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The Reliability, Bias, Differences, and Agreement Between Velocity Measurement Devices During the Hang Clean Pull

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Abstract

Kissick, CR, Techmanski, BS, Comfort, P, and Suchomel, TJ. The reliability, bias, differences, and agreement between velocity measurement devices during the hang clean pull. *J Strength Cond Res* 39(3): 289–294, 2025—This study examined the reliability, bias, differences, and agreement between the GymAware PowerTool (GA) and Tendo Power Analyzer (TENDO) during the hang clean pull (HCP). Fourteen resistance-trained men performed HCP repetitions with 20, 40, 60, 80, 100, 120, and 140% of their 1 repetition maximum hang power clean (1RM HPC) with GA and TENDO devices attached to the barbell. Least-products regression was used to examine instances of proportional and fixed bias for mean barbell velocity (MBV) and peak barbell velocity (PBV) between devices. In addition, Hedge's *g* effect sizes were calculated to determine the magnitude of the differences between devices. Excellent reliability was displayed by the GA for all measurements. While excellent reliability for the TENDO was displayed for MBV across all loads, only moderate-good reliability was present for PBV at loads >80% 1RM. The TENDO displayed proportional bias for both MBV and PBV as well as fixed bias for PBV at 140% 1RM compared with the GA. Despite the small effect sizes that existed between devices for both MBV (g = 0.35–0.57) and PBV (g = 0.23–0.54), none of these differences were practically meaningful. The GA and TENDO are reliable devices that can measure MBV and PBV accurately during the HCP; however, practitioners should note that the TENDO may overestimate MBV and PBV to a small extent (3.7–6.8% and 1.8–2.9%).

Key Words: weightlifting, Olympic lift, power clean, velocity-based training, load-velocity profile

Introduction

Weightlifting movements (e.g., snatch and clean and jerk) and their derivatives have been shown to provide a superior strength-power stimulus compared with traditional resistance training (e.g., squats, presses, and pulls) (33), jump training (58), and kettlebell training (34). Researchers have also shown that weightlifting pulling derivatives (i.e., clean and snatch variations that omit the catch phase) (40) have the potential to improve an individual's strength, jump, sprint, and change of direction performance (4,44–46). These training adaptations are likely underpinned by the ability of weightlifting pulling derivatives to provide both a force and velocity overload stimulus during the triple extension of the hip, knee, and ankle (plantar flexion) joints (35,39,40). For example, the hang clean pull (HCP) and other pulling derivatives (e.g., countermovement shrug, mid-thigh pull, pull from the floor, etc.) may be classified as force-dominant weightlifting pulling derivatives because they allow individuals to use loads greater than their 1 repetition maximum (1RM) of a catching variation such as a hang power clean (HPC) (6,7,27,28,30). Furthermore, researchers have shown that pulling derivatives that are more ballistic exercises such as the jump shrug and hang high pull performed with lighter loads may provide an effective velocity stimulus (19,20,36,38,54–56). Despite the existing findings, it is important that strength and conditioning practitioners understand best practices regarding loading each exercise to provide an optimal training stimulus to their athletes.

When examining the available weightlifting research, readers will find that weightlifting pulling derivatives have primarily been loaded using percentages of the subjects' 1 repetition maximum hang power clean (1RM HPC) or power clean (4–8,14,20,21,27,29,30,36–38,42–46,50,51,54,55). If a combination of weightlifting catching and pulling derivatives are prescribed, loading tends not to be an issue; however, if strength and conditioning practitioners prescribe pulling variations by themselves, it is important to be able to provide loads that represent the relative loads needed for the sought after performance adaptation(s). Researchers have discussed percentages of an individual's body weight (25,26), attempted to perform 1RM tests (3), and attempted to predict a 1RM using a load-velocity profile with a catching derivative 1RM velocity (53) as alternative loading methods for pulling derivatives. However, it is important to acknowledge that each method possesses its own limitations. First, performing weightlifting derivatives at different body weight percentages does not account for differences in relative strength (47,48), which may make it difficult to prescribe loads using this method. Second, there are currently no criteria to establish the 1RM of a weightlifting pulling derivative. Despite researchers using predetermined pulling heights for each subject during the 1RM high pull from the knee and mid-thigh clean pull tests (3), changes in barbell displacement (vertical and horizontal) and an

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individual's technique (e.g., increased back extension) may prevent this method from providing accurate information. Finally, researchers have also shown that using a load-velocity profile of the hang high pull that uses a 1RM HPC velocity as 1RM criteria possess considerable variation due to the subjects' exercise technique, anthropometrics, relative strength, and mobility and should, thus, not be used (53). In summary, despite the potential of some loading methods, additional research on loading alternatives appears warranted.

A popular method of load prescription termed velocity-based training (VBT) has become quite popular when implementing traditional resistance training exercises. Velocity-based training may be characterized by using technology to measure the velocity of an exercise (typically barbell velocity) throughout exercise sets to determine if the desired goal(s) of a training session or phase is being met (49,59). In this light, some researchers have indicated that velocity monitoring may be used to increase athlete motivation, estimate daily 1RMs for exercises, and establish velocity loss thresholds to promote more accurate loading (12,49,59). However, it should be noted that others have challenged the use of load-velocity profiles for estimating 1RMs (24) and the use of velocity loss thresholds in training (16–18). Despite the existing literature on the reliability and validity of VBT devices (1,2,11,31,60), most of this research has focused on traditional resistance training exercises, often performed using a fixed axis, Smith machine. By contrast, relatively few studies have examined the use of velocity measurement devices when using weightlifting derivatives (3,13,52,57). Despite the previous studies, there is currently no research that has examined the reliability and validity of VBT devices during the HCP performed with supramaximal loads (i.e., >100% 1RM). Given the potential to use loads upward to 140% 1RM HPC with the HCP (27), this information may benefit practitioners using VBT loading. The purpose of this study was to examine the reliability, bias, agreement, and magnitude of the differences between 2 VBT devices during the HCP performed across a spectrum of loads. It was hypothesized that both devices would provide reliable barbell velocity data but show some instances of either proportional or fixed bias. Based on previous findings (52), it was also hypothesized that there would be small-moderate differences in mean barbell velocity (MBV) and peak barbell velocity (PBV) between devices.

Methods

Experimental Approach to the Problem

A repeated-measures, cross-sectional design was used to examine the reliability, differences, and agreement between 2 different barbell velocity measurement devices during the HCP performed across 7 different loads. Each subject attended 2 testing sessions that included a 1RM HPC and familiarization session as well as a HCP testing session. The HCP loads were determined based on each subject's 1RM HPC.

Subjects

Fourteen resistance-trained men (age = 25.5 ± 4.5 years, body mass = 88.3 ± 15.4 kg, height: 176.1 ± 8.5 cm, relative 1RM back squat: 2.0 ± 0.3 kg·kg^{-1}, relative 1RM HPC: 1.2 ± 0.2 kg·kg^{-1}) with at least 4 years of resistance training experience with the HPC volunteered to participate in this study. Before the study, each subject had been training at least 3 times per week for the last year and incorporated the HPC or other weightlifting derivatives in their training at least once per week. Each subject read and signed an informed consent form before their participation. This study was approved by the Carroll University institutional review board (#19-015; approved April 15, 2019).

An a priori sample size estimation for a repeated-measures comparison was completed for this study. At a statistical power level of 0.90, it was determined that at least 10 subjects were needed with measurements that were largely correlated with each other (i.e., $r = 0.80$ or $R^2 = 0.64$) (52).

Procedures

Each subject attended the first testing session to obtain a 1RM HPC using previously discussed procedures (50,51,54). Subjects were weighed and then completed a general warm-up consisting of light-moderate cycling and dynamic stretching. The subjects then performed a specific warm-up with HPC sets using 30, 50, 70, and 90% of their self-estimated 1RM HPC. After the 90% warm-up set, the subjects performed maximum attempts until a 1RM HPC was achieved. Briefly, each subject performed all HPC repetitions by starting in the mid-thigh (power) position, performing a hip-hinge movement where the barbell was lowered to the top of their patellae and without pausing, transitioning back to the mid-thigh position, rapidly extending their hip, knee, and ankle joints and shrugging their shoulders, and performing the catch phase by racking the barbell across their shoulders in a front squat position (37,41). A minimum increase of 2.5 kg was required between 1RM attempts, and the subject was required to perform the lift without the top of their thighs dropping below parallel during the catch phase. This was visually monitored by the principal investigator and other testers. No more than 4 attempts were required to achieve a 1RM. Two to 3 minutes of rest were provided between warm-up sets, while 3–5 minutes were provided between 1RM attempts. After the 1RM was achieved, the subjects were given a self-selected rest period and then were familiarized with the HCP exercise by performing lightly loaded repetitions (<50% 1RM HPC). Subjects were provided with coaching cues that have been previously discussed within the literature (10).

The HCP testing session took place 1 week after the 1RM HPC session. Upon arrival, the subjects completed the same general and dynamic warm-up as the first testing session before performing a self-selected warm-up with an empty 20 kg barbell. The subjects then completed an exercise-specific warm-up that included sets of 3 repetitions of the HCP exercise with 30 and 50% of their 1RM HPC. After the warm-up, subjects performed 3, single HCP repetitions at 20, 40, 60, 80, 100, 120, and 140% of their 1RM HPC, with 1 minute of rest between repetitions and 2 minutes of rest between loads. Each load was performed in a progressive order to increase ecological validity. Briefly, the HCP repetitions started with the subject standing with the load in the mid-thigh (power) position. After receiving a countdown of "3, 2, 1, Go!," the subjects performed a hip-hinge movement where they lowered the barbell down to a position just above their patellae and without pausing, transitioned back to the mid-thigh position by flexing the knees and elevating the barbell back up to the thighs. After returning to the mid-thigh position, the subjects rapidly extended their hip, knee, and ankle (plantar flexion) joints to perform the second pull phase of the movement (10). It should be noted that every subject used lifting straps for the HCP repetitions performed at 100, 120, and 140% 1RM to minimize the impact of grip strength.

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Data Analyses. Mean barbell velocity and PBV of each HCP repetition were measured using a GymAware PowerTool ([GA] Kinetic Performance Technology, Braddon, Australia) and Tendo Power Analyzer ([TENDO] Tendo Sports Machines, London, United Kingdom). The GA and TENDO devices were placed outside of the weights on the right barbell sleeve where the tethers were vertical and parallel to each other (52). The GA device was connected through Bluetooth to a tablet (iPad 2, Apple Inc., Cupertino, CA) with the latest GA application version. The TENDO was attached through a wired connection to the device's computer that displayed the velocity information. Both devices measured the vertical displacement determined by their respective cable and spool designs; however, it should be noted that the GA accounted for horizontal displacement of the barbell by using angle correction and trigonometry in its calculations (60). The GA uses variable rate sampling with level crossing detection (32) whereby pulses from its optical encoder are used to track the cable position. The GA sensor waits every 20 ms for a transition on the position counter before time stamping and recording the cable position when a transition is detected. Using this approach, the data are not filtered as the sampling system adapts to the rate of change in the received signal. This, in turn, removes any potential noise or measurement error. In contrast, the TENDO used a minimum detectable threshold filter of 35 cm for sampling based on factory settings. Barbell velocity data were then calculated by each device as the change in displacement divided by the change in time; MBV and PBV represented the average or the greatest velocity measured during the concentric (upward) movement of the barbell, respectively.

Statistical Analyses

Normality of the data distribution of each variable was examined using the Shapiro-Wilks test. Two-way, mixed interclass class coefficients (ICC) and typical error expressed as coefficients of variation percentages (CV%) were used to determine the relative and absolute reliability of each device, respectively. The ICC values were interpreted as poor, moderate, good, and excellent if the magnitudes were <0.50, 0.50–0.74, 0.75–0.90, and >0.90, respectively (22). In addition, acceptable CV% were classified as $<10\%$ (9). Because the GA device was shown to have the highest validity against other VBT devices compared with 3D motion capture in previous research for the power clean (60), it was used as the criterion measurement in this study. Fixed and proportional bias were examined and compared with the GA device using previously described methods with ordinary least-products regression (23,52,57). Fixed bias was present if the 95% confidence interval for the intercept (x) did not include 0, whereas proportional bias was present if the 95% confidence interval for the slope (y) did not include 1.0. Lastly, Hedge's g effect sizes were used to examine the magnitude of the differences between devices. Effect sizes of 0.00–0.19, 0.20–0.59, 0.60–1.19, 1.20–1.99, 2.00–3.99, and ≥ 4.00 were interpreted as trivial, small, moderate, large, very large, and nearly perfect, respectively (15). All statistical tests were completed using SPSS 28 (IBM, Chicago, IL).

Results

The MBV and PBV data were normally distributed across all loads. The GA displayed excellent reliability for all MBV and PBV measurements, while the TENDO displayed excellent reliability for MBV across all loads and PBV at 20–80% 1RM, and good and moderate reliability for PBV at 100 and 120% 1RM and 140% 1RM, respectively (Table 1). The least-products regression statistics are displayed in Table 2. The TENDO displayed proportional bias for MBV and PBV as well as fixed bias for PBV at 140% 1RM HPC. In addition, small differences in MBV and PBV existed between the GA and TENDO across all loads (Table 3).

Discussion

The reliability, bias, differences, and agreement of 2 different VBT devices across a wide spectrum of loads during the HCP were examined in this study. The findings of this study were threefold; first, excellent reliability was displayed by the GA for all MBV and PBV measurements and the TENDO for MBV at all loads. However, only moderate-good reliability was present for PBV at loads $>80\%$ 1RM for the TENDO device. Second, the TENDO displayed proportional bias for both MBV and PBV and fixed bias for PBV at 140% 1RM compared with the GA. Finally, there were no practically meaningful differences in MBV or PBV between the GA and TENDO across any of the examined loads.

There was a high level of consistency for MBV and PBV measurements displayed for both the GA and TENDO devices during the HCP. These findings are similar to those displayed during the jump shrug and hang high pull exercises (52). It should, however, be noted that the PBV measured by the TENDO became less reliable during loads that were greater than 80% 1RM HPC, as indicated by progressively lower ICC values. Specifically, the ICC values were considered excellent with loads ranging 20–80%, good from 100 to 120%, and moderate at 140% 1RM. An explanation for these findings includes the barbell path during the transition and second pull phases of the HCP repetitions performed at heavier loads. Despite the ability to use loads upward to 140% with the HCP (27), it is possible that the technique of the current subjects may have broken down at heavier loads, ultimately leading to greater horizontal barbell displacement. While this may not be an issue for devices such as the GA that account for horizontal movement in determining barbell velocities (60), the TENDO fails to account for this. While the TENDO results in this study cannot be directly compared with other research, other researchers examined the reliability of PBV using the GA during the HCP. Despite displaying good-excellent reliability for 4 out of the 6 examined loads, Meechan and colleagues (27) showed moderate ICC values for PBV during the HCP performed with 40% (0.660) and 80% (0.676) of their subjects' 1RM power clean. While the previous findings may be explained by a potential lack of maximal effort with submaximal loads, it is important that strength and conditioning practitioners emphasize maximal effort regardless of the external load. In summary, the GA and TENDO may provide reliable barbell velocity information during the HCP; however, readers should be aware of a potential drop in reliability with heavier loads while using the TENDO.

When compared with the GA, the TENDO showed several instances of proportional and fixed bias during the HCP. Specifically, proportional bias for MBV and PBV as well as fixed bias for PBV was present during the 140% 1RM condition. The TENDO consistently overestimated MBV and PBV values by 3.7–6.8% and 1.8–2.9%, respectively, compared with the GA. The biases of the TENDO compared with the GA may be explained by the ability of the GA to account for horizontal displacement (60). It should be noted that although several instances of bias were present between devices, the differences between devices (g = 0.35–0.57 for MBV and g = 0.23–0.54 for PBV)

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Table 1

Test-retest reliability with 95% confidence intervals for the GymAware PowerTool and Tendo Power Analyzer devices during the hang clean pull.*

	ICC		CV%	
Load (%)	MBV	PBV	MBV	PBV
GymAware PowerTool				
20	0.97 (0.95–0.99)	0.94 (0.83–0.98)	3.6 (2.6–5.9)	3.6 (2.6–5.9)
40	0.97 (0.91–0.99)	0.90 (0.74–0.96)	4.2 (3.0–6.9)	3.9 (2.8–6.4)
60	0.97 (0.93–0.99)	0.95 (0.87–0.98)	3.3 (2.4–5.4)	2.9 (2.1–4.8)
80	0.96 (0.90–0.99)	0.93 (0.83–0.98)	3.5 (2.5–5.6)	3.7 (2.7–6.0)
100	0.97 (0.92–0.99)	0.93 (0.83–0.98)	3.5 (2.5–5.6)	2.8 (2.0–4.5)
120	0.94 (0.86–0.98)	0.88 (0.69–0.96)	4.3 (3.1–7.1)	3.1 (2.2–5.0)
140	0.96 (0.89–0.99)	0.90 (0.76–0.97)	3.5 (2.5–5.9)	3.5 (2.5–5.8)
Tendo Power Analyzer				
20	0.97 (0.92–0.99)	0.90 (0.44–0.97)	5.1 (3.7–8.4)	3.7 (2.6–6.0)
40	0.96 (0.91–0.99)	0.90 (0.75–0.96)	4.4 (3.1–7.1)	4.1 (3.0–6.8)
60	0.97 (0.93–0.99)	0.92 (0.80–0.97)	3.2 (2.3–5.2)	4.0 (2.9–6.5)
80	0.97 (0.91–0.99)	0.90 (0.75–0.96)	3.1 (2.2–5.1)	3.9 (2.8–6.3)
100	0.93 (0.82–0.97)	0.86 (0.65–0.95)	4.8 (3.5–7.9)	3.3 (2.4–5.4)
120	0.95 (0.87–0.98)	0.83 (0.58–0.94)	3.8 (2.7–6.2)	3.7 (2.7–6.1)
140	0.95 (0.87–0.99)	0.73 (0.24–0.92)	3.7 (2.7–6.2)	3.1 (2.2–5.2)

*CV% = typical error expressed as a coefficient of variation percentage; ICC = 2-way, mixed intraclass correlation coefficient; Load = % 1RM hang power clean; MBV = mean barbell velocity; PBV = peak barbell velocity.

were not classified as moderate and, thus, the amount of bias present may be considered acceptable. Although this is the first study to examine the bias between devices during the HCP, these findings are supported by researchers who showed that similar biases were present when comparing the TENDO to the GA during the jump shrug and hang high pull exercises (52).

Another unique finding of this study was the small effect size magnitudes that were present between the GA and TENDO devices when comparing MBV and PBV across all loads. Based on the effect size confidence intervals of each comparison, none of the differences between devices were considered practically meaningful; however, as noted above, proportional bias was present for both MBV and PBV at 140% 1RM indicating that practitioners should be cautious when comparing devices with heavier loads. The study findings are consistent with previous research on the jump shrug and hang high pull that showed no practically meaningful differences between the GA and TENDO for MBV and PBV across loads ranging from 20 to 100% 1RM HPC (52). However, the previous research did show moderate effect size magnitudes between devices for MBV at lighter loads 40 ($g = 0.64$) and 60% 1RM HPC ($g = 0.72$) during the jump shrug and PBV at 40% 1RM HPC ($g = 0.64$) during the hang high pull. The current and previous findings are important to consider when using VBT devices with weightlifting pulling derivatives. Strength and conditioning practitioners and sport scientists should note that despite both being linear position transducers, the GA and TENDO calculate MBV and PBV differently and should thus not be used interchangeably.

There are limitations to this study that should be acknowledged. First, since 3D high-speed motion capture was unavailable at the authors' institution, the GA was used as a criterion measurement for comparison. While a limitation, it should be noted that researchers have shown that the GA showed the greatest accuracy compared with 3D high-speed motion capture during various resistance training exercises (60). A second limitation may be the lack of previous research to compare the study findings with. Except for the GA reliability comparisons that can be made with Meechan et al. (27) and bias similarities with Suchomel et al. (52), there is a lack of literature to compare the study findings to. To the authors' knowledge, this is the first study that has examined the reliability, bias, differences, and agreement between VBT devices during the HCP. It is suggested that researchers interested in using VBT with weightlifting movements should continue to examine the use of different devices with the HCP and other weightlifting derivatives. Finally, this study included resistance-trained men; however, the study findings may not be generalized to other populations. As a result, researchers and

Table 2

Least-products regression for the Tendo Power Analyzer during the hang clean pull compared with GymAware PowerTool.*

	Slope (95% confidence interval)		Intercept (95% confidence interval)	
Load (%)	MBV	PBV	MBV	PBV
20	0.937 (0.846–1.028)	1.054 (0.888–1.221)	0.003 (−0.129 to 0.136)	−0.190 (−0.595 to 0.215)
40	0.947 (0.838–1.055)	0.902 (0.642–1.163)	0.005 (−0.147 to 0.157)	0.180 (−0.404 to 0.764)
60	0.941 (0.787–1.094)	0.941 (0.639–1.244)	0.005 (−0.184 to 0.195)	0.082 (−0.542 to 0.705)
80	0.971 (0.907–1.035)	1.170 (0.863–1.477)	−0.034 (−0.101 to 0.032)	−0.361 (−0.955 to 0.232)
100	0.969 (0.904–1.035)	1.131 (0.946–1.316)	−0.019 (−0.083 to 0.045)	−0.287 (−0.619 to 0.046)
120	0.936 (0.772–1.101)	0.996 (0.710–1.282)	0.010 (−0.152 to 0.172)	−0.038 (−0.492 to 0.417)
140	0.916 (0.846–0.986)†	0.816 (0.678–0.953)†	0.036 (−0.025 to 0.097)	0.234 (0.045 to 0.423)‡

*Load = % 1RM hang power clean; MBV = mean barbell velocity; PBV = peak barbell velocity.
†Proportional bias present.
‡Fixed bias present.

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Table 3

Descriptive mean and peak barbell velocity statistics and Hedge's *g* effect size magnitudes with 95% confidence intervals for the GymAware PowerTool and Tendo Power Analyzer during the hang clean pull.*

	Mean barbell velocity ($m \cdot s^{-1}$)		
Load (%)	GymAware PowerTool	Tendo Power Analyzer	*g*
20	1.33 ± 0.22	1.42 ± 0.23	0.36 (−0.38 to 1.11)
40	1.25 ± 0.16	1.31 ± 0.17	0.37 (−0.37 to 1.12)
60	1.15 ± 0.14	1.22 ± 0.15	0.46 (−0.29 to 1.21)
80	1.05 ± 0.11	1.11 ± 0.12	0.57 (−0.19 to 1.32)
100	1.00 ± 0.12	1.05 ± 0.12	0.42 (−0.33 to 1.17)
120	0.91 ± 0.10	0.96 ± 0.11	0.49 (−0.27 to 1.24)
140	0.81 ± 0.09	0.84 ± 0.10	0.35 (−0.39 to 1.10)
	Peak barbell velocity ($m \cdot s^{-1}$)		
Load (%)	GymAware PowerTool	Tendo Power Analyzer	*g*
20	2.34 ± 0.23	2.40 ± 0.21	0.26 (−0.48 to 1.01)
40	2.18 ± 0.15	2.22 ± 0.16	0.23 (−0.52 to 0.97)
60	2.00 ± 0.15	2.04 ± 0.15	0.25 (−0.50 to 0.99)
80	1.80 ± 0.14	1.85 ± 0.12	0.34 (−0.40 to 1.09)
100	1.74 ± 0.10	1.79 ± 0.09	0.54 (−0.22 to 1.29)
120	1.59 ± 0.09	1.63 ± 0.09	0.49 (−0.26 to 1.24)
140	1.41 ± 0.09	1.45 ± 0.10	0.42 (−0.33 to 1.17)

*Load = % 1RM hang power clean; MBV = mean barbell velocity; PBV = peak barbell velocity.

practitioners should interpret the study findings with caution until more research is completed with various populations.

Practical Applications

The GA and TENDO can provide reliable MBV and PBV measurements during the HCP performed using loads ranging 20–140% 1RM HPC. It should be noted, however, that the TENDO may become less reliable as loads increase, possibly due to increases in horizontal displacement. While the TENDO may overestimate barbell velocity, this may be accounted for if the device is consistently used within training. Despite the small differences in MBV and PBV between the GA and TENDO shown across all loads, strength and conditioning practitioners and sport scientists should note that VBT devices should not be used interchangeably. Moreover, users should be aware of the limitations of the factory settings of the TENDO as well as its inability to account for horizontal velocity. Researchers interested in using VBT devices for athlete monitoring purposes should continue to evaluate the reliability of different devices with the HCP and other weightlifting derivatives.

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