Measuring maximal horizontal deceleration ability using radar technology: Reliability and sensitivity of kinematic and kinetic variables

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Radar technology has potential for providing new insights into maximal horizontal deceleration ability. This study aimed to investigate the intra- and inter-day reliability and sensitivity of kinematic and kinetic variables obtained from a novel, maximal horizontal deceleration test, using radar technology. Thirty-eight university sport athletes completed testing for intra-day analysis. Twelve of these participants also completed the deceleration test on a second day for inter-day analysis. The maximal horizontal deceleration test required participants to decelerate maximally following 20 m maximal horizontal sprint acceleration. Reliability was assessed using the intraclass correlation coefficient (ICC) and coefficient of variation (CV%). Sensitivity was evaluated by comparing typical error (TE) to smallest worthwhile change (SWC). A number of kinematic and kinetic variables had good (ICC > 0.75, CV < 10%) overall intra-day reliability, and were sensitive to detect small-to-moderate changes in deceleration performance after a single familiarisation session. Only kinetic variables had good overall inter-day reliability and were sensitive to detect moderate changes in deceleration performance. Utilisation of this test protocol to assess maximal horizontal deceleration can provide new insights into individual maximal horizontal deceleration capabilities. Future work using this or similar approaches may provide insights into the neuromuscular performance qualities needed to decelerate maximally.

Keywords: braking, velocity, force, power, impulse, profiling

Introduction

Within competitive team sports contexts players must frequently and rapidly change velocity to dynamically adapt to evolving technical and tactical game demands. Such velocity changes can be positive (acceleration) or negative (deceleration), with both considered to be critical components of match-play performance. As illustrated in team sports such as soccer, players typically perform between 16-39 high-intensity accelerations (>3 m/s^2) and 43-59 high-intensity decelerations (<-3 m/s^2) per match (de Hoyo et al., 2016; Russell et al., 2016; Tierney, Young, Clarke, & Duncan, 2016). Furthermore, during the most demanding passages of play, players typically perform between 6.4 to 7.9 high-intensity accelerations and decelerations per minute (Martín-García, Casamichana, Gómez Díaz, Cos, & Gabbett, 2018). Consequently, the capacity to profile individual players' maximal horizontal sprint acceleration and deceleration abilities, and subsequently apply these insights to inform the design of performance enhancement and injury prevention strategies, may be highly beneficial within team sports environments.

Sprint accelerations have been extensively researched, providing new insights into the technical and mechanical capabilities needed to accelerate rapidly (Colyer, Nagahara, Takai, & Salo, 2018; Cross, Brughelli, Samozino, & Morin, 2017). Subsequently, training interventions targeting specific components of acceleration, such as the capacity to generate a greater horizontal component of ground reaction force, have been designed and practically implemented (Morin, Edouard, & Samozino, 2011; Morin et al., 2015; Morin & Samozino, 2016). Crucially, however, far fewer investigations have documented player's ability to decelerate rapidly. As such, there is substantially less available evidence capable of informing training strategies targeting the development of rapid deceleration capabilities (Harper & Kiely, 2018). This is problematic for sports science and medical professionals working with team sport athletes, where high intensity decelerations are typically performed more frequently than high intensity accelerations, and also inflict more negative consequences than equivalently intense accelerations (Harper, Carling, & Kiely, 2019).

Indeed, in comparison to accelerations, rapid decelerations impose higher mechanical loads during match play (Dalen, Ingebrigtsen, Ettema, Hjelde, & Wisløff, 2016) and result in a ground reaction force profile with significantly higher impact peaks and loading rates (Verheul et al., 2019). As such, there is an exacerbated risk of tissue damage and the likelihood of injury occurrence (Howatson & Milak, 2009; Keane, Salicki, Goodall, Thomas, & Howatson, 2015). Hence, the development of superior acceleration capabilities, if not accompanied by concurrently improving deceleration capabilities, could potentially lead to performance deficiencies in tasks that demand rapid decelerations from high approach velocities (Loturco et al., 2019). Accordingly, protocols capable of comprehensively and accurately profiling a player's ability to rapidly decelerate may provide important diagnostic information to help inform and guide performance enhancement and injury prevention training strategies.

Radar and laser devices are recommended for profiling horizontal sprint acceleration capabilities (Nagahara et al., 2017). Such devices could also be beneficially employed to profile maximal horizontal decelerations in more detail than previously possible (Simperingham, Cronin, & Ross, 2016). For example, commonly estimated mechanical outputs, such as horizontal force and power, can be derived for sprint accelerations by applying simple computational methods based on Newtonian principles applied to the centre of mass (Morin, Samozino, Murata, Cross, & Nagahara, 2019). Such metrics, potentially, provide valuable insights into the mechanical capabilities needed to decelerate rapidly. Only a small number of studies, however, have attempted to assess horizontal deceleration (Ashton & Jones, 2019; Cesar & Sigward, 2015, 2016; Graham-Smith, Rumpf, & Jones, 2018; Harper, Jordan, & Kiely, 2018; Naylor & Greig, 2015). Furthermore, only one of these studies examined the reliability and sensitivity of a laser device to measure maximal horizontal deceleration abilities (Ashton & Jones, 2019). However, this study only reported deceleration distances measured at 75, 50, 25 and 0% of the players maximal 15 m sprint velocity. Importantly, the trial-to-trial variability (measurement error) for all four of these variables was large (CV >10%), making it difficult to detect small but meaningful changes in horizontal deceleration ability. The authors suggested that these large CV values could be due to inter-trial differences in when, and where, athletes commenced their decelerations. Consequently, it is feasible that regulating the velocity at which decelerations commence, as per previous work investigating maximal horizontal deceleration abilities (Harper et al., 2018), could improve the reliability and sensitivity of collated deceleration data.

Therefore, the aim of this study was to determine the intra- and inter-day reliability and sensitivity of radar-derived kinematic and kinetic measurements, obtained during maximal horizontal decelerations from a regulated running velocity. It was hypothesised that a range of kinematic and kinetic variables would have good (ICC > 0.75, CV <10%) overall intra- and inter-day reliability, and would be sufficiently sensitive to detect small-to-moderate changes in deceleration performance.

Methods

Participants

Thirty-eight university sport athletes (*n* = 29 male, *n* = 9 female, age: 19.7 ± 1.7 years, height: 176 ± 10 cm, body mass: 73.0 ± 14.7 kg) engaging primarily in team sports (soccer, rugby league, rugby union, netball) volunteered to participate. The eligibility criteria specified, that for inclusion in the study, all participants had to be regularly partaking (3 times per week) in moderate to high intensity exercise, and be familiar with change of direction (COD) tasks requiring high intensity accelerations and decelerations. Participants who had suffered musculoskeletal injury, that had prevented participation in sport or physical activity within the previous 3 months, were excluded. Testing was conducted mid-way through the UK University competitive sport season. All participants completed testing on day 1 (intra-day analysis), whilst twelve participants (*n* = 8 male, *n* = 4 female, age: 19.4 ± 1.5 years, height: 175 ± 10 cm, body mass: 74.4 ± 14.3 kg) also completed testing on day 2 (inter-day analysis). The institutional ethics review committee at the University of Central Lancashire granted ethical approval. All participants were provided with a written information sheet that explained the requirements of the study, and the benefits and risks of participation. Participants were also given opportunity to ask any questions before providing voluntary informed written consent.

Experimental design

A within-subject repeated measures research design was used to determine the intra- and inter-test reliability of kinetic and kinematic variables obtained from a new test of maximal horizontal deceleration measuring using radar technology. All experimental procedures took place over a 2-week period, in which participants were required to complete 3 testing sessions with at least 48 hours recovery between. In the first test session all participants had anthropometric measurements taken and completed a 20 m horizontal sprint. They were then familiarised with the protocols of the maximal horizontal deceleration test. Familiarisation involved participants firstly observing a demonstration of the maximal horizontal deceleration test. Following this all participants practiced the deceleration test following a progressive increase in intensity (70, 80, 100% perceived effort). In the subsequent 2 sessions participants completed the maximal horizontal deceleration test to allow determination of intra- and inter-test reliability. Prior to all testing participants completed the same 15-minute standardised warm-up that included forward and backward jogging, dynamic stretching, and 3 practice trials of the deceleration test following a progressive increase in intensity (70,80 and 100% perceived effort). To reduce the potential influence of confounding variables all sessions were completed at the same time of the day (9:00am to 12:00pm) on an indoor artificial sports surface. Furthermore, the same accredited sport and exercise scientist administered all test instructions, and measurements, and conducted subsequent data analysis.

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

Sprints times were recorded over 20 m distance using timing gates (Witty, Microgate, Bolzano, Italy) set to a height of 0.8m (Cronin & Templeton, 2008). Times were recorded to the nearest 0.01s. 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 2 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 was assessed using an acceleration-deceleration ability (ADA) test (Harper et al., 2018). Participants were instructed to use the same start protocol employed for the horizontal sprint test and to sprint maximally over 20 m before performing a maximal horizontal deceleration. The 20 m point marking the start of the deceleration phase was identified with tall marker poles. Immediately following the end of the deceleration, players backpedalled to the 20 m line. This created a clear change in velocity on the instantaneous velocity-time graph captured by the radar device, and enabled the end of the deceleration phase to be easily identified (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 was asked to repeat the test following at least a 3-minute recovery period. Participants were asked to perform a maximum of 5-trials, with the 2 successful trials with the highest average deceleration used for analysis.

<INSERT FIGURE 1 ABOUT HERE>

Instantaneous horizontal velocity was measured throughout all phases of the test using a radar device (Stalker ATS II, Applied Concepts, Inc., Dallas, TX, USA) sampling at 47 Hz, which was connected to a laptop with the Stalker ATS system software (Version 5.0, Applied Concepts, Inc., Dallas, TX, USA) for data acquisition. To enable instantaneous horizontal velocity to be recorded whilst participant was moving away (acceleration and deceleration phases) and towards (backpedal to signify end of deceleration phase) the radar, the target direction setting on the radar was set to 'both'. The radar device was mounted on a heavy-duty tripod and positioned 5 m behind the start line, which is within the 4.6 to 9.6 m distance recommended by the manufacturer for recording acceleration and braking run tests. The radar device was set to a height 1 m above the ground to approximately align with the participant's centre of mass. When the participant was in the stationary start position, data recording was started using the 'any key' feature of the Stalker ATS system software, and a verbal instruction of 'when you are ready' provided to the participant. Data capture was ended using the 'any key' feature once the participant had backpedalled to the 20 m line following the maximal horizontal deceleration.

Data analysis

All data was manually processed in the graph mode editor of the Stalker ATS software following similar procedures outlined by Simperingham et al. (2017) for horizontal force-velocity-power profiling during short sprint-running acceleration. This involved: (i) deleting all data recorded before the start of the sprint and following the end of the deceleration phase, (ii) nominating all trials to be ‘acceleration runs’ thereby forcing the start of the velocity-time curve through the zero point, (iii) applying a digital fourth order, zero lag Butterworth filter (as recommended by the manufacturer), and (iii) manually removing unexpected high and low data points on the velocity-time curve that were likely caused by segmental movements of the participants while sprinting. Once manual processing had been completed instantaneous horizontal velocity (*v*), time (*t*) and distance (*d*) for each trial was exported to Microsoft Excel for further analyses.

The start of the deceleration phase was defined as the time point immediately following the maximum velocity (V_{max}) achieved during the 20 m sprint. The end of the deceleration phase was defined as the lowest velocity (V_{low}) following V_{max}. The deceleration phase was also further divided into early and late deceleration phases by using the time point associated with 50% V_{max} (Figure 2).

< INSERT FIGURE 2 ABOUT HERE >

Instantaneous horizontal deceleration was calculated between each data point captured across the entire deceleration phase using the following equation:

$$Deceleration\ (m/s^2) = \frac{(v_f - v_i)}{(t_f - t_i)} \qquad (1)$$

Where *v* is the velocity, *t* is the time, *f* is the final velocity or time, and *i* is the initial velocity or time.

Kinematic variables analyzed included: (1) average deceleration (DEC_{ave}; average of all instantaneous deceleration values calculated from start to end of deceleration phase), (2) maximum deceleration (DEC_{max}; highest instantaneous deceleration value calculated between start and end of deceleration phase), (3) early-deceleration (E-DEC; average of all instantaneous deceleration values calculated between start of deceleration phase to 50% V_{max}, (4) late-deceleration (L-DEC; average of all instantaneous deceleration values calculated between 50% V_{max} and end of deceleration phase), (5) time to stop (TTS; time taken from start to end of deceleration phase), (6) time to 50% V_{max} (TT50%V_{max}; time taken from the start of the deceleration phase to 50% V_{max}) and (7) distance to stop (DTS; distance travelled from start to end of deceleration phase).

Kinetic variables estimated in the deceleration phase included average horizontal braking force (HBF_{ave}), braking power (HBP_{ave}) and braking impulse (HBI_{ave}) calculated using the average of all instantaneous HBF, HBI and HBP values obtained from start to end of deceleration. Also estimated were the average HBF, HBP and HBI during the early and late deceleration phases using instantaneous values obtained between the start of deceleration and 50% V_{max}, and 50% V_{max} and end of deceleration, respectively. Maximal HBF, HBP and HBI were calculated using the highest instantaneous value between start and end of deceleration phase.

Instantaneous HBF was calculated between each data point during the deceleration phase using Newton's second law of motion:

$$\mathrm{HBF}\,(t) = [m \times a\,(t)] + \mathrm{F}_{air}\,(t) \quad (2)$$

Where *m* is the body mass of the participant and F_{air} is the air friction, which is influenced by the frontal area of the participant (Af) (Morin et al., 2019):

$$\mathrm{A_f} = (0.2025 \times \mathrm{height}^{0.725} \times \mathrm{mass}^{0.425}) \times 0.266 \quad (3)$$

Instantaneous HBP was calculated between each data point during the deceleration phase using the product of HBF and *v*:

$$\mathrm{HBP} = \mathrm{HBF} \times v \quad (4)$$

Instantaneous HBI was calculated between each data point during the deceleration phase using change in momentum:

$$\mathrm{J\,(t)} = \mathrm{M_f} - \mathrm{M_i} \quad (5)$$

Where J is the impulse, M_f is the final momentum and M_i is the initial momentum. Instantaneous momentum was calculated using the following equation:

$$\text{Momentum (t)} = \text{v} \times \text{mass} \quad (6)$$

Statistical analysis

The mean ± SD was calculated for all radar derived variables. Intra- and inter-day reliability was calculated by determining the relative (intra-class correlation coefficient; ICC) and absolute (coefficient of variation; CV%) reliability using the 'consecutive pairwise' Microsoft Excel spreadsheet (Hopkins, 2015). This spreadsheet uses the ICC (3,1), which provides the correlation expected between pairs of measurements in any two trials, when all participants have performed the same two trials. CV was calculated from the TE, and expressed as a %. The thresholds used to interpret the ICC were taken from guidelines (Koo & Li, 2016) for reporting ICC values: ≤ 0.49 = poor; 0.50 to 0.74 = moderate; 0.75 to 0.89 = good; ≥ 0.90 = excellent. The CV% was interpreted using the following scale (McMahon, Lake, & Comfort, 2018): > 15 poor; 10 to 15 moderate; 5 to 10 good; < 5 excellent. Overall reliability was interpreted by combining both the ICC and the CV% scales as follows: ICC > 0.9 and CV% < 5 = excellent; ICC 0.75 to 0.9 and CV% < 10 = good; ICC < 0.75 or CV% > 10 = moderate; ICC <0.75 and CV% <10 = poor. The 90% confidence intervals for all reliability results were also included.

To determine the sensitivity of each radar derived variable the raw TE obtained from the Microsoft Excel spreadsheet (Hopkins, 2015) was compared to the smallest worthwhile change (SWC). SWC was calculated by multiplying the between-subject SD by 0.2 ($SWC_{0.2}$), which is a small effect, or by 0.5 ($SWC_{0.5}$), which is an alternative moderate effect. If the TE was less than the SWC the test variable was rated as 'good', if the TE was equal to the SWC it was rated as 'OK', and if the TE was higher than the SWC it was rated 'poor'.

Results

Intra-day reliability and sensitivity

The mean and standard deviation for all kinematic and kinetic variables connected with the best 2 average deceleration trials on day 1 of testing are shown in table 1. The corresponding ICC and CV% values to determine intra-day reliability, and the TE and SWC to determine the sensitivity of each test variable are also shown in table 1. Of the kinematic variables only V_{max} had excellent (ICC = 0.97, CV = 1.4%) overall intra-test reliability, and was able to detect the $SWC_{0.2}$. TT50%V_{max} (ICC = 0.76, CV = 8%), TTS (ICC = 0.82, CV = 5.3%), DTS (ICC = 0.76, CV = 7.2%), DEC_{ave} (ICC = 0.87, CV = 5.2%) and E-DEC_{ave} (ICC = 0.76, CV = 8.8%) had good overall intra-test reliability.

However, only TTS and DEC_{ave} demonstrated sufficient sensitivity to detect the $SWC_{0.5}$, with TT50%V_{max}, DTS and E-DEC_{ave} rated as 'OK'.

All kinetic variables apart from L-HBP_{ave}, HBF_{max} and HBP_{max} had good (ICC > 0.8, CV < 10%) overall reliability. However, only HBP_{ave} had sufficient sensitivity to detect the $SWC_{0.2}$. All kinetic variables were sensitive to detect $SWC_{0.5}$.

Inter-day reliability and sensitivity

The mean and standard deviation for all kinematic and kinetic variables from day 1 and day 2 of testing are shown in table 2. The corresponding ICC and CV% values to determine inter-test reliability, and the TE and SWC to determine the sensitivity of each variable across days are also shown in table 2. Similar to intra-day reliability for the kinematic variables, only V_{max} had excellent (ICC = 0.96, CV = 1.7%) overall inter-day reliability, and was able to detect the $SWC_{0.2}$. TTS (ICC = 0.45, CV = 8.2%), DEC_{ave} (ICC = 0.73, CV = 8.0%) and DEC_{max} (ICC = 0.61, CV = 7.9%) had moderate overall inter-day reliability. All other kinematic variables had poor (ICC = < 0.75, CV > 10%) inter-day reliability.

For the kinetic variables HBF_{ave} (ICC = 0.90, CV = 9.3%), HBP_{ave} (ICC = 0.93, CV = 8.9%) and HBI_{ave} (ICC = 0.90, CV = 9.0%) had overall good inter-day reliability. However, only HBP_{ave} and HBI_{ave} were sensitive to detect the $SWC_{0.5}$. HBF_{max} (ICC = 0.89, CV = 8.2%), HBP_{max} (ICC = 0.96, CV = 6.2%) and HBI_{max} (ICC = 0.90, CV = 8.2%) also had good overall inter-day reliability, and were sensitive enough to detect the $SWC_{0.5}$. Both E-HBF_{ave} (ICC = 0.89, CV = 12.2) and L-HBF_{ave} (ICC = 0.76, CV = 11.7) had moderate inter-day reliability, and were sensitive enough to detect $SWC_{0.5}$. Similarly, both E-HBI_{ave} (ICC = 0.87, CV = 8.2%) and L-HBI_{ave} (ICC = 0.77, CV = 11.4%) had moderate inter-day reliability, although only E-HBI_{ave} was sensitive to detect the $SWC_{0.5}$.

Discussion and Implications

To our knowledge, this is the first study to examine the intra- and inter-day reliability and sensitivity of radar-derived kinematic and kinetic variables measured during a novel maximal horizontal deceleration test. The major findings of this study are: (1) a number of kinematic (i.e. TT50%V_{max}, TTS, DTS, DEC_{ave}, E-DEC_{ave}) and kinetic (i.e. HBF_{ave}, HBP_{ave}, HBI_{ave}, HBI_{max}) variables had good overall intra-day reliability, and were sensitive to detect moderate changes in performance, (2) kinematic variables (TTS, DEC_{ave} and DEC_{max}) had moderate overall inter-day reliability, and (3) only kinetic variables (HBF_{ave}, HBP_{ave}, HBI_{ave}, HBF_{max}, HBP_{max}, and HBI_{max}) had good overall inter-day reliability, and were adequately sensitive to detect moderate changes in performance. Therefore, the original study hypothesis can be rejected, since only kinetic variables had good overall intra- and inter-day reliability, and were sufficiently sensitive to detect small-to-moderate changes in horizontal deceleration ability.

Previous studies measuring deceleration performance have used either a COD (Hader, Mendez-Villanueva, Palazzi, Ahmaidi, & Buchheit, 2016; Hader, Palazzi, & Buchheit, 2015; Jones, Thomas, Dos'Santos, McMahon, & Graham-Smith, 2017) or horizontal sprint acceleration-to-deceleration task (Ashton & Jones, 2019; Cesar & Sigward, 2015, 2016; Graham-Smith et al., 2018; Harper et al., 2018; Naylor & Greig, 2015). The use of a horizontal sprint acceleration to deceleration task allows deceleration performance to be examined independently of COD-imposed technical constraints. Furthermore, the deceleration phase during a COD task typically occurs from sub-maximal sprinting velocities (Dos'Santos, Thomas, Comfort, & Jones, 2018; Hader et al., 2015), and subsequently may be unreflective of the deceleration characteristics necessary to successfully decelerate from near-maximum sprint velocities. Accordingly, during COD-related deceleration tasks, the deceleration challenge may not be a valid representation of a performer's maximal deceleration capacity.

Whilst a number of previous studies have used a horizontal sprint acceleration-to-deceleration task to examine maximal deceleration capabilities, only one of these studies examined the reliability and sensitivity of the measures obtained (Ashton & Jones, 2019). Here, deceleration performance was measured using a laser device following 15 m sprint acceleration, and evaluated using the deceleration distance measured at 75, 50, 25 and 0% of the participant's 15 m horizontal sprint velocity. Based on their findings, the authors subsequently suggested using total DTS (0% of 15 m velocity) to measure deceleration ability. However, due to the higher average CV (10.52%) for this variable, it was also recommended that further work to be conducted to establish a protocol that is more sensitive to tracking changes in horizontal deceleration ability. It is likely, as suggested by the authors of this study, that the high measurement variability, using this protocol, was due to the start of the deceleration phase being defined as the velocity at the 15 m mark. For instance, the average 15 m velocity was 5.39 m/s, which was much lower than the average peak velocity (6.84 m/s) recorded during the test. This finding implies that participants had already started to decelerate prior to the 15 m mark. To overcome this problem, in the current study, we defined the start of the deceleration phase as the time point immediately following V_{max} achieved during the 20 m sprint. This definition has previously been used to quantify deceleration ability using a laser device (Graham-Smith et al., 2018). Furthermore, in order to reduce the likelihood of participants commencing deceleration prior to the 20 m mark, and to ensure better precision and consistency in when the deceleration phase commenced, any 20 m time that was 5% greater than the participants 20 m linear sprint time (without a maximal deceleration) was considered an unsuccessful trial. Using this criteria the average distance at which deceleration commenced was 17.2 m, with excellent (3.7%) to good (5.9%) consistency demonstrated between trials and between days, respectively. Therefore, these findings demonstrate that by using V_{max} to denote the start of deceleration, and by regulating the time at which deceleration commenced, consistent distances at which deceleration commences can be obtained.

The DTS variable in the present study had good overall intra-day reliability (ICC = 0.76, CV = 7.2%), but poor inter-day reliability (ICC = 0.45, CV = 10.8%). The kinematic variable with the best intra- and inter-day reliability and sensitivity was DEC_{ave}. The overall reliability of this variable was good (ICC = 0.87, CV = 5.2%) to moderate (ICC = 0.73, CV = 8.0%), with the sensitivity to detect small changes in performance rated as ‘good’, for intra-day reliability. These findings are similar to those of Varley, Fairweather, & Aughey (2012), who reported a CV of 6% for DEC_{ave} when the deceleration phase was measured using a 10Hz global positioning system during a horizontal running task performed from velocities ranging between 5 and 8 m/s. In the present study decelerations commenced from a much narrower velocity range (7.17 to 7.36 m/s) and were measured using a higher sampling rate (47 Hz). In the study by Varley et al. (2012) the rate of deceleration was not reported. Therefore, the similar CV% found between these studies is likely due to the higher rates of deceleration (-4.36 to -4.44 m/s^2) performed in the present study. Nonetheless, based on the findings of the present study, DEC_{ave} is the kinematic variable of choice when monitoring SWC in maximal horizontal deceleration ability.

In sprint acceleration research, laser, radar and video devices are commonly used, in conjunction with using simple computational methods, to provide advanced insights into the mechanical (kinetic) determinants of sprint acceleration performance

(Morin et al., 2019; Romero-Franco et al., 2017; Simperingham et al., 2016). Such an approach provides a more in-depth understanding of the underpinning mechanical features determining maximal sprint acceleration performance, and can be subsequently used to inform individualised and specific training prescriptions (Morin & Samozino, 2016). Despite widespread use in sprint acceleration profiling, this is the first study to use instantaneous horizontal velocity-time data to estimate the horizontal braking force (HBF), power (HBP) and impulse (HBI) during a maximal horizontal deceleration task. The findings of this study show that, when averaged across the entire deceleration phase, HBF, HBP and HBI had good overall intra-day (ICC = 0.95 to 0.96, CV = 5.1 to 5.7%) and inter-day reliability (ICC = 0.90 to 0.93, CV = 8.9 to 9.3%), and were sufficiently sensitive to detect moderate changes in horizontal deceleration ability.

Subsequently, as is the case with horizontal sprint acceleration profiling, coaches and sport science professionals can productively use these mechanical outputs to obtain more in-depth understanding of their athlete's deceleration capabilities. In different athletic context, such as rugby and American Football, within which players operating in different positions typically have widely varying body masses, changes in whole-body momentum—referred to in this study as the horizontal braking impulse (HBI)—could provide particularly insightful information. Especially since these players will inevitably have to generate higher braking forces in order to reduce higher whole-body momentums. Future research should investigate the influence of these mechanical variables on maximal deceleration performance capacities (e.g. average deceleration), and compare the validity of these variables to direct measures obtained from embedded force platforms.

In order to obtain a more thorough evaluation of deceleration performance, the deceleration velocity profile was sub-divided into 'early' and 'late' deceleration phases. It has previously been shown in walking gait termination that decelerating can involve distinct phases: 'preparatory brake', 'fast brake' and 'final brake' (Jian, Winter, Ishac, & Gilchrist, 1993). The 'fast brake' period comprising a rapid reduction in velocity with greater braking forces, whereas the 'final brake' comprised a small reduction in velocity, with the main goal being to stabilise the centre of mass above the base of support. By examining both the early and late deceleration phases, it is subsequently possible to calculate a horizontal deceleration or braking-ratio, which could allow further identification of individual-specific deceleration strategies and training needs. In the present study, only HBF and HBI variables had good overall intra-day reliability

(ICC = 0.84 to 0.91, CV = 8.7 to 9.6%), and were sensitive enough to detect moderate changes in the early and late deceleration phases. Furthermore, both of these variables had moderate overall inter-day reliability (ICC = 0.76 to 0.87, CV = 11.4 to 12.2%) and were able to detect moderate changes in the early deceleration phase. Subsequently, for the purpose of monitoring the early and late deceleration phases, the kinetic variables HBF and HBI are recommended. Further research is required to investigate the importance of the early and late deceleration phases on overall deceleration performance, and the neuromuscular performance characteristics that may contribute to superior early and late deceleration performance.

This study has limitations similar to those highlighted in previous work examining the reliability of horizontal force-velocity power profiling during short sprint accelerations (Simperingham et al., 2019). Specifically, raw data captured from the radar was filtered using the manufacturers own proprietary software. Therefore, it is possible that alternative post-processing methods may be more applicable. For example, analysing the raw data points using a rolling average across different time frames (e.g. 0.2, 0.3s) or by filtering using different cut-off frequencies. Although this study attempted to control the start and end of the deceleration phase, it is possible that different approaches may lead to improved reliability and sensitivity. For example, using a 'start' and 'end' of deceleration phase criteria that is based on a deceleration threshold, such as, when deceleration is below and above -0.2 m/s^2, respectively. Therefore, future research should investigate the reliability and sensitivity of different criteria that could be used to define the 'start' and 'end' of the deceleration phase. Furthermore, the radar device used in this study sampled at a rate of 47Hz. Other devices, such as lasers, capable of sampling at higher frequencies, may prove more reliable and sensitive to deceleration data. Additionally, low-cost, user friendly high speed video (capable of sampling at 240 Hz), as used to profile sprint acceleration performance and the associated mechanical outputs (Romero-Franco et al., 2017), could be used to simultaneously gain important deceleration kinematic and kinetic data. The simple computational methods used to calculate mechanical outputs have not been validated and, subsequently, may therefore under- or over-estimate the actual values reported. The participants used in this study were all young University sport athletes. Research to investigate whether more experienced and higher performing (and perhaps less variable) athletes demonstrate a greater level of assessment consistency is merited. Also the horizontal acceleration-to-deceleration task used in this study was performed after one familiarisation session, and on an artificial indoor surface. Reliability and sensitivity of the data may, subsequently, be further improved when performed on sport-specific surfaces, or with more than one familiarisation session.

Finally, although the horizontal deceleration test used in the current study protocol requires multiple high intensity efforts, it replicates common team sport training tasks. Therefore, practitioners could implement this horizontal deceleration test into routine athlete monitoring systems, whilst also gaining performance and injury risk reduction benefits. Furthermore, simple adjustments to this deceleration test protocol—for example using different acceleration distances (5, 10 and 15 m) and prescribed distance targets, similar to those commonly used in COD tests (such as the 505), could provide an adaptive means to gather information on a diversity of deceleration tasks and abilities. Clearly, however, future research is needed to determine if the deceleration abilities assessed at lower horizontal velocities or momentums are reflective of the deceleration abilities assessed at higher horizontal velocities or momentums.

Conclusions

Using a novel maximal horizontal deceleration test, a number of radar derived kinematic and kinetic variables had good intra-day reliability and were sufficiently sensitive to detect small-to-moderate worthwhile changes in deceleration performance. Only kinetic variables had good inter-day reliability, and were adequately able to detect moderate worthwhile changes in deceleration performance after a single familiarisation session. Consequently, coaches and sport science professionals can use mechanical outputs obtained from simple computational methods to profile an individual's maximal horizontal deceleration performance. In future, these approaches may provide insights illuminating the neuromuscular capabilities needed to decelerate maximally.

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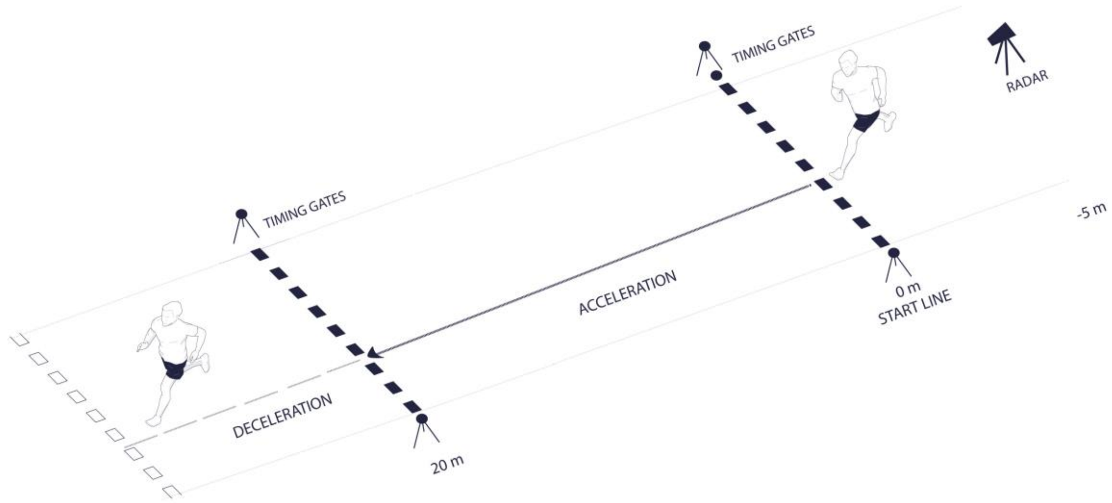

Figure 1. Acceleration-deceleration ability (ADA) test layout used to assess players maximal horizontal deceleration ability.

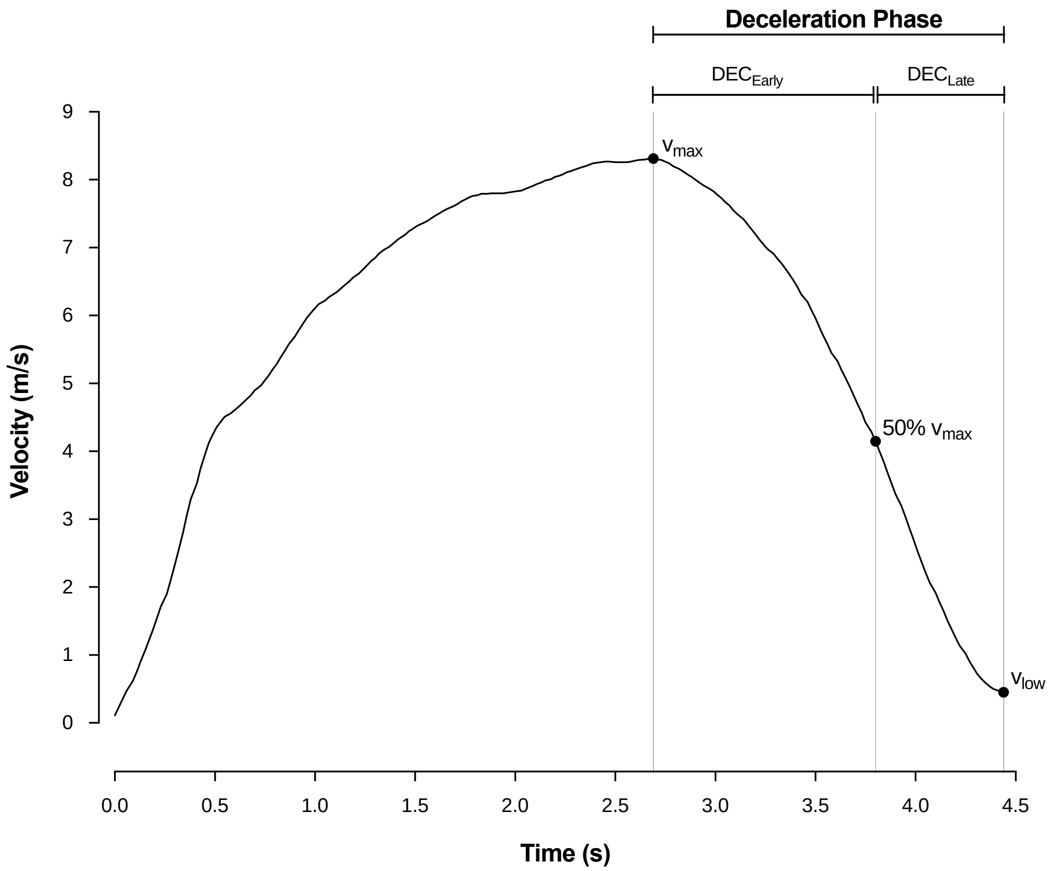

Figure 2. Example of velocity-time profile showing deceleration phase following manual processing with Stalker ATS™ system software.

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; $\mathrm{DEC}_{\mathrm{Early}}$ = early deceleration phase representing time between V_{max} and 50%V_{max}; $\mathrm{DEC}_{\mathrm{Late}}$ = late deceleration phase representing time between 50%V_{max} and V_{low}

Table 1. Intra-day reliability and sensitivity of radar-derived kinematic and kinetic variables collected from the best 2 trials.

			Intra-day reliability			Sensitivity				
Variable	**Trial 1**	**Trial 2**	**ICC (90% CL)**	**CV% (90% CL)**	**Rating**	**TE**	**$SWC_{0.2}$**	**Rating**	**$SWC_{0.5}$**	**Rating**
Kinematic										
V_{max} (m/s)	7.34 ± 0.55	7.36 ± 0.54	0.97 (0.95 to 0.98)	1.4 (1.1 to 1.6)	*Excellent*	0.10	0.11	*Good*	0.27	*Good*
TT50%V_{max} (s)	0.96 ± 0.18	0.98 ± 0.13	0.76 (0.62 to 0.85)	8.3 (7.2 to 10.3)	*Good*	0.08	0.03	*Marginal*	0.08	*OK*
TTS (s)	1.49 ± 0.18	1.51 ± 0.17	0.82 (0.70 to 0.89)	5.3 (4.7 to 6.7)	*Good*	0.08	0.04	*Marginal*	0.09	*Good*
DTS (m)	6.78 ± 1.06	6.92 ± 0.89	0.76 (0.61 to 0.85)	7.2 (6.0 to 10.1)	*Good*	0.49	0.20	*Marginal*	0.49	*OK*
DEC_{ave} (m/s^2)	-4.45 ± 0.61	-4.44 ± 0.62	0.87 (0.78 to 0.92)	5.2 (4.3 to 6.3)	*Good*	0.23	0.12	*Marginal*	0.31	*Good*
E-DEC_{ave} (m/s^2)	-3.89 ± 0.72	-3.86 ± 0.63	0.76 (0.61 to 0.85)	8.8 (7.5 to 10.8)	*Good*	0.34	0.13	*Marginal*	0.34	*OK*
L-DEC_{ave} (m/s^2)	-5.57 ± 0.79	-5.62 ± 0.78	0.53 (0.31 to 0.70)	9.7 (8.2 to 12.0)	*Moderate*	0.54	0.16	*Marginal*	0.39	*Marginal*
DEC_{max} (m/s^2)	-8.50 ± 1.07	-8.46 ± 1.30	0.55 (0.33 to 0.71)	9.6 (8.0 to 11.8)	*Moderate*	0.81	0.24	*Marginal*	0.59	*Marginal*
$TTDEC_{max}$ (s)	1.11 ± 0.27	1.15 ± 0.22	0.10 (-0.17 to 0.36)	20.4 (17.8 to 25.7)	*Poor*	0.23	0.05	*Marginal*	0.12	*Marginal*
Kinetic										
HBF_{ave} (N)	-318 ± 81	-318 ± 78	0.95 (0.92 to 0.97)	5.5 (4.7 to 6.9)	*Good*	17.6	15.9	*Marginal*	39.7	*Good*
E-HBF_{ave} (N)	-271 ± 81	-270 ± 74	0.89 (0.82 to 0.94)	9.6 (8.1 to 11.9)	*Good*	25.9	15.5	*Marginal*	38.7	*Good*
L-HBF_{ave} (N)	-406 ± 90	-407 ± 98	0.84 (0.74 to 0.91)	9.4 (7.9 to 11.7)	*Good*	38.3	18.9	*Marginal*	47.1	*Good*
HBP_{ave} (W)	-1282 ± 371	-1273 ± 370	0.96 (0.94 to 0.98)	5.7 (4.8 to 7.0)	*Good*	72	74	*Good*	185	*Good*
E-HBP_{ave} (W)	-1508 ± 498	-1500 ± 479	0.93 (0.87 to 0.96)	9.1 (7.7 to 11.3)	*Good*	137	98	*Marginal*	244	*Good*
L-HBP_{ave} (W)	-927 ± 229	-907 ± 248	0.84 (0.73 to 0.90)	10.8 (9.1 to 13.3)	*Moderate*	99	48	*Marginal*	119	*Good*
HBI_{ave} (N/s)	-6.81 ± 1.71	-6.80 ± 1.65	0.96 (0.93 to 0.98)	5.1 (4.3 to 6.3)	*Good*	0.35	0.34	*Marginal*	0.84	*Good*
E-HBI_{ave} (N/s)	-5.89 ± 1.71	-5.85 ± 1.57	0.91 (0.84 to 0.95)	8.7 (7.3 to 10.9)	*Good*	0.51	0.33	*Marginal*	0.82	*Good*
L-HBI_{ave} (N/s)	-8.52 ± 1.89	-8.55 ± 2.05	0.85 (0.75 to 0.91)	9.1 (7.7 to 11.4)	*Good*	0.78	0.39	*Marginal*	0.99	*Good*
HBF_{max} (N)	-616 ± 137	-610 ± 149	0.82 (0.71 to 0.89)	10.1 (8.6 to 12.6)	*Moderate*	62.1	28.6	*Marginal*	71.4	*Good*
HBP_{max} (W)	-2555 ± 781	-2544 ± 713	0.85 (0.75 to 0.91)	11.8 (9.9 to 14.6)	*Moderate*	301	150	*Marginal*	374	*Good*
HBI_{max} (N/s)	-12.44 ± 2.75	-12.26 ± 2.96	0.83 (0.72 to 0.90)	9.8 (8.3 to 12.2)	*Good*	1.21	0.57	*Marginal*	1.43	*Good*

V_{max} = maximum velocity; TT50%V_{max} = 50% of maximal velocity; TTS = time to stop; DTS = distance to stop; DEC_{ave} = average deceleration; E-DEC = average early deceleration; L-DEC = average late deceleration; DEC_{max} = maximum deceleration; $TTDEC_{max}$ = time to maximum deceleration; HBF_{ave} = average braking force; E-HBF_{ave} = average early braking force; L-HBF_{ave} = average late braking force; HBP_{ave} = average braking power; E-HBP_{ave} = average early braking power; L-HBP_{ave} = average late braking power; HBI_{ave} = average braking impulse; E-HBI_{ave} = average early braking impulse; L-HBI_{ave} = average late braking impulse; HBF_{max} = maximum braking force; HBP_{max} = maximum braking power; HBI_{max} = maximum braking impulse.

Table 2. Inter-day reliability and sensitivity of radar-derived kinematic and kinetic variables collected from the average of the best 2 trials, completed on 2 separate days of testing.

			Inter-test reliability			Sensitivity				
Variable	**Day 1**	**Day 2**	**ICC (90% CL)**	**CV% (90% CL)**	**Rating**	**TE**	**$SWC_{0.2}$**	**Rating**	**$SWC_{0.5}$**	**Rating**
Kinematic										
V_{max} (m/s)	7.19 ± 0.54	7.17 ± 0.50	0.96 (0.88 to 0.98)	1.7 (1.3 to 2.6)	*Excellent*	0.12	0.19	*Good*	0.46	*Good*
TT50%V_{max} (s)	0.97 ± 0.18	0.96 ± 0.13	0.59 (0.16 to 0.83)	10.8 (8.1 to 16.8)	*Poor*	0.10	0.03	*Marginal*	0.08	*Marginal*
TTS (s)	1.49 ± 0.17	1.47 ± 0.14	0.45 (-0.03 to 0.77)	8.2 (6.1 to 12.7)	*Moderate*	0.12	0.03	*Marginal*	0.08	*Marginal*
DTS (m)	6.71 ± 1.02	6.53 ± 0.83	0.45 (-0.03 to 0.76)	10.8 (8.0 to 16.7)	*Poor*	0.71	0.19	*Marginal*	0.46	*Marginal*
DEC_{ave} (m/s^2)	-4.36 ± 0.64	-4.39 ± 0.63	0.73 (0.40 to 0.90)	8.0 (6.0 to 12.4)	*Moderate*	0.35	0.13	*Marginal*	0.32	*Marginal*
E-DEC_{ave} (m/s^2)	-3.79 ± 0.71	-3.77 ± 0.59	0.55 (0.10 to 0.81)	12.1 (9.0 to 18.7)	*Poor*	0.46	0.13	*Marginal*	0.33	*Marginal*
L-DEC_{ave} (m/s^2)	-5.55 ± 0.60	-5.53 ± 0.70	0.28 (-0.23 to 0.67)	10.1 (7.6 to 15.7))	*Poor*	0.56	0.13	*Marginal*	0.32	*Marginal*
DEC_{max} (m/s^2)	-8.27 ± 0.91	-8.40 ± 1.07	0.61 (0.19 to 0.84)	7.9 (5.9 to 12.2)	*Moderate*	0.65	0.20	*Marginal*	0.50	*Marginal*
$TTDEC_{max}$ (s)	1.16 ± 0.17	1.17 ± 0.17	0.49 (0.01 to 0.78)	11.0 (8.2 to 17.1)	*Poor*	0.13	0.03	*Marginal*	0.09	*Marginal*
Kinetic										
HBF_{ave} (N)	-322 ± 91	-321 ± 75	0.90 (0.73 to 0.96)	9.3 (7.0 to 14.4)	*Good*	29.9	16.7	*Marginal*	41.8	*Good*
E-HBF_{ave} (N)	-273 ± 91	-273 ± 70	0.86 (0.65 to 0.95)	12.2 (9.1 to 18.9)	*Moderate*	33.2	16.2	*Marginal*	40.5	*Good*
L-HBF_{ave} (N)	-413 ± 102	-409 ± 80	0.76 (0.45 to 0.91)	11.7 (8.8 to 18.2)	*Moderate*	48.2	18.3	*Marginal*	45.8	*Marginal*
HBP_{ave} (W)	-1272 ± 414	-1252 ± 340	0.93 (0.81 to 0.97)	8.9 (6.6 to 13.8)	*Good*	112	76	*Marginal*	189	*Good*
E-HBP_{ave} (W)	-1490 ± 550	-1476 ± 436	0.89 (0.73 to 0.96)	12 (9.0 to 18.6)	*Moderate*	178	99	*Marginal*	248	*Good*
L-HBP_{ave} (W)	-926 ± 254	-899 ± 209	0.66 (0.26 to 0.86)	21.6 (16.2 to	*Poor*	259	83	*Marginal*	208	*Marginal*
HBI_{ave} (N/s)	-6.87 ± 1.93	-6.86 ± 1.59	0.90 (0.74 to 0.96)	9.0 (6.8 to 14.0)	*Good*	0.62	0.35	*Marginal*	0.88	*Good*
E-HBI_{ave} (N/s)	-5.91 ± 1.91	-5.91 ± 1.49	0.87 (0.67 to 0.95)	11.6 (8.6 to 17.9)	*Moderate*	0.68	0.34	*Marginal*	0.86	*Good*
L-HBI_{ave} (N/s)	-8.68 ± 2.13	-8.59 ± 1.70	0.77 (0.47 to 0.91)	11.4 (8.6 to 17.7)	*Moderate*	0.99	0.39	*Marginal*	0.96	*Marginal*
HBF_{max} (N)	-616 ± 149	-623 ± 134	0.89 (0.73 to 0.96)	8.2 (6.2 to 12.8)	*Good*	51.0	28.4	*Marginal*	70.9	*Good*
HBP_{max} (W)	-2456 ± 725	-2372 ± 627	0.96 (0.89 to 0.99)	6.2 (4.7 to 9.7)	*Good*	151	136	*Marginal*	339	*Good*
HBI_{max} (N/s)	-12.35 ± 2.99	-12.48 ± 2.68	0.90 (0.73 to 0.96)	8.2 (6.1 to 12.7)	*Good*	1.02	0.57	*Marginal*	1.42	*Good*

V_{max} = maximum velocity; TT50%V_{max} = 50% of maximal velocity; TTS = time to stop; DTS = distance to stop; DEC_{ave} = average deceleration; E-DEC = average early deceleration; L-DEC = average late deceleration; DEC_{max} = maximum deceleration; $TTDEC_{max}$ = time to maximum deceleration; HBF_{ave} = average braking force; E-HBF_{ave} = average early braking force; L-HBF_{ave} = average late braking force; HBP_{ave} = average braking power; E-HBP_{ave} = average early braking power; L-HBP_{ave} = average late braking power; HBI_{ave} = average braking impulse; E-HBI_{ave} = average early braking impulse; L-HBI_{ave} = average late braking impulse; HBF_{max} = maximum braking force; HBP_{max} = maximum braking power; HBI_{max} = maximum braking impulse.