−0.54; 0.03)	−0.46 (−0.68; −0.17)	**−0.52* L** (−0.72; −0.25)	−0.15 (−0.44; 0.17)
RSI (m/s)	1.24 ± 0.27	0.98 ± 0.16	**1.20*** (0.92; 1.48)	**Large**	−0.33 (−0.58; −0.02)	**−0.61* L** (−0.77; −0.37)	**−0.65* L** (−0.72; −0.25)	−0.31 (−0.57; 0.00)
LS ($kN^{-1}{\cdot}m{\cdot}kg^{-1}$)	0.51 ± 0.13	0.51 ± 0.07	0.00 (−0.11; 0.11)	Trivial	−0.21 (−0.49; 0.11)	−0.21 (−0.49; 0.11)	−0.26 (−0.53; 0.06)	−0.17 (−0.46; 0.15)

Note: Abbreviations: V_{Peak} = peak approach velocity; M_{Peak} = peak approach momentum, $HDEC_{Peak}$ = peak horizontal deceleration, HDEC = average horizontal deceleration, $HDEC_{Early}$ = average early phase horizontal deceleration, $HDEC_{Late}$ = average late phase horizontal deceleration, CMF = concentric mean force, GCT = ground contact time, EMF = eccentric mean force, JH = jump height, RSI = reactive strength index, LS = leg stiffness, * = $P < .01$, L = large correlation, VL = very large correlation.

isometric contraction levels (Colby et al., 2000) in order to generate the high internal extensor moments needed to resist and control knee flexion immediately following foot strike. Furthermore, as a consequence of the rapid stretch of the quadriceps muscle-tendon complex following ground contact, muscle activation may be in excess of 150% maximal voluntary contraction, thereby augmenting shock attenuation and yielding control capacities (Colby et al., 2000). Accordingly, rapid muscle pre-activation and reflex responses seem to be important NMP qualities contributing to the attainment of both higher maximal sprinting speeds and rapid horizontal decelerations. In agreement with Douglas et al. (2020), greater DJ RSI scores seem indicative of both higher maximal eccentric strength and better neuromuscular activation abilities.

The larger associations we observed between DJ RSI and the early compared to the late horizontal deceleration sub-phase are a novel finding. Interestingly, $HDEC_{Early}$ had a larger shared variance with overall HDEC ability than the late horizontal deceleration sub-phase (85% vs. 46%, respectively). Together with the observation that high HDEC group also had significantly larger DJ RSI scores than the low HDEC group, these findings highlight the potential importance of the reactive strength quality represented by DJ RSI and players' ability to brake quickly from higher horizontal sprint velocities. A "preparatory" braking period associated with postural adjustments and a gradual reduction in velocity prior to a "fast" braking period consisting of a high posteriorly directed braking force and a rapid reduction in velocity has previously been defined (Jian, Winter, Ishac, & Gilchrist, 1993). A longer preparatory braking period could be driven by a "self-regulatory" avoidance strategy whereby those with inadequate strength to cope with the large impact peaks and loading rates distribute these forces across more deceleration steps. In agreement with this, our findings suggest that players with a lower HDEC ability spend more time "preparing" to brake before the "fast" brake period commences, resulting in lower $HDEC_{Early}$ sub-phase performance. This may also explain why the shared variance between $HDEC_{Peak}$ and $HDEC_{Late}$ was much larger than $HDEC_{Peak}$ and $HDEC_{Early}$ (79% vs. 29%, respectively) – indicating that particularly in players with lower early horizontal deceleration performance, higher peak deceleration values and accompanying forces, may occur towards the end of the deceleration phase. Potentially, this early horizontal "deceleration-deficit" could also have a detrimental effect on player's COD ability (Jones, Thomas, Dos'Santos, McMahon, & Graham-Smith, 2017) and increase lower limb mechanical load and injury-risk during the final braking steps of severe COD manoeuvres (Jones, Herrington, & Graham-Smith, 2016; Thomas, Dos'Santos, Comfort, & Jones, 2020; Thomas, Dos'Santos, Cuthbert, Fields, & Jones, 2020). These findings suggest that training programmes that enhance players DJ RSI capabilities may drive better early phase deceleration performance, aligning with previous observations that players with greater eccentric quadriceps strength can attain greater deceleration in the preparatory deceleration steps prior to a severe COD, which subsequently enables them to approach the COD faster and attain faster overall COD performance (Jones et al., 2017).

Of the DJ kinetic variables analysed, concentric mean force relative to body mass had the largest correlations with HDEC ability at both drop heights. McBride et al. (2008) reported significant correlations between concentric force during DJ performed from an approximate height of 40 cm and increased pre-impact and eccentric muscle activation. Interestingly, the findings of the present study support this observation, with results showing significant large-to-very large correlations between DJ40 eccentric mean force and both DJ20 ($r = 0.64$) and DJ40 ($r = 0.77$) concentric mean force. In contrast, DJ20 eccentric mean force had only small correlations with DJ20 ($r = 0.40$) and DJ40 ($r = 0.22$) concentric mean force. Similarly, there were only small differences in DJ20 eccentric mean force ($d = 0.51$) between those with high and low horizontal deceleration ability, but at DJ40 differences were approaching large ($d = 1.11$). This highlights the potential importance of generating high eccentric braking forces during short GCT, revealed when the more demanding higher DJ height is used in underpinning horizontal deceleration ability. Indeed, DJ40 eccentric mean force had an almost perfect negative correlation with DJ40 GCT ($r = -0.93$) explaining 86% of the shared variance. These observations agree with the prediction of the impulse-momentum relationship whereby impulse is directly proportional to change in velocity of a mass (i.e. a higher magnitude of force in less time, creating a "tall-thin" impulse shape) enabling a reduced GCT. Douglas and colleagues (2018, 2020) also highlighted the importance of training approaches that can increase the magnitude and rate of braking force application for attainment of shorter GCTs and higher maximal sprint velocities. Interestingly, individuals with greater lower limb strength (1RM squat > 1.6 × body mass) have been shown to have lower eccentric (negative) work demands under increasing eccentric loads, leading to more optimal dampening strategies and greater movement efficiency (McBride & Nimphius, 2020). This may have important performance and injury-risk reduction implications for team sport athletes who experience a large frequency of high-intensity decelerations during match play (Harper et al., 2019), and where enhanced efficiency would reduce cumulative load and stress on soft tissue structures during high-intensity horizontal decelerations.

Although there was a very large correlation between V_{Peak} and HDEC ability, the correlation between the maximal approach momentum (M_{Peak}) and HDEC was lower ($r = -0.33$), with a shared variance of just 11%. Therefore, while higher forward momentum would require higher braking forces in order to achieve higher horizontal deceleration, these findings suggest that those with higher approach momentum immediately prior to deceleration do not necessarily have this capacity meaning horizontal deceleration ability is hindered, potentially requiring greater training focus. This proposition agrees with previous findings showing that players with higher sprint velocities and momentum capabilities also had higher COD-deficits (Fernandes, Bishop, Turner, Chavda, & Maloney, 2021; Freitas et al., 2019; Loturco et al., 2019). Higher COD-deficit indicates players have a greater relative "drop-off" in speed and momentum when changing direction in comparison to the horizontal speed and momentum that is attained when no COD is required. Accordingly, these authors speculated that larger COD-deficits may be due to players with higher sprint momentums being unable to attain the higher braking forces required to decelerate prior to COD, resulting in longer deceleration times.

Interestingly however, we observed significantly higher approach velocities in the high HDEC ability group than in the low HDEC ability group (7.74 vs. 6.98 $m \cdot s^{-1}$, respectively) despite only trivial to small differences in body mass (73.5 vs. 72.2 kg, respectively). These findings suggest that the small-to-moderately higher approach momentum observed in the high compared to low HDEC ability groups (568 vs. 509 $kg \cdot m \cdot s^{-1}$, respectively) were largely determined by the higher maximal sprint velocities achieved prior to decelerating. Accordingly, in COD-deficit studies that did not directly measure deceleration performance, higher sprint velocities may not negatively influence horizontal deceleration performance. Indeed, greater acceleration and sprinting speeds have been shown to provide the "opportunity" to attain higher rates of deceleration during competitive match play scenarios (Newans, Bellinger, Dodd, & Minahan, 2019; Oliva-Lozano et al., 2020). Consequently, sports science and medicine practitioners should aim to thoroughly profile a team sport player's maximal horizontal deceleration ability, alongside the assessment of maximal horizontal acceleration and top speed capabilities. Based on these profiles, practitioners can then determine if a greater relative training focus is required on horizontal acceleration, deceleration or top speed running capabilities.

Future research should investigate individual horizontal acceleration-to-deceleration ratios and aim to ascertain associations with important performance outcomes and injury-risk mechanisms. One might speculate that a lower horizontal deceleration compared to acceleration ability (i.e. lower deceleration-to-acceleration ratio) could be associated with a greater lowering of "speed potential" during match play (i.e. self-regulation), and thus a reduced ability to perform frequent and prolonged high-intensity multi-directional movements. Furthermore, in unanticipated situations when rapid decelerations are required, these players may be at a heightened risk of tissue damage and injury due to increased likelihood of the forces in abrupt decelerations coming closer to or surpassing tissue tensile strength capacities. Accordingly, collection of such information could have significant implications for the design of training programmes aimed at ensuring players are optimally prepared for competition demands. Future research should also investigate if the findings of the current study are also observed in more highly trained athletes and with unanticipated horizontal decelerations. Furthermore, as with any study involving the assessment of DJ performance, there may be intra-and inter-participant variability in the actual drop height performed. In an attempt to address this, all participants in the current study were instructed to initiate the DJ by "stepping out" of the box with a single-leg (Pedley et al., 2017) and were familiarised with these procedures one week prior to testing. Nevertheless, homogenous drop height cannot be assumed.

Conclusion

In this study, team sport players with greater reactive strength, assessed using DJ-RSI, demonstrated superior horizontal deceleration abilities. As previously reported with respect to maximal velocity sprinting, athletes with greater DJ RSI scores seem able to produce, attenuate and re-utilise higher eccentric-braking forces, thereby enabling them to achieve superior horizontal deceleration. We also found that there were larger associations between DJ RSI and the early, compared to the late deceleration sub-phase. This has potential implications for the design of training and injury-risk mitigation strategies aimed at both enhancing horizontal deceleration performance and reducing the excessive braking forces that maybe experienced during the late deceleration phase, particularly in those with poorer early deceleration ability. Accordingly, we recommend DJ RSI as an alternative in-direct marker of horizontal deceleration ability that can be easily and quickly obtained in field-based environments using relatively inexpensive equipment.

Finally, by examining not only DJ performance, but also DJ kinetic variables, important underlying mechanical variables associated with horizontal deceleration ability were identified. Concentric mean force had large associations with DJ RSI along with large effect size differences between low and high HDEC ability groups at both DJ heights. However, DJ40 eccentric mean force strongly correlated with both DJ20 and DJ40 concentric mean force, and had a higher discriminative ability than the lower drop height when comparing high versus low HDEC ability groups. Accordingly, these findings highlight the importance of being able to generate and re-utilise high eccentric forces, particularly at higher drop heights for superior horizontal deceleration. In light of these results, and in consideration of the cross-sectional nature of this investigation, future research should establish if improving the DJ performance and NMP qualities reported here transfers to improved horizontal deceleration performance.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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