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Article

Horizontal Deceleration Performance in Professional Female Handball Players

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Abstract: Given the multidirectional nature of the sport, handball athletes must frequently perform high-intensity decelerations to avoid defenders, generate space, or perform directional changes. The aim of the present study was twofold: (i) to investigate different kinematic measures of horizontal deceleration performance by comparing the acceleration-deceleration assessment (ADA) with the 5-0-5 test and (ii) to investigate relationships between force-time characteristics derived from the countermovement vertical jump (CVJ) and measures of horizontal deceleration performance. Eleven female handball players competing in the first-tier professional league in Europe performed three CVJs while standing on a uni-axial force plate system sampling at 1000 Hz, followed by two ADAs (i.e., maximal-effort acceleration over a 10 m distance, followed by rapid deceleration) and 5-0-5 test trials. Tripod-mounted radar sampling at 47 Hz, placed 5 m behind the start line, was used to record horizontal velocity data. Each test was separated by a 5–7 min rest interval to minimize the influence of fatigue. No statistically significant differences were found in horizontal deceleration performance parameters between ADA and the 5-0-5 test. However, athletes with a higher CVJ height and reactive strength index-modified showed better performance in terms of horizontal deceleration measures such as maximal approach velocity and average and maximal deceleration. Overall, these results may be of interest to practitioners working with multidirectional sport athletes such as handball players as they provide critical insight for the selection of assessments and training strategies targeted toward optimizing on-court athlete performance.

Keywords: sport; athlete; sprinting; biomechanics; testing; speed; force; jump; propulsive; braking

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1. Introduction

Handball is arguably one of the most popular sports, particularly across a number of European countries. It is played by more than 19 million people globally [1]. From a physical standpoint, success in competitive handball is underpinned by a number of performance attributes such as aerobic conditioning, strength, power, running speed, and throwing velocity [2,3].

When investigating differences among playing positions and competitive level of play, previous research has found that wings from the German first division had superior sprint performance compared to the wings from the second division [4]. Given the dimensions of the playing field, court-based athletes such as handball and/or basketball players are frequently exposed to a large number of high-intensity accelerations, decelerations, and directional changes, especially over shorter distances [3]. In particular, rapid change-in-direction tasks, which are frequently performed during handball matches, are often preceded by high-intensity decelerative actions to allow athletes to efficiently slow down their body's center of mass [5]. Frequently, during such high-intensity decelerations, athletes are exposed to challenging loading rates and higher mechanical loads compared to sprint accelerations [6–8]. Thus, the aforementioned loads must be met with sufficient levels of strength, particularly eccentric strength, in order to accommodate these forces and effectively reduce whole-body momentum [9,10]. In certain instances, when these high mechanical demands are not met with the required skills and physical qualities, athletes' tissues may be exposed to greater levels of neuromuscular and mechanical fatigue, which may ultimately increase the likelihood of injury [11,12]. In an effort to avoid this and to better prepare athletes for on-court competitive demands, sports practitioners often implement various types of non-invasive and time-efficient neuromuscular performance assessments (e.g., jumping, landing, and change-in-direction tests) [5,13].

Generally speaking, one aspect of change-in-direction performance that has historically received less attention within the realm of sports science is the quantification of horizontal deceleration performance, including kinematic measures that go well beyond mere completion times in 5-0-5 and/or 5-10-5 tests [11]. In recent years, more attention has been dedicated to the importance of measuring and enhancing athletes' deceleration qualities [11,14–18]. For instance, Graham-Smith et al. [17] have investigated the links between the percentage of maximum speed attained with acceleration and stopping distance, which may help set realistic conditions for acceleration–deceleration drills and tests. Also, a couple of recently published research reports have found positive relationships between other field-based neuromuscular performance assessments (e.g., countermovement vertical jump) and measures of horizontal deceleration performance [14,15,19,20]. From a biomechanical standpoint, horizontal deceleration performance has primarily been assessed via acceleration-deceleration assessment (ADA) [14,15]. However, despite the inability to quantify performance beyond test-completion times, the 5-0-5 change-in-direction test has been frequently used in the applied setting. Within sports science the scientific literature focused on investigating horizontal deceleration performance in highly trained athlete populations is still scarce, especially pertaining to research focused on examining female athletes, who are often more susceptible to lower-body injuries such as anterior cruciate ligament tears [21]. In female populations most anterior cruciate ligament injuries occur via non-contact mechanisms during landings and/or lateral pivoting, which are movement tasks similar to maximal horizontal decelerations that place large impact-peak forces and loading rates on the athlete's tissues [6,22].

Therefore, to add to the scientific body of literature, the purposes of the present study are twofold. The primary aim was to investigate different kinematic measures of horizontal deceleration performance in professional female handball players by comparing the ADA test to the 5-0-5 test. It was hypothesized that notable differences would be observed based on the nature of each test and the anticipated turning location. The secondary aim of this study was to investigate relationships between force-time characteristics derived from the countermovement vertical jump (CVJ) and measures of horizontal deceleration performance, similar to previously published research reports [14,15,20].

2. Materials and Methods

2.1. Participants

The sample for this investigation consisted of eleven professional female handball players ($\bar{x} \pm$ SD; age = 21.4 ± 2.9 years, body mass = 69.7 ± 11.4 kg, height = 175.2 ± 5.5 cm) competing in the first-tier professional league in Europe. All participants were free of musculoskeletal injuries at the time of data collection and cleared for participation in team activities by their respective sports medicine staff. The testing procedures performed in the present study were previously approved by the University's Institutional Review Board, and all participants signed an informed consent form.

2.2. Acceleration–Deceleration Assessment

Procedures for the ADA were adapted from prior research reports [14,15,20]. The starting position required athletes to stand still at the start line (i.e., 0 m mark) in a staggered stance position, prior to initiating the maximum-effort sprint acceleration. From there, athletes were instructed to sprint as fast as possible through a set of cones positioned at the 10 m mark. After crossing the 10 m mark, athletes were instructed to rapidly decelerate, come to a full stop, and backpedal back to the 10 m mark. The backpedal was implemented for researchers to identify the end of the deceleration phase within the instantaneous velocity tracing [14,15]. Also, athletes were instructed to avoid slowing down prematurely and aim to initiate the deceleration phase immediately after crossing the 10 m mark. If athletes were visually observed to slow down prior to the 10 m mark, a 2 min rest period was given, and the trial was carried out again. Each athlete completed two trials of the ADA, with the average value being used for analysis purposes. Prior to this, all athletes were given two practice trials for familiarization purposes. This specific assessment was chosen based on its practical relevance and logistical appropriateness for the professional sport setting, in which sport scientists are often tasked with limited time to conduct data collection.

Similar to previously published research reports [14,15,23], instantaneous horizontal velocity was recorded during the entire ADA using a radar device (Stalker ATS II, Applied Concepts, Inc., Dallas, TX, USA) sampling at a frequency of 47 Hz. The tripod-mounted radar device was placed 5 m behind the start line (i.e., the 0 m mark), according to the manufacturer's recommendations. The target direction on the radar was set to "both" to enable the device to record movement going away and toward the radar. Lastly, the height of the radar placed on the tripod was in line with each respective athlete's center of mass.

2.3. The 5-0-5 Change-in-Direction Test

The 5-0-5 test was based on the methodology of Spiteri et al. [10]. Similar to the ADA, the 5-0-5 test required athletes to stand still at the start line (i.e., 0 m mark) in a staggered stance position, prior to initiating the maximum-effort sprint acceleration. Athletes were instructed to sprint through the cones placed at the 10 m mark as fast as possible, perform a 180-degree turn at another set of cones placed at the 15 m mark, and rapidly reaccelerate back through the 10 m mark. Each athlete performed a total of two trials within the 5-0-5 test, one by changing the direction with the dominant leg and the other with the non-dominant leg. Prior to this, each athlete was given one practice trial on each limb for familiarization purposes. The average value across two testing trials was used for analysis purposes. The instantaneous horizontal velocity was recorded as highlighted within the ADA assessment section.

2.4. Radar Data Analysis

The raw and instantaneous horizontal velocity data provided by the radar were manually processed using the device's own software program (Version 5.0, Applied Concepts Inc., Dallas, TX, USA), as suggested by Simperingham et al. [23]. Following this procedure, data were exported into the RStudio software (Version 1.4.1106) for further treatment and analysis. In line with suggestions by Harper et al. [14,15], with the ADA, the start of the deceleration phase was defined as the time point immediately following peak velocity, while the end of the deceleration phase was defined as the lowest velocity following the peak velocity. During the 5-0-5 test, the deceleration phase was defined as the time point immediately following the peak velocity, while the end of the deceleration phase was defined as the lowest velocity, prior to the final reacceleration. The horizontal-deceleration variables examined in this investigation are presented in Table 1. These metrics have been previously used and were shown to possess moderate to excellent levels of inter- and intra-day reliability [14,15].

Table 1. Deceleration and countermovement vertical jump metrics and their definitions. CVJ—countermovement vertical jump; RSI_{mod}—reactive strength index modified.

Deceleration Metrics (Unit)	**Definition**
Maximal approach velocity ($m \cdot s^{-1}$)	Maximal velocity prior to deceleration
Maximal approach momentum ($kg \cdot m \cdot s^{-1}$)	Maximal momentum prior to deceleration
Average deceleration ($m \cdot s^{-2}$)	Average change in velocity over time
Maximal deceleration ($m \cdot s^{-2}$)	Maximal change in velocity over time
Time to stop (s)	Time from start to end of deceleration
Distance to stop (m)	Distance from start to end of deceleration
CVJ metrics (unit)	**Definition**
Jump height (cm)	Jump height via impulse-momentum
RSI_{mod} (ratio)	Jump height divided by contraction time
Propulsive mean force (N)	Average force during the propulsive phase
Braking mean force (N)	Average force during the braking phase

2.5. Countermovement Vertical Jump Test

Following a dynamic warm-up protocol consisting of a set of dynamic stretching exercises (e.g., A-skips, quad pulls, side-to-side lunges), athletes performed a total of three CVJs. CVJ testing procedures were performed on the same day as ADA and 5-0-5 tests. Each test was separated by a 5–7 min rest interval to minimize the possible influence of fatigue. Also, each CVJ was separated by a 15–30-s rest interval. Data were recorded using a portable dual force plate system sampling at 1000 Hz (ForceDecks Max, VALD Performance Ltd., Brisbane, Australia). The force plates were calibrated/zeroed prior to each participant. Athletes were given instructions to step onto the force plate and stand still for 2–3 s, and then jump as fast and as high as possible while keeping their hands on their hips during the entire movement [24]. Verbal encouragement was provided to ensure maximal effort was given for each jump. CVJ subphases were defined in line with previous research [14,15,20,25]. Within this study, jump height was calculated using the impulse-momentum relationship, while reactive strength index-modified (RSI_{mod}) was calculated by dividing jump height by contraction time. The contraction time started when the athlete's system weight was reduced by 20 N, which is termed the movement onset, and ended at take-off. Similarly, the take-off was defined as the time point at which vertical force dropped below a threshold of 20 N. In line with manufacturer recommendations, the eccentric phase was defined as the phase with negative velocity. For the sake of this study, the braking phase was defined as a sub-phase of the eccentric phase, starting at peak eccentric velocity, and ending at the point of zero velocity of the center of mass. Lastly, the propulsive phase began immediately following the braking phase, when the center of mass velocity was zero, and ended at take-off. Dependent variables of interest are presented in Table 1.

2.6. Statistical Analysis

All data were assessed for normality using the Shapiro-Wilk test and Q-Q plots. In line with the primary aim of the study, between-test comparisons for horizontal deceleration metrics were performed using paired sample *t*-tests. For all comparisons, the magnitude of the difference was calculated using Cohen's *d* effect sizes, which were interpreted as trivial ($d < 0.25$), small ($d = 0.25$–0.50), moderate ($d = 0.50$–1.0), or large ($d > 1.0$) [26]. With regard to the secondary aim of the study, relationships between measures of horizontal deceleration performance and CVJ force-time characteristics were determined using Pearson's r and Spearman's rho based on the distribution of the data. Given the relationship between body weight and ground reaction forces, both propulsive and braking CVJ mean forces were allometrically scaled using a log-linear regression to develop the allometric exponents ("*b*") for comparing body weight for each outcome variable [27,28]. Allometrically scaled values for each kinetic metric of interest were calculated using the traditional formula (y/x^b), in which "*b*" is the derived exponent for each kinetic metric from the log-linear regression [28]. For paired sample *t*-tests, statistical inferences were made using an alpha level of $p \leq 0.05$. For the correlation analysis, to account for potential type 1 errors when performing multiple correlations, statistical inferences were made at both the $p \leq 0.05$ and $p \leq 0.013$ (Bonferroni-adjusted) levels. Bonferroni-adjusted *p*-values were generated by dividing 0.05 by the number of analyses performed on each respective dependent variable from the tests quantifying deceleration performance. All data were analyzed using the R software (Version 1.4.1106).

3. Results

Pertaining to the primary objective of this study, no statistically significant differences ($p > 0.05$) were found between measures of deceleration performance in the ADA compared to the 5-0-5 test. Magnitudes of differences between groups revealed small-to-moderate effect sizes.

With regard to the second aim of this study, significant correlations between CVJ force-time characteristics and different measures of deceleration performance derived from the ADA were found. At the $p \leq 0.05$ significance level, the jump height revealed a statistically significant association with maximal deceleration (rho = −0.702, $p = 0.016$). At the $p \leq 0.013$ significance level, jump height revealed a significant correlation with average deceleration (r = −0.757, $p = 0.007$) and maximal approach velocity (r = 0.833, $p = 0.001$).

Within the 5-0-5 test, only maximal approach velocity showed a significant relationship with jump height (r = 0.845, $p = 0.001$) at the $p \leq 0.013$ significance level. Similarly, RSI_{mod} was found to be significantly correlated with average deceleration (r = −0.687, $p = 0.019$) at the $p \leq 0.05$ significance level and maximal approach velocity (r = 0.825, $p = 0.002$) at the $p \leq 0.013$ significance level, which were derived from the ADA. Additionally, only the maximal approach velocity in the 5-0-5 test was found to be significantly related to RSI_{mod} (r = 0.812, $p = 0.002$) at the $p \leq 0.013$ significance level.

The allometrically scaled average propulsive and braking force from the CVJ revealed no significant correlations with any of the deceleration metrics from either ADA or the 5-0-5 test ($p > 0.05$). See Tables 2 and 3 for descriptive and variability statistics, as well as between-test comparison data for all metrics of interest. Figure 1 visualizes between-test effect sizes, and respective confidence intervals.

Table 2. Descriptive statistics for CVJ force-time metrics ($\bar{x} \pm$ SD [coefficient of variation percentage—CV%]). CVJ—countermovement vertical jump; RSI_{mod}—reactive strength index modified.

Metric (Unit)	CVJ
Jump height (cm)	28.0 ± 5.01 [2.20]
RSI_{mod} (ratio)	0.42 ± 0.10 [8.06]
Propulsive mean force (N)	1423 ± 168 [2.81]
Braking mean force (N)	1243 ± 200 [2.33]
Propulsive mean force ($N \cdot kg^{b-1}$)	95.3 ± 4.09 [2.81]
Braking mean force ($N \cdot kg^{b-1}$)	51.6 ± 3.81 [2.33]

Table 3. Between-assessment comparisons for all deceleration metrics of interest ($\bar{x} \pm$ SD [coefficient of variation percentage—CV%]). ADA—acceleration-deceleration assessment. ES—effect size.

Metric (Unit)	ADA	5-0-5	*p*-Value	ES
Maximal approach velocity ($m \cdot s^{-1}$)	6.42 ± 0.34 [3.01]	6.54 ± 0.26 [1.50]	0.114	0.52
Maximal approach momentum ($kg \cdot m \cdot s^{-1}$)	454 ± 62.9 [3.01]	462 ± 70.3 [1.50]	0.101	0.54
Average deceleration ($m \cdot s^{-2}$)	-3.65 ± 0.51 [8.5]	-3.29 ± 0.58 [11.78]	0.129	0.50
Maximal deceleration ($m \cdot s^{-2}$)	-8.79 ± 1.17 [8.10]	-9.53 ± 1.56 [15.47]	0.088	0.57
Time to stop (s)	1.67 ± 0.16 [10.36]	1.45 ± 0.28 [11.41]	0.074	0.60
Distance to stop (m)	6.03 ± 0.48 [16.66]	6.66 ± 1.41 [11.40]	0.203	0.41

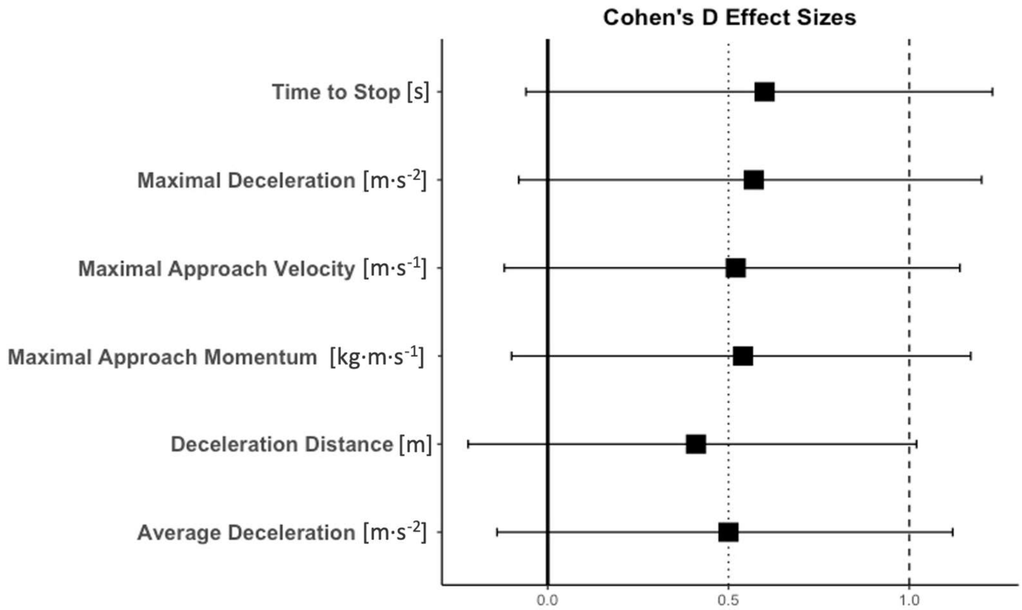

Figure 1. Between-assessment effect sizes and associated confidence intervals for deceleration metrics of interest. Dotted line—moderate effect size; dashed line—large effect size.

4. Discussion

The primary aim of this study was to investigate different kinematic measures of horizontal deceleration performance in professional female handball players by comparing two different testing modalities (i.e., the ADA and the 5-0-5 test). During the ADA, athletes rapidly accelerated through the 10 m mark and then quickly decelerated until coming to a complete stop. On the other hand, during the 5-0-5 test, athletes maximally accelerated over a 10 m distance, with a predetermined turning point set at the 15 m mark, followed by a rapid reacceleration. It is reasonable to hypothesize that deceleration mechanics between the aforementioned tests are likely to differ when a known target/turning point is present. The secondary aim of this study was to explore the relationships between horizontal deceleration performance measures and neuromuscular performance qualities obtained from a CVJ, as a non-invasive and time-efficient testing modality commonly used in a practical setting.

In regard to the first study objective, no statistically significant differences were found in deceleration mechanics between the two assessments. While the sample size could have influenced the results, the moderate effect sizes may provide deeper insight into the different deceleration strategies used within each test. For instance, during the 5-0-5 test, the maximal deceleration was found to be greater, and it took athletes approximately 0.22 s less to go from maximal to minimal sprint velocity compared to ADA. Conversely, the deceleration distance was shorter for the ADA, likely due to a greater preparatory deceleration period in anticipation of the change in direction followed by rapid reacceleration. These observations align with previously published research reports highlighting a potential preparatory braking period during which athletes go through postural adjustments and a more gradual velocity reduction prior to a faster braking period that consists of a higher posteriorly directed braking force and a more rapid reduction in velocity [19,29]. Thus, it is reasonable to speculate that such a preparatory braking phase is a greater need for team sport athletes when tasked with a directional change and reacceleration following the deceleration phase, compared to only being asked to come to a complete stop following a sprint run-up. Indeed, during the 5-0-5 test, the average deceleration was slightly lower and maximal deceleration was greater when compared to ADA, which supports the notion of a gradual reduction in velocity followed by a fast-braking period immediately prior to the change in the direction of movement. Additionally, our data suggest that athletes on average initiated the deceleration phase within the 5-0-5 test 6.66 m ahead of the turning mark when operating under the assumption that minimum velocity occurred there. Lastly, the maximal approach velocity and momentum, while not statistically significant, were found to be greater in the 5-0-5 test compared to the ADA. In addition to a skill or technique component, this may place greater neuromuscular demand on athletes performing this kind of assessment compared to the ADA. For instance, Jones et al. [30] have proposed the importance of eccentric strength qualities with regard to performance with 180-degree changes in direction. Greater magnitudes of the approach momentum likely require greater force-attenuation qualities to effectively reduce whole-body momentum [7].

While the following idea is speculative and warrants further research, performance within the ADA may be thought of as an athlete's absolute or maximal deceleration capability under more controlled circumstances. On the other hand, the deceleration ability within assessments such as the 5-0-5 test may be viewed more as sport- and/or task-specific. For instance, the ratio between an athlete's absolute ability to reduce movement velocity and deceleration performance in a task that requires directional change and reacceleration may offer practitioners potential insights for the design of training regimens. For example, an athlete with a high deceleration potential, such as that seen during ADA, who fails to achieve similar performance levels within the 5-0-5 test may benefit from training strategies aimed at developing change-in-direction skills. DosSantos et al. [31,32] suggested that training in change-in-direction speed and technique modification have the ability to improve cutting performance within athletes in multi-directional team sports. For example, within our sample, athlete 10 had the second-highest average deceleration within the ADA. However, they performed below the sample median for average deceleration within the 5-0-5 test. Therefore, this specific athlete may benefit from change-in-direction technique-modification training to get closer to their maximal deceleration potential within a task that requires a directional change and re-acceleration, which is common in the majority of multidirectional sports (e.g., handball, basketball). On the other hand, athlete 8 displayed deceleration performance above the team median on the 5-0-5 test and below the median deceleration performance within the ADA. While the idea is speculative, this athlete may benefit from strategies aiming to enhance their maximal deceleration potential, such as eccentric strength, reactive strength, and braking and force-attenuation strategies [11,33]. Raising their potential deceleration ceiling within the ADA could positively impact performance in more sport-specific or contextual deceleration tasks. Figure 2 highlights a potential way to visualize discrepancies in deceleration qualities between the two assessments, and it was founded on previous research reports [20,34]. A next step within the research agenda could be implementing similar analyses within assessments where athletes do not know the exact location of their anticipated change in direction and rather have to react to some kind of external stimulus (e.g., visual, auditory).

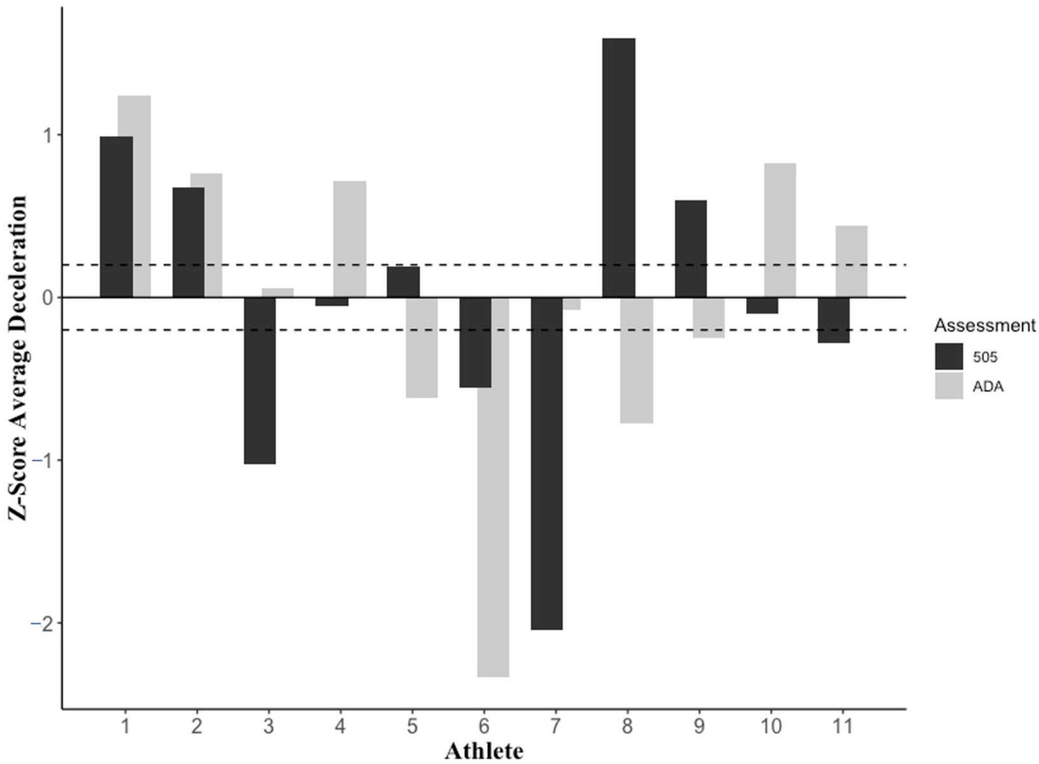

Figure 2. Athlete z-score plot for average deceleration across both assessments. Horizontal dashed lines indicate the smallest worthwhile change. ADA—Acceleration–deceleration assessment.

In regard to the secondary aim of the present investigation, both vertical jump height and RSI_{mod} showed statistically significant correlations with multiple deceleration performance metrics obtained from the ADA. These observations suggest that greater jump performance is positively related to superior proficiency across different deceleration metrics. This is in partial agreement with previous studies that have observed large effect sizes for CVJ height as a factor capable of distinguishing between high- and low-performance groups with regard to average horizontal deceleration [20] and horizontal braking impulse [14,15]. Interestingly, within the 5-0-5 test, besides the maximal approach velocity, neither CVJ height nor RSI_{mod} was shown to be a significant predictor of horizontal deceleration performance. This may again highlight the change-in-direction skill or technique component involved in assessments containing a directional change followed by a re-acceleration phase. Further, allometrically scaled propulsive or braking mean force displayed no significant correlations with horizontal deceleration performance.

The overarching strength of this study is likely the highly trained cohort of participants combined with the fact that data on professional female athletes are still scarce, especially with regard to horizontal deceleration performance. However, readers should be aware of certain limitations of the present study. The sample size certainly poses challenges with regard to the generalization of the findings obtained in this investigation. Also, likely due to the number of trials performed, combined with the novelty of the task, the mean CV% for some of the measures of deceleration performance, especially within the 5-0-5 test ranged between 10 and 20%, which is in line with previous research and is considered to fall within the good-to-acceptable range of reproducibility [35]. It should be noted that CV% values were higher within the 5-0-5 test compared to the ADA, likely due to the athlete's limb preferences within the turning task (e.g., dominant vs. non-dominant limb). Elevated CV%'s for the deceleration distance in the ADA are in line with findings from previous research reports suggesting poor inter-test reliability for this metric [15]. Future studies may aim to implement similar methodologies with a larger sample of athletes and across more testing trials to enhance the understanding of deceleration performance within multidirectional sports, especially within trained female populations. Additionally, future investigations may improve data-collection procedures by including a 10 m linear sprint assessment as a "criterion" for deceleration assessments, during which athletes may apply a pacing strategy. While more time-intensive, this would allow researchers to hold athletes accountable for initiating the deceleration phase as close to the 10 m marker as possible by comparing times in the deceleration assessment to this "criterion", as mentioned in prior investigations [15]. Lastly, future research should examine if the findings of the present study remain applicable to other levels of handball competition (e.g., amateur, collegiate) and if they are gender-specific.

5. Conclusions

Despite not reaching the level of statistical significance, the findings of the present study suggest that different deceleration assessments may pose different challenges to athletes, which should be acknowledged by practitioners in charge of implementing such test batteries. Although the idea is speculative, if performed correctly and with maximal intent, performance within the ADA may be thought of as an athlete's total deceleration potential, while performance on the 5-0-5 test may be viewed as more specific to the nature of most team sports. The difference in performance between the two assessments could be used to make an informed decision with regard to the implementation of training strategies aimed toward enhancing deceleration and change-in-direction performance in athletes in multidirectional sports such as handball. Both jump height and RSI_{mod} derived from the CVJ test showed significant correlations with a number of different measures of horizontal deceleration performance, all in favor of those athletes presenting greater values. Results from this study may be of interest to practitioners working with athletes in multidirectional team sports (e.g., handball, basketball) and may give direction and guidance within the selection of assessments and training strategies directed toward enhancing athletes' performance on sport-specific tasks.

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