COUNTERMOVEMENT JUMP FORCE-TIME METRICS AND MAXIMAL HORIZONTAL DECELERATION PERFORMANCE IN PROFESSIONAL MALE BASKETBALL PLAYERS

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ABSTRACT

Basketball is a sport that relies heavily on an athlete's ability to rapidly decelerate in order to change direction, avoid a defender, or create space. Recent literature has proposed novel ways of measuring maximal horizontal deceleration using radar technology. The aim of this study was to investigate the relationships between different countermovement jump (CMJ) force-time characteristics and metrics related to maximal horizontal deceleration for a sample of professional male basketball players. To gain further insight into performance qualities that influence horizontal deceleration performance, athletes were separated into high- and low-performance groups for all horizontal deceleration metrics, using a median split analysis, and differences in CMJ force-time metrics were investigated between groups. The results revealed no significant correlations between any CMJ force-time metrics and horizontal deceleration performance. However, athletes' height and body mass were correlated with different deceleration performance measures, such as average deceleration, horizontal deceleration impulse, and time to stop. Higher performing athletes with regards to average horizontal deceleration and horizontal braking impulse relative to body mass generated greater concentric power (effect size (ES) = 1.04, ES = 0.86) and concentric velocities (ES = 1.17, ES = 0.97), as well as greater jump heights (ES = 1.19, ES = 0.99). Reactive Strength Index modified values were also greater in the higher performing group for horizontal braking impulse relative to body mass (ES = 1.06). On the other hand, higher-performing athletes with regard to horizontal braking impulse generated greater eccentric deceleration force (ES = 0.81) and eccentric power values (ES = 0.88) in the CMJ. Findings may be of interest to practitioners physically preparing basketball players for the sport-specific deceleration actions they may encounter.

Keywords: *team sports, radar, force plate, deceleration, neuromuscular testing*

INTRODUCTION

Rapid decelerations are seen in a wide range of sports when stopping or as a precursor to changes in direction (Hewit et al., 2011). According to McBurnie et al. (2021), and specific to different sporting activities, the performance of horizontal decelerations, in particular, presents unique biomechanical and physiological characteristics. One sport that relies heavily on these maximal and rapid decelerations is basketball. Given the nature of basketball gameplay, athletes frequently perform high-intensity accelerations, decelerations, and changes in direction, as well as vertical jumps (Petway et al., 2020; Ramos-Campo et al., 2017). Elite basketball athletes may experience up to 95 total decelerations and 40 high-intensity decelerations (>3.5 $m \cdot s^{-2}$)

per game (Petway et al., 2020). According to Vasquez-Guerrero et al. (2018), professional basketball players across all positions perform a greater number of maximal decelerations compared to accelerations. In contrast, the number of accelerations at moderate intensities was greater than the deceleration From a biomechanical standpoint, the objective of decelerating when moving over ground is to decrease the body's momentum (i.e., mass x velocity) by applying as much force as possible over minimal time to allow a complete stop or change in direction to occur (i.e., force x time = mass x velocity) (Kreighbaum & Barthels, 1996). Considering that basketball is a sport with a wide range of anthropometric features, it must be acknowledged that these decelerating force production requirements are elevated within athletes possessing greater body mass (Harper et al., 2020). Therefore, decelerations of higher intensity likely impose greater mechanical loads on athletes, which require large degrees of eccentric braking force, eccentric strength, reactive strength, and power (Dalen et al., 2016; Vanrenterghem et al., 2017; Kovacs et al., 2008; Spiteri et al., 2014). Furthermore, Harper et al. have suggested that concentric peak torque measured at the higher knee joint angular velocities was strongly correlated with deceleration distances and deceleration time to stop, potentially being an additional neuromuscular performance quality influencing horizontal decelerations (Harper et al., 2021). Although the previously mentioned neuromuscular qualities are modifiable within the realms of resistance training and plyometric training, there is a lack of scientific literature focused on examining biomechanical characteristics of horizontal decelerations in most sports, especially in basketball, as well as the effects of different training strategies on such characteristics. Given the amount of research literature documenting the importance of sprint acceleration for peak performance across a variety of sports (Colyer et al., 2018; Cross et al., 2016) and the potential health risk factors associated with the neglection of deceleration abilities in athlete populations (Harper et al., 2018), attention has recently been brought to this gap within the field of sports science (McBurnie et al., 2021; Harper et al., 2020; Harper et al., 2021; Harper et al., 2018; Harper et al., 2021; Harper et al., 2022; Harper et al., 2020). This issue becomes even more pressing when analyzing sports such as basketball which is mainly dependent on athlete's ability to perform high-intensity decelerations, especially when taking into account that the athletes' health is one of the key determinants of professional teams' success, and, therefore, revenue (Sarlis et al., 2021; Walia & Boudreaux, 2020).

In recent years, different performance tests and protocols have been established to measure horizontal deceleration ability, with radar and laser devices being commonly viewed as the gold standard testing methodology (Harper et al., 2020; Simperingham et al., 2016). However, given the greater mechanical loads imposed during maximal deceleration, particularly within heavier athletes such as basketball players, tests involving high-velocity running approaches and rapid maximal reductions in the body's momentum may not be as feasible to implement on a regular basis as others. On the other hand, a different assessment commonly used to measure athletes' neuromuscular performance qualities, such as maximal and rapid ground reaction force production and vertical power, is the countermovement jump (CMJ). When performed on a force platform and broken down into subphases (e.g., eccentric, concentric), many different force-time characteristics may be gleaned from this simple task, providing practitioners with additional insight into athletes' force production capabilities. More specifically, these force-time characteristics may be used in decision-making processes related to the individualization of training (Morris et al., 2020), rehabilitation from injury (Lonergan et al., 2018), as well as the identification of neuromuscular readiness and fatigue (Gathercole et al., 2015). In a recent study, Harper et al. (2020) aimed to identify whether or not different countermovement jump force-time metrics were able to differentiate maximal horizontal deceleration ability in a sample of team sport athletes (e.g., soccer, rugby league, rugby union). This study used average horizontal deceleration (i.e., change in velocity) and average horizontal braking impulse (i.e., change in momentum) to group athletes into high- and low-performance groups based on the sample median. The findings suggested that greater eccentric and concentric peak velocities were able to differentiate athletes with high change in momentum abilities. In contrast, eccentric and concentric peak force was able to differentiate athletes with high change in velocity abilities (Harper et al., 2020). However, as with most studies utilizing a cross-sectional research design, clear conclusions based on the results may not be confidentially drawn for other populations (e.g., basketball).

Therefore, to bridge a gap in scientific literature, the aim of the present study was to determine if a battery of easily accessible CMJ force-time characteristics is able to determine horizontal deceleration performance within a sample of professional male basketball players. Moreover, given the prevalence of using force plates to test basketball athletes, particularly focused on examining CMJ characteristics, makes this investigation worthwhile completing. It was hypothesized that force-time metrics from both the eccentric and concentric phases of the CMJ would be able to distinguish between high and low-performers in different performance metrics related to maximal horizontal decelerations and that significant correlations would exist between horizontal deceleration performance and CMJ force-time metrics and athletes' anthropometrics.

METHODS

Subjects

The sample for this investigation involved 10 professional male basketball players (age= 25.7±2.5 years; weight= 88.2±11.8 kg, height= 1.95±0.13 m) competing in various European leagues, having an average professional playing experience of 2.9±1.4 years. All participants had a background in playing collegiate basketball within the United States of America and were free of musculoskeletal injuries. All testing procedures were approved by the University's Institutional Review Board, and all subjects signed an informed consent form prior to participation. All procedures were carried out at the beginning of a training session, prior to any fatiguing activities.

Maximal Horizontal Deceleration Test

Procedures to assess athletes' maximal horizontal deceleration qualities were adapted from the previous literature (Harper et al., 2020). Athletes were asked to perform three trials within the horizontal acceleration-deceleration ability (ADA) test. This test has been shown to be reliable and sensitive to detecting kinematic and kinetic deceleration metrics (e.g., average horizontal deceleration, horizontal braking impulse) (Harper et al., 2020). The ADA test was slightly modified from its original form, given the dimensions of the basketball court and athletes' need to rapidly accelerate and decelerate over shorter distances, compared to other field-based sports. Athletes were asked to start in a staggered two-point stance prior to the commencement of the sprint. From there, athletes were asked to accelerate over 10 meters maximally and to perform a maximal horizontal deceleration immediately after crossing the 10-meter mark. The start line, as well as the 10-meter mark, were set using floor tape and cones. Athletes were instructed to initiate their sprint acceleration without a backward or "false" step or "rocking motion" and to sprint as fast as possible through the 10-meter mark. Following the maximal horizontal deceleration, athletes were instructed to backpedal to the 10-meter mark to highlight a clear change in instantaneous velocity, signifying the end of the deceleration phase. Each athlete performed three trials, with their best trial (i.e., highest peak velocity achieved) used for further analyses. All trials were conducted in a basketball arena on a hardwood floor, and all athletes wore basketball footwear.

Similar to previous research (Harper et al., 2020; Simperingham et al., 2016), instantaneous horizontal velocity was recorded throughout the entire ADA test using a radar device (Stalker ATS II, Applied Concepts, Inc., Dallas, TX, USA) sampling at a frequency of 47 Hz. The tripod-mounter radar device was placed 5 meters behind the start line, which was in line with the manufacturer's recommendations for measuring acceleration and deceleration trails. The target direction on the radar was set to 'both' to enable the device to record movement going away and towards the radar. Lastly, the radar was placed on the tripod at a height that was in line with each respective athlete's center of mass.

Radar Data Analysis

The raw and instantaneous horizontal velocity data provided by the radar was manually processed using the device's software program (Version 5.0, Applied Concepts, Inc., Dallas, Texas, USA), as suggested by Simperingham et al. (2016). Following this procedure, data were exported into the RStudio software (Version 1.4.1106) for further analysis. In line with suggestions by Harper et al. (2020), the start of the deceleration phase was defined as the time point immediately following peak velocity (Vmax), while the end of the deceleration phase was defined as the lowest velocity (Vlow) following Vmax. Similar to previous literature, maximal horizontal deceleration performance was analyzed using three different metrics: average horizontal deceleration (HDEC), average horizontal braking impulse (HBI), and time to stop (TTS). Distance to stop was highly correlated ($r = .899$) with TTS. Therefore, TTS was included for further analyses.

Furthermore, given the wide range of body weights on a normal basketball team and the influence of body mass on momentum, HBI was analyzed as an absolute change in momentum, as well as a change in momentum relative to the athletes' body mass (HBI_{rel}). All three metrics were calculated from velocity and time data point captured between the start and the end of the deceleration phase. Instantaneous HDEC was calculated as the change in velocity over time using the following equation: "$HDEC\ (m \cdot s^{-2}) = (Vf - Vi) / (Tf - Ti)$" with Vf and Vi being the final and initial velocity, and *Tf* and *Ti* being the final and initial time, respectively. Instantaneous HBI was calculated as the change in momentum over time using the following equation: "$HBI\ (N \cdot s \cdot kg^{-1}) = Mf - Mi$", with *Mf* and *Mi* being the final and initial momentum, respectively. Momentum was calculated by multiplying the athlete's body mass by their horizontal velocity. TTS was calculated using the following equation: "$Tf - Ti$" with *Tf* and *Ti* being the final and initial times of the deceleration phase, respectively. The coefficient of variation (CV%) for all radar metrics ranged from 2.99–10.24 and was therefore deemed reliable. All deceleration metrics and respective equations are reported in Table 1.

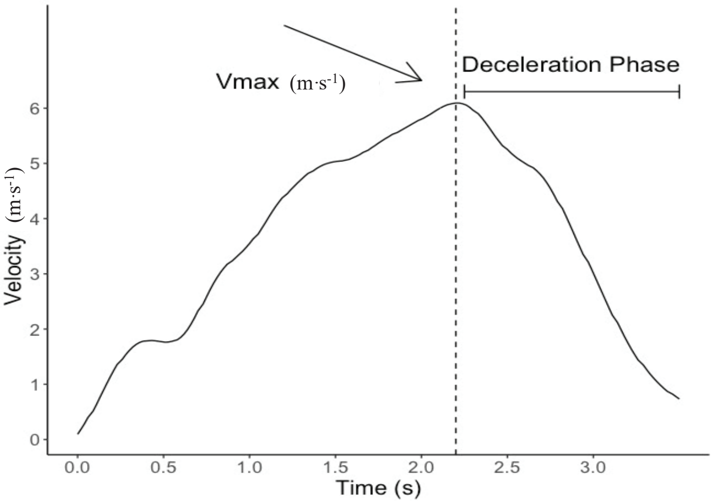

Figure 1. *Visual representation of instantaneous horizontal velocity during the ADA test*

Table 1. *Explanation of horizontal deceleration metrics examined in the present study*

Horizontal deceleration metrics (unit)	Definition - Equation
Approach Velocity ($m \cdot s^{-1}$)	Maximal velocity achieved prior to deceleration
Approach Momentum ($kg \cdot m \cdot s^{-1}$)	Maximal momentum achieved prior to deceleration
Average horizontal deceleration ($m \cdot s^{-2}$)	Change in velocity over time - *(Vf–Vi)/(Tf–Ti)*
Time to stop (s)	Time from start to end of deceleration phase - *Tf–Ti*
Horizontal braking impulse ($N \cdot s$)	Change in momentum over time - *Mf–Mi*
Relative horizontal braking impulse ($N \cdot s \cdot kg^{-1}$)	Change in momentum over time relative to body mass - (*Mf–Mi)/BM*

*Note: Vf= final velocity, Vi= initial velocity, Tf= final time, Ti= initial time, momentum = mass * velocity, Mf= final momentum, Mi= initial momentum, BM= body mass.*

Countermovement Jump Test

Following a dynamic warm-up implemented by a Certified Strength and Conditioning Specialist, athletes perform a total of three CMJs. CMJs were performed on the same day as the ADA assessment. To minimize the effect of acute fatigue on jump performance, each jump was separated by a 15-30-second rest interval. Data were recorded using portable dual force plates (ForceDecks Max, Vald Performance Pty Ltd., Brisbane, Australia). The force plates were zeroed prior to each subject's test. Athletes were given instructions to step onto the force plate and to stand as still as possible for 2-3 seconds, and then to jump as fast and as high as possible while keeping their hands on their hips during the entire movement. Verbal encouragement was provided to ensure maximal effort was given for each jump.

Countermovement Jump Analyses

The CMJ is commonly broken down into subphases (e.g., eccentric, concentric) to gain a deeper insight into the athlete's neuromuscular performance profile. Within the scope of this study, the unloading phase was defined as the period from when the total force of the athlete was reduced by more than 20 N from baseline system mass until the minimum force recorded during the eccentric phase of the CMJ, as suggested by the manufacturer. The phase containing negative velocity was defined as being the eccentric phase. The eccentric braking phase was defined as a sub-phase of the eccentric phase, starting at minimum force and ending when the athlete's system mass returns to baseline. Further, the deceleration phase was defined as another subphase of the eccentric phase, starting at peak eccentric velocity and ending when the eccentric phase ends. The

CMJ take-off was defined as the time point when vertical force decreased below a threshold of 20 N (Harper et al., 2020). For each metric of interest, the average of the three trials was used for further analyses (Merrigan et al., 2021). The different CMJ force-time metrics used within this study and between-repetition coefficients of variation (CV), are presented in Table 2. Force-dependent CMJ metrics were divided by the athlete's body weight for normalization purposes.

Table 2. *List and definition of force-time metric examined in the present study*

Eccentric metrics (unit)	**Definition (CV%)**
Braking phase duration (s)	Duration of the braking phase (4.8%)
ECC braking impulse (N·s·kg^{-1})	Area under the ECC braking phase of the net force-time curve (9%)
ECC braking RFD (N·s^{-1}·kg^{-1})	Average change in force over time during ECC braking time (11.7%)
ECC mean braking force (N·kg^{-1})	Average force generated during the ECC braking phase (2.5%)
Deceleration phase duration (s)	Duration of the ECC deceleration phase (7.9%)
ECC deceleration impulse (N·s·kg^{-1})	Area under the ECC deceleration phase of the net force-time curve (6.5%)
ECC deceleration RFD (N·s^{-1}·kg^{-1})	The average change in force overtime during the ECC deceleration phase (18.4%)
ECC mean deceleration force (N·kg^{-1})	Average force generated during the ECC deceleration phase (5.8%)
ECC peak velocity (m·s^{-1})	Maximal velocity obtained during the ECC phase (6.4%)
ECC peak power (W·kg^{-1})	Peak power during the ECC phase (11.2%)
ECC mean power (W·kg^{-1})	Mean power during the ECC phase (7.7%)
ECC unloading impulse (N·s·kg^{-1})	Net impulse from start of movement to start of deceleration phase (6.3%)
Concentric metrics (unit)	**Definition**
CON duration (s)	Duration of the concentric phase (2.2%)
CON impulse (N·s·kg^{-1})	Area under the CON phase of the net force-time curve (2.3%)
CON mean force (N·kg^{-1})	Average force of the CON phase (1.7%)
CON peak force (N·kg^{-1})	Peak force of the CON phase (2.9%)
CON peak velocity (m·s^{-1})	The average change in force overtime during the CON phase (1.4%)
CON peak power (W·kg^{-1})	Peak power during the CON phase (5.3%)
CON mean power (W·kg^{-1})	Mean power during the CON phase (3.4%)
Other metrics (unit)	**Definition**
Jump height (cm)	Maximal jump height via impulse - momentum calculation (3.6%)
RSI-modified (ratio)	Jump height divided by contraction time (7%)
ECC:CON mean force ratio (%)	Ratio of mean forces in the ECC and CON phases (1.4%)
Force at zero velocity (N·kg^{-1})	Total force at the instance velocity is zero prior to take-off (6.7%)
Countermovement depth (cm)	Lowest center of mass displacement, transition from ECC to CON phase (4.7%)

Note: RFD= rate of force development; ECC= eccentric; CON= concentric; RSI= reactive strength index; CV= coefficient of variation.

Statistical Analysis

All data were assessed for normality using the Shapiro-Wilk statistics, and within-session coefficients of variation (CV) were calculated for all maximal horizontal deceleration and CMJ metrics. All variables assessed for normality met the necessary assumptions. Given the normal data distribution, relationships between maximal horizontal deceleration metrics and the CMJ force-time metrics were analyzed using Pearson's correlation coefficient (r). In addition, separately, athletes were divided into high and low-performance groups, utilizing a median split analysis for all three maximal horizontal deceleration measures. Student's independent sample's t-tests were used to investigate differences in CMJ force-time characteristics between high and low performers groups for all three deceleration measures. To evaluate the group-specific magnitude of difference for all metrics of interest, Cohen's d effect sizes (ES) were calculated. ESs were classified as either trivial (<0.20), small (0.20-0.49), moderate (0.50-0.79), or large (>0.80) (Cohen, 1977). Statistical inferences were made using an alpha level of $p \leq$

.05. All data were analyzed and visualized using the RStudio Software (Version 1.4.1106), as well as the R statistical computing environment and language (v. 4.0; R Core Team, 2020) via the Jamovi graphical user interface.

RESULTS

Correlation Analyses

Regarding HDEC, none of the CMJ force-time metrics revealed statistically significant correlations. However, a significant positive relationship was found between HDEC and athlete's height (r = .633, p = .049), as well as an important negative relationship between approach velocity and HDEC (r = -.686, p = .029).

Similarly, when looking at HBI, which was defined as the athlete's change in momentum during the horizontal deceleration phase, regardless of body mass, no significant correlations were found with any of the CMJ force-time metrics. However, as hypothesized, significant negative relationships were revealed between HBI and athlete's body mass (r = -.888, p < .001), athlete's height (r = -.813, p = .004), as well as athlete's approach momentum (r = -.937, p < .001). A similar trend was observed with only approach velocity showing a significant negative correlation (r = -.843, p = .002) with HBI_{rel} (i.e., athlete's change in momentum during the deceleration phase relative to their body mass). Lastly, TTS only showed a statistically significant positive relationship with the athlete's height (r = .712, p = .021).

Group Comparisons Between High & Low-Performers

Descriptive data between high and low performers regarding HDEC, HBI, HBI_{rel}, and TTS is presented in Tables 2 and 3. High performers with regards to HDEC completed the deceleration phase in a significantly shorter amount of time (p = .007, ES = 2.26). Despite not reaching the level of statistical significance, a large effect size was observed for height between the two groups, with the high-performing group being shorter (ES = 1.22). Looking at TTS, the group of high performers had a significantly greater HDEC (p = .022, ES = 1.79). Additionally, a large between-groups effect size was found with regard to height (ES = 1.07). Comparing groups by looking at HBI, athletes' body mass of high performers was found to be significantly heavier (p = .012, ES = -2.06). While not statistically significant, athletes within the high HBI group were also taller (ES = -1.33). Lastly, looking at HBI relative to athletes' body mass, the high-performing group showed a significantly higher running velocity during their approach (p = .007, ES = -2.27).

Table 3. *Descriptive data between high and low performers for average horizontal deceleration and time to stop*

Metric	High HDEC	Low HDEC	ES	High TTS	Low TTS	ES
Body mass (kg)	84.9 ± 14.6	91.4 ± 8.5	0.54	83.7 ± 14.1	92.2 ± 7.9	0.79
Height (m)	1.89 ± 0.14	2.02 ± 0.08	1.22	1.89 ± 0.14	2.01 ± 0.1	1.07
Peak velocity (m·s^{-1})	6.53 ± 0.35	6.25 ± 0.39	-0.76	6.44 ± 0.38	6.34 ± 0.41	-0.24
Approach momentum (kg·m/s^{-1})	554.7 ± 89.9	573.5 ± 66.6	0.23	538.5 ± 84.4	589.2 ± 63.1	0.68
HDEC (m·s^{-2})	-4.45 ± 0.77	-3.29 ± 0.41	1.89†	-4.44 ± 0.79	-3.30 ± 0.43	1.78†
HBI (N·s)	-493.3 ± 82.9	-517.9 ± 69.9	-0.32	-479.9 ± 83.1	531.4 ± 59.9	-0.71
HBI$_{rel}$ (N·s·kg^{-1})	-5.80 ± 0.28	-5.64 ± 0.47	0.41	-5.73 ± 0.37	-5.72 ± 0.42	0.03
TTS (s)	1.33 ± 0.17	1.73 ± 0.19	2.26†	1.31 ± 0.16	1.75 ± 0.16	2.74†

***†** *= p-value of <0.05, HDEC = horizontal deceleration, TTS = time to stop, HBI = horizontal braking impulse, HBI$_{rel}$ = horizontal braking impulse relative to body mass. High tts group indicated fasters tts, while low tts group indicated slower tts.*

Table 4. *Descriptive data between high and low performers for horizontal braking impulse and relative horizontal braking impulse*

Metric	High HBI	Low HBI	ES	High HBI$_{rel}$	Low HBI$_{rel}$	ES
Body mass (kg)	96.6 ± 7.3	79.8 ± 8.9	-2.06†	85.9 ± 10.7	90.4 ± 13.6	0.37
Height (m)	2.02 ± 0.07	1.88 ± 0.13	-1.33	1.93 ± 0.12	1.98 ± 0.12	0.35
Peak velocity (m·s^{-1})	6.53 ± 0.40	6.26 ± 0.35	-0.73	6.67 ± 0.34	6.11 ± 0.07	-2.27†
Approach momentum (kg·m·s^{-1})	629.7 ± 19.4	498.0 ± 38.8	-4.29†	574.3 ± 74.2	553.5 ± 83.3	-0.26
HDEC (m·s^{-2})	-3.84 ± 0.70	-3.90 ± 1.06	-0.07	-4.25 ± 0.93	-3.49 ± 0.62	0.96
HBI (N·s)	-567.1 ± 31.5	-444.2 ± 41.3	3.34†	-516.1 ± 76.2	-495.2 ± 77.9	0.27
HBI$_{rel}$ (N·s·kg^{-1})	-5.87 ± 0.42	-5.57 ± 0.47	0.85	-5.98 ± 0.34	-5.46 ± 0.16	1.93†
TTS (s)	1.56 ± 0.25	1.49 ± 0.32	-0.24	1.46 ± 0.28	1.60 ± 0.27	0.53

**ES = effect size, † = p-value of <0.05, HDEC = horizontal deceleration, TTS = time to stop, HBI = horizontal braking impulse, HBI$_{rel}$ = horizontal braking impulse relative to body mass.*

Group comparisons for respective CMJ force-time metrics with regards to HDEC, HBI, HBI$_{rel}$, and TTS are presented in Tables 4 and 5. When examining HDEC, no CMJ force-time metric revealed a statistically significant difference between the high and low-performing groups. However, multiple metrics showed large between-group effect sizes, with concentric peak velocity (ES = -1.17), jump height (ES = -1.19), and concentric mean power (ES = -1.04) showing the largest. Regarding TTS, no significant between-group differences were shown for any of the CMJ force-time metrics. However, multiple metrics produced moderate to large effect sizes, as can be viewed in Table 4. Further, Figure 2 and 3 show metrics that produced moderate and large between-group effect sizes.

Table 5. *Group comparisons for respective CMJ force-time metrics between high and low performers in HDEC and TTS*

Metric	High HDEC	Low HDEC	ES	High TTS	Low TTS	ES
Braking phase duration (s)	0.33 ± 0.13	0.29 ± 0.03	0.42	0.34 ± 0.12	0.28 ± 0.04	0.74
ECC braking impulse (N·s·kg^{-1})	0.62 ± 0.16	0.61 ± 0.07	0.10	0.60 ± 0.15	0.63 ± 0.09	-0.19
ECC braking RFD (N·s^{-1}·kg^{-1})	75.6 ± 35.8	68.2 ± 10.6	0.27	68.0 ± 28.5	75.8 ± 25.4	-0.29
Deceleration phase duration (s)	0.18 ± 0.08	0.16 ± 0.03	0.30	0.19 ± 0.08	0.16 ± 0.03	0.50
ECC deceleration impulse (N·s·kg^{-1})	1.56 ± 0.28	1.17 ± 0.23	-0.03	1.16 ± 0.28	1.16 ± 0.22	0.00
ECC deceleration RFD (N·s^{-1}·kg^{-1})	98.0 ± 55.3	81.8 ± 31.3	0.36	86.2 ± 38.9	93.6 ± 51.6	-0.16
ECC peak velocity (m·s^{-1})	-1.16 ± 0.28	-1.17 ± 0.23	-0.03	-1.16 ± 0.28	-1.16 ± 0.22	0.00
ECC peak power (W·kg^{-1})	17.24 ± 6.87	16.12 ± 3.8	0.20	16.48 ± 6.00	16.88 ± 5.16	-0.07
ECC peak force (N·kg^{-1})	23.98 ± 3.48	22.46 ± 3.29	0.45	23.46 ± 2.65	22.98 ± 4.14	0.14
ECC mean power (W·kg^{-1})	5.67 ± 0.87	5.78 ± 1.13	-0.11	5.85 ± 1.04	5.60 ± 0.97	0.25
ECC unloading impulse (N·s·kg^{-1})	-1.16 ± 0.28	-1.16 ± 0.23	0.03	-1.16 ± 0.28	-1.16 ± 0.22	-0.01
CON duration (ms)	236.6 ± 24.4	242.0 ± 38.5	-0.17	246.0 ± 19.13	232.8 ± 40.33	0.42
CON impulse (N·s·kg^{-1})	5.19 ± 0.38	5.04 ± 0.41	0.39	5.24 ± 0.37	5.00 ± 0.39	0.62
CON mean force (N·kg^{-1})	22.02 ± 1.44	21.04 ± 1.84	0.59	21.28 ± 0.66	21.78 ± 2.34	-0.29
CON peak force (N·kg^{-1})	26.90 ± 2.51	27.66 ± 4.25	-0.22	25.90 ± 0.58	28.66 ± 4.44	-0.87
CON peak velocity (m·s^{-1})	3.01 ± 0.21	2.82 ± 0.08	1.17	2.96 ± 0.19	2.87 ± 0.18	0.47
CON peak power (W·kg^{-1})	62.52 ± 6.11	57.76 ± 5.21	0.84	59.34 ± 5.97	60.94 ± 6.44	-0.26
CON Mean Power (W·kg^{-1})	34.82 ± 4.13	31.12 ± 2.85	1.04	33.10 ± 1.99	32.84 ± 5.45	0.06
Jump height (cm)	42.40 ± 6.68	36.42 ± 2.38	1.19	40.88 ± 6.04	37.94 ± 5.55	0.51
RSI-modified (ratio)	0.58 ± 0.12	0.53 ± 0.05	0.48	0.54 ± 0.09	0.56 ± 0.11	-0.18
ECC:CON mean force ratio (%)	44.78 ± 2.78	47.00 ± 3.93	-0.65	46.20 ± 1.38	45.58 ± 4.91	0.17
Force at zero velocity (N·kg^{-1})	23.98 ± 3.49	22.36 ± 3.32	0.48	23.44 ± 2.65	22.90 ± 4.20	0.16
Countermovement depth (cm)	-30.08 ± 4.16	-27.60 ± 6.91	-0.44	-31.30 ± 4.00	-26.38 ± 6.15	-0.95

**† = p-value of <0.05, HDEC = horizontal deceleration, TTS = time to stop, HBI = horizontal braking impulse, HBI_{rel} = horizontal braking impulse relative to body mass.*

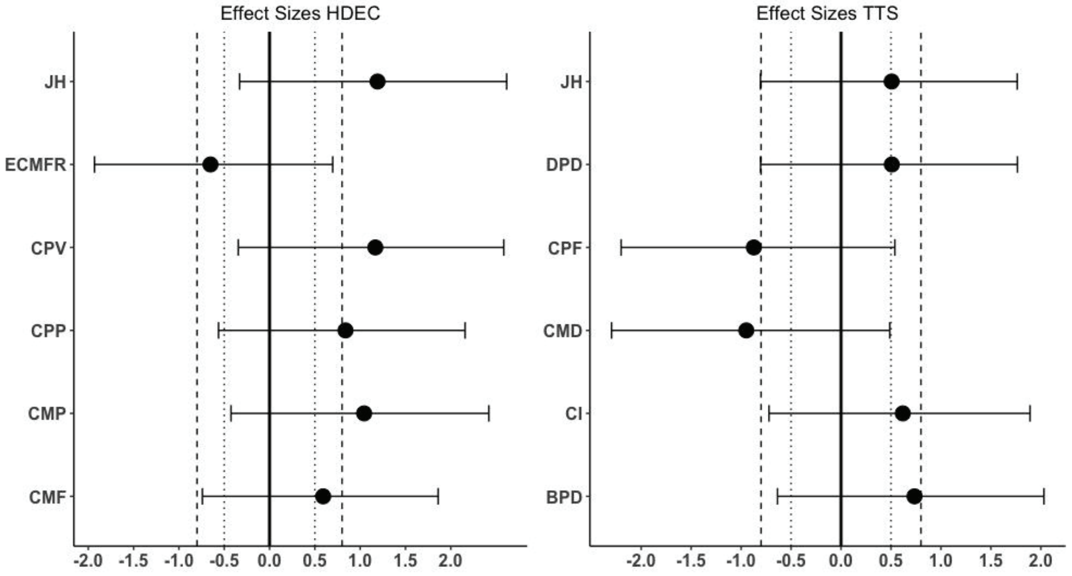

Figure 2. *Between-group effect sizes for CMJ force-time metrics >0.5 (medium effect), and >0.80 (large effect), differentiating between high and low-performing groups for HDEC and TTS*

Note: JH= jump height, ECMFR= eccentric:concentric mean force ratio, CPV= concentric peak velocity, CPP= concentric peak power, CMP= concentric mean power, CMF= concentric mean force, DPD= deceleration phase duration, CPF= concentric peak force, CMD= countermovement depth, CI= concentric impulse, BPD= braking phase duration. Dotted line = moderate effect size border, dashed line = large effect size border.

Similarly, looking at HBI, no CMJ force-time metric revealed a statistically significant difference between the high and low-performing groups. However, eccentric deceleration impulse (ES = -0.81), eccentric mean power (ES = -0.88), as well as eccentric peak velocity (ES = 0.81), and eccentric unloading impulse (ES=0.80) showed large between-group effect sizes in favor of the high performing group. When looking at HBI$_{rel}$, concentric peak velocity (ES = -0.97), jump height (ES = -0.99), as well as RSImod (ES = -1.06) and concentric mean power (ES = -0.86) revealed large between-group effect sizes in favor of the higher performing group, that was not statistically significant.

Table 6. *Group comparisons for respective CMJ force-time metrics between high and low-performers in HBI and HBI$_{rel}$*

Metric	High HBI	Low HBI	ES	High HBI$_{rel}$	Low HBI$_{rel}$	ES
Braking phase duration (s)	0.30 ± 0.07	0.31 ± 0.11	-0.18	0.29 ± 0.07	0.32 ± 0.11	-0.30
ECC braking impulse (N·s·kg^{-1})	0.66 ± 0.11	0.58 ± 0.12	0.70	0.62 ± 0.10	0.61 ± 0.14	0.10
ECC braking RFD (N·s^{-1}·kg^{-1})	73.8 ± 29.70	70.0 ± 24.70	0.14	77.60 ± 29.71	66.20 ± 23.12	0.43
Deceleration phase duration (s)	0.17 ± 0.05	0.18 ± 0.08	-0.07	0.16 ± 0.05	0.19 ± 0.07	-0.42
ECC deceleration impulse (N·s·kg^{-1})	1.26 ± 0.11	1.07 ± 0.31	0.81	1.22 ± 0.11	1.11 ± 0.33	0.46
ECC deceleration RFD (N·s^{-1}·kg^{-1})	89.20 ± 52.78	90.60 ± 37.73	-0.03	102.2 ± 51.6	77.60 ± 34.06	0.56
ECC peak velocity (m·s^{-1})	-1.26 ± 0.11	-1.07 ± 0.31	-0.81	-1.22 ± 0.11	-1.11 ± 0.33	-0.46
ECC peak power (W·kg^{-1})	18.26 ± 4.46	15.10 ± 6.02	0.60	17.98 ± 4.56	15.38 ± 6.11	0.48
ECC peak force (N·kg^{-1})	23.08 ± 3.88	23.36 ± 3.04	-0.08	23.98 ± 3.84	22.46 ± 2.85	0.45
ECC mean power (W·kg^{-1})	6.13 ± 0.50	5.33 ± 1.18	0.88	5.86 ± 0.37	5.59 ± 1.36	0.27
ECC unloading impulse (N·s·kg^{-1})	-1.25 ± 0.11	-1.07 ± 0.31	-0.80	-1.22 ± 0.11	-1.11 ± 0.33	-0.45
CON duration (ms)	249.8 ± 32.65	229.0 ± 27.67	0.69	237.0 ± 24.30	241.8 ± 38.69	-0.15
CON impulse (N·s·kg^{-1})	5.25 ± 0.40	4.99 ± 0.35	0.69	5.18 ± 0.36	5.05 ± 0.43	0.33
CON mean force (N·kg^{-1})	21.16 ± 2.04	21.90 ± 1.26	-0.59	21.96 ± 1.50	21.10 ± 1.84	0.51
CON peak force (N·kg^{-1})	26.62 ± 2.99	27.94 ± 3.84	-0.38	27.30 ± 2.41	27.26 ± 4.36	0.01
CON peak velocity (m·s^{-1})	2.95 ± 0.25	2.88 ± 0.08	0.38	3.00 ± 0.21	2.83 ± 0.10	0.97
CON peak power (W·kg^{-1})	60.54 ± 7.38	59.74 ± 4.88	0.13	59.34 ± 5.67	58.00 ± 5.92	0.74
CON mean power (W·kg^{-1})	32.76 ± 5.75	33.18 ± 0.75	-0.10	34.56 ± 4.50	31.38 ± 2.67	0.86
Jump height (cm)	40.32 ± 8.01	38.50 ± 2.55	0.31	42.04 ± 6.69	36.80 ± 3.31	0.99
RSI-modified (ratio)	0.56 ± 0.12	0.54 ± 0.07	0.22	0.60 ± 0.10	0.51 ± 0.07	1.06
ECC:CON mean force ratio (%)	46.78 ± 4.28	45.00 ± 2.44	0.51	44.94 ± 2.91	46.84 ± 3.94	-0.55
Force at zero velocity (N·kg^{-1})	23.02 ± 3.92	23.32 ± 3.07	-0.09	23.99 ± 3.84	22.35 ± 2.89	-0.16
Countermovement depth (cm)	-30.19 ± 4.44	-27.50 ± 6.70	-0.47	-28.92 ± 4.30	-28.76 ± 7.10	-0.03

**† = p-value of <0.05, HDEC = horizontal deceleration, TTS = time to stop, HBI = horizontal braking impulse, HBI$_{rel}$ = horizontal braking impulse relative to body mass.*

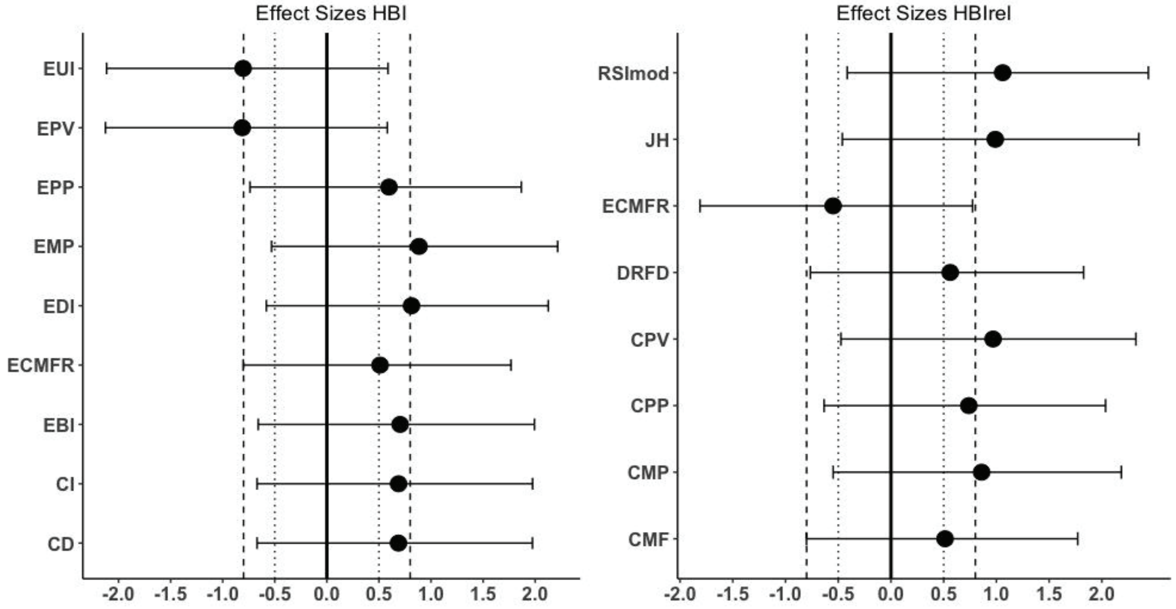

Figure 3. *Between-group effect sizes for CMJ force-time metrics >0.5 (medium effect), and >0.80 (large effect), differentiating between high and low-performing groups for HBI and* HBI_{rel}

Note: JH= jump height, ECMFR= eccentric:concentric mean force ratio, CPV= concentric peak velocity, CPP= concentric peak power, CMP= concentric mean power, CMF= concentric mean force, CI= concentric impulse, EBI= eccentric braking impulse, EDI= eccentric deceleration impulse, CD= concentric duration, EMP= eccentric mean power, EPP= eccentric peak power, EPV= eccentric peak velocity, EUI= eccentric unloading impulse, DRFD= deceleration rate of force development, RSImod= reactive strength index modified. Dotted line = moderate effect size border, dashed line = large effect size border.

DISCUSSION

The purpose of the present study was to determine the effectiveness of using a low-impact, commonly utilized neuromuscular performance assessment for identifying potential neuromuscular performance qualities affecting horizontal deceleration performance within a sample of professional male basketball players. Results from this study may provide sports scientists and strength and conditioning practitioners with actionable insights into physical performance qualities influencing horizontal deceleration performance. These insights may be used to further individualize the implementation of different training strategies to enhance deceleration qualities in male basketball players. To our knowledge, this is the first investigation focused on quantifying horizontal deceleration performance using radar technology within professional male basketball players.

None of the CMJ force-time metrics examined in the present study demonstrated significant relationships with the four horizontal deceleration metrics used within the study, likely influenced by the small sample size. A significant correlation between HDEC and athlete's height was found, suggesting that taller individuals may find it harder to reduce their velocity following a maximal acceleration rapidly. Additionally, as hypothesized, taller and heavier athletes initiating the horizontal deceleration following a greater approach momentum generated larger horizontal braking impulses. Given the wide range of anthropometric features on a basketball team, athletes need to be capable of rapidly reducing their momentum efficiently, especially the ones taller and heavier in stature. Practitioners may consider athletes' anthropometric features when individualizing training modalities aimed at increasing horizontal deceleration performance. One may argue that taller players don't experience as many high-intensity decelerations compared to perimeter players (Vasquez-Guerrero et al., 2018). However, considering that average game demands drastically underestimate the most demanding passages of basketball match-play, it is suggested that athletes are well prepared to effectively encounter such scenarios (Garcia et al., 2021).

To gain further insight into what physical performance qualities may be influencing horizontal deceleration performance, athletes were broken into high and low-performing groups with regards to the four different horizontal deceleration measures, and differences in CMJ force-time metrics were investigated between groups. Athletes within the high HDEC group were shorter (ES = -1.22), and lighter (ES = -0.54). The larger between-group effect size for height compared to mass speaks to the fact that an athlete's limb length, in addition to total mass, should also be considered when implementing training programs aimed at enhancing an athlete's ability to reduce their horizontal velocity rapidly. Further, with regards to the CMJ metrics, athletes within the high HDEC group displayed greater jump heights (ES = 1.19), greater peak concentric velocities (ES = 1.17), and greater concentric mean power (ES = 1.04). These findings are somewhat in disagreement with the common belief that CMJ force-time characteristics from the eccentric portion of the jump may show a higher transfer to horizontal deceleration performance. However, similar results were reported by Harper et al. (2020), who noted the largest between-group differences in concentric peak and mean force and concentric mean power for HDEC performance within a larger cohort of team sport athletes. In addition, it has been found that concentric knee flexor and extensor strength at faster angular velocities was found to be related to TTS and distance to stop within a horizontal deceleration test Harper et al., 2021). A possible explanation may be that concentric muscle actions produce force faster than eccentric ones (Tillin et al., 2012). Different modes of training have been suggested to enhance this physical quality (Aagard et al., 2002; Oliveira et al., 2015), which could potentially transfer to HDEC performance.

When examining the difference in TTS between the groups, the only CMJ force-time metrics showing large ES were peak concentric force (ES = -0.87) and countermovement depth (ES = -0.95). Interestingly, the higher-performing group (i.e., shorter TTS) generated less concentric peak force compared to the lower-performing group (i.e., longer TTS). With peak concentric force only being measured during a single instance throughout the movement, this finding is likely influenced by the respective athletes' jump strategies. The higher-performing group showed a deeper countermovement and longer countermovement, therefore generating a larger concentric impulse (ES = 0.62). As hypothesized, the present study's findings indicate that HBI was highly influenced by the athlete's height, mass, and approach momentum. Despite having greater body mass, athletes within the higher-performing HBI group were capable of generating larger amounts of eccentric deceleration impulse (ES = 0.81) and eccentric mean power (ES = 0.88) relative to their own body mass within the CMJ. While speculative, these findings suggest that in order to reduce their momentum horizontally efficiently, athletes need to possess rapid eccentric force generation abilities, which may be reflected within the CMJ task.

Further, higher-performing athletes with regard to HBI demonstrated greater eccentric unloading impulse relative to their body weight and greater peak eccentric velocities. These metrics likely reflect the efficient use of the stretch-shortening cycle, setting athletes up for a greater vertical force generation potential later in the CMJ (Laffaye et al., 2013). These findings may point towards the fact that strength and conditioning practitioners working with basketball athletes are encouraged to implement exercises enhancing athletes' ability to rapidly develop eccentric force, particularly when these athletes possess greater amounts of body mass that they need to slow down during horizontal decelerations.

Although not specific to horizontal deceleration, different methodologies have been suggested to improve eccentric strength and force production capabilities. For instance, it has been found that resistance training involving fast eccentric contractions increases rapid force production in the lower body to a greater degree when compared to slow eccentric contractions (Stasinaki et al., 2019). Another training modality that has gained increasing amounts of popularity recently is flywheel training. The goal of this modality is to provide additional resistance during the eccentric portion of the exercise through kinetic energy transferred to a flywheel (Petre et al., 2018). Despite documenting the beneficial effects of flywheel training on force-generating capabilities (Nunez Sanchez et al., 2017), there is a lack of scientific research on highly trained individuals examining the direct effects on different horizontal deceleration qualities.

Further, a growing body of evidence has investigated the effects of accentuated eccentric resistance training on different physical qualities. Accentuated eccentric resistance training has been shown to acutely enhance concentric force production and power (Wagle et al., 2017). Some authors have suggested the beneficial effects of accentuated eccentric training on change of direction speed (Chaabene et al., 2018; Liu et al., 2020). However, as previously noted, when looking at accentuated eccentric resistance training, research again lacks highly trained athletic populations performing deceleration tasks as done within this study. In a more task-specific manner, other recent studies have tried to quantify the effects of field-based/multidirectional training interventions on technical and biomechanical characteristics underpinning effective horizontal decelerations (McBurnie et al., 2021; Dos'Santos et al., 2019; Dos'Santos et al., 2021). While the literature looking at training interventions influencing maximal horizontal decelerations in trained populations is relatively scarce, it is at this point, based on the existing literature, reasonable to suggest that training interventions consisting of both resistance training and field-based, task-specific exercises may provide the best stimulus to athletes aiming to enhance their horizontal deceleration qualities. However, as mentioned previously, research investigating the underpinning physical characteristics of maximal horizontal decelerations and how to train them, especially among high-level athletes of different sports, is still in its infant stages. Therefore, suggestions on how to interpret data must be viewed with caution.

Lastly, CMJ force-time metrics showed large between-group effect sizes when HBI was investigated relative to the athlete's body mass. In rapidly reducing the horizontal momentum relative to each individual's body mass, those athletes in the higher-performing group showed greater RSImod values (ES = 1.06), greater jump heights (ES = 0.99), greater concentric mean power (ES = 0.86), and concentric peak velocity (ES = 0.97). These observations are similar to the findings of the present study examining between-group comparisons for HDEC. It seems that when looking at athlete's ability to horizontally reduce their momentum relative to their body mass, as well as when reducing their horizontal velocity quickly over time, concentric force-related metrics, as well as CMJ outcome metrics such as jump height or RSImod, seem to have the greatest power of distinguishing between athletes in the high and low-performing groups. On the other hand, when looking at athletes' ability to reduce their overall momentum rapidly, eccentric force-related CMJ metrics seemed to best distinguish between higher and lower-performing athletes. This potential phenomenon may also be observed when observing athletes' eccentric to concentric mean force ratios extracted from the CMJ task. When comparing HDEC groups, athletes in the higher-performing group showed lower eccentric to concentric mean force values (ES = -0.65). On the other hand, when comparing HBI groups, the higher-performing group showed greater eccentric to concentric mean force ratios (ES = 0.51). These findings imply the importance of training individualization to develop well-rounded athletes from a neuromuscular performance standpoint.

While novel, this study is not without limitations. Studying highly trained athletes, such as the ones in the present investigation, is significant to the field of sports science. However, with this goal come challenges often related to smaller sample sizes. Therefore, these findings should be interpreted with caution, given our population's relatively small and specific nature. Additionally, this study looked at maximal horizontal deceleration performance over the entire deceleration phase, starting immediately after athletes achieved max velocity during their approach and ending when athletes came to a complete stop. Future investigations may divide the deceleration phase into an early and a late deceleration phase, as done in the previous literature[16]. In addition, future studies may want to quantify neuromuscular performance by means of other commonly implemented assessments such as vertical drop jumps, single-leg CMJ, and single-leg drop jumps. Lastly, upcoming research looking at maximal horizontal decelerations should also investigate trained female populations.

CONCLUSION

In conclusion, the findings of the present study indicate that maximal horizontal deceleration performance in basketball players is largely influenced by athlete anthropometric characteristics. Athletes' height and weight were shown to be influential factors in how effective athletes were able to reduce horizontal velocity and momentum rapidly. Further, CMJ force-time metrics (e.g., jump height, deceleration impulse, concentric peak velocity) used within this study were capable of distinguishing between higher and lower-performing athletes when looking at different means for quantifying maximal horizontal deceleration performance. Higher performing athletes with regards to HDEC and HBI_{rel} generated greater concentric forces and velocities, jump heights and RSImod values. On the other hand, higher-performing athletes with regard to HBI generated greater eccentric force and power values in the CMJ. Also, TTS seemed to be affected by the athlete's height largely. Thus, strength and conditioning practitioners working with basketball athletes are encouraged to individually assess athletes' anthropometric and neuromuscular performance characteristics and implement training strategies to enhance athletes' rapid eccentric and concentric force generation qualities.

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