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Running title: Fast bowling intensity using inertial sensors

The relationship between wearable microtechnology device variables and cricket fast bowling intensity

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Abstract

To date, the monitoring of fast bowling workloads across training and competition environments has been limited to counting total balls bowled. However, bowling at faster velocities is likely to require greater effort while also placing greater load on the bowler. This study investigated the relationship between prescribed effort and microtechnology outputs in fast bowlers to ascertain whether the technology could provide a more refined measure of workload. Twelve high performing fast bowlers (mean ± SD age; 20.3 ± 2.2 yr) participated in this study. Each bowler bowled 6 balls at prescribed bowling intensities of 60%, 70%, 85% and 100%. The relationship between microtechnology outputs, prescribed intensity and ball velocity were determined using polynomial regression. Very large relationships were observed between prescribed effort and ball velocity for peak PlayerLoad^{TM} ($R = 0.83 \pm 0.19$ and 0.82 ± 0.20). The Player Load^{TM} across lower ranges of prescribed effort exhibited higher coefficient of variation (CV) [60% = 19.0 (17.0 – 23.0)%] while the CV at higher ranges of prescribed effort was lower [100% = 7.3 (6.4 - 8.5)%]. Routinely used wearable microtechnology devices offer opportunities to examine workload and intensity in cricket fast bowlers outside the normal metrics reported. They offer a useful tool for prescribing and monitoring bowling intensity and workload in elite fast bowlers.

Keywords: Workload; Microsensors; Team Sport; Training

Introduction

Cricket, like many other popular international team sports, requires varying player types to perform very specific roles within the team. One of these roles within cricket is fast bowling. Fast bowlers are required to bowl at high ball velocities to opposition batters. Fast bowling has been associated with greater injury risk in comparison to other playing activities.[1] Fast bowling injury rates have been associated with both poor technique and bowling workloads.[1-3] A current method of monitoring the preparedness of fast bowlers includes both planning and reviewing the chronic (28 day average) and acute (7 day average) bowling loads.[4] Although this provides a general view of the preparedness of the fast bowler, it fails to account for the range of bowling intensities across sessions, their contribution to the overall load and ultimately, preparedness.[5] While it is possible that coaches could subjectively identify periods of high bowling intensity, this can become relatively unstructured and fail to account for the individual bowler's fatigue responses to workloads. The method of monitoring bowling speed is a possible indicator of intensity, although practical limitations exist with this method. Individual fast bowlers are routinely spread across varying training nets or often competing at different locations; considerable resources are required to allow sport scientists to collect this data. Understandably, bowling velocity also acts as a performance indicator and provides meaningful data to coaches, particularly in match-play.[6] While bowling velocity may provide a simple option for measuring intensity in a single controlled bowling session, when multiple bowlers are performing across various sessions and locations this process becomes somewhat laborious and difficult.

Various team sports, including Australian Football and Rugby League, use microtechnology and global positioning system (GPS) devices to monitor external workload.[7-9] In addition to GPS data, a combination of accelerometers (electromechanical device that measures acceleration forces), gyroscopes (electronic device that measures rotation around three axes: x, y, and z) and magnetometers (electronic device that measures magnetic fields) provide information on external workloads.[10,11] Accelerometer loads has been shown to have acceptable stability across 3, 6 and 12 over bowling spells.[6] In addition to a tri-axial accelerometer, gyroscopes capable of detecting rotation about the yaw, pitch and roll axes are housed within this unit. Microtechnology has also been successful in detecting fast bowling events in elite cricketers.[12] This technology allows for retrospective analysis of external workload in large groups of athletes and does not require a coach or sport scientist to be present at the time of data collection. This method of load monitoring is important to cricket as players often train in de-centralized programs or are required to participate for various domestic teams across the world within the same competitive year. These units are not limited to training environments and are commonly worn during competition in many sports including cricket.

Although the use of this technology to monitor fast bowling intensity is yet to be validated, it does provide opportunity to further advance the workload monitoring of elite fast bowlers during training and competition. This would allow insightful data for the prescription of individual fast bowling workloads. Therefore, the aim of this study was to assess the relationship between prescribed bowling intensities, bowling velocity and data outputs from wearable microtechnology during a training environment to ascertain whether the technology could provide a more refined measure of bowling workload and intensity.

Methods

Subjects

Twelve elite fast bowlers (mean ± SD age; 20.3 ± 2.2 yr) participated in this study. At the time of the study all players were participants in a national level high performance camp. All participants were free from injury or other medical conditions that would compromise participation. Participants received a clear explanation of the study, and written consent was obtained. The Australian Catholic University Human Research Ethics Committee approved all experimental procedures.

Design

This cohort study required participants to complete six deliveries in four categories of effort; 1. warm up (~60%), 2. light intensity (~70%), 3. match-play (~85%), and 4. maximal effort (~100%). All bowlers completed the bowling protocol in the same pre-determined order and replicated an assessment protocol routinely used by Cricket Australia. To help represent the varying bowling lengths in cricket match-play, during the 85% (match-play) and 100% (maximal effort) overs, each player bowled two short balls, two full balls and two good length balls. No balls, wides, balls bowled with illegal actions and those that were not performed at the prescribed bowling length were excluded from analyses. All data were collected in a purpose built indoor facility. Bowling run up lengths were self-selected, and were not limited by the size of the indoor facility. This data were monitored and confirmed by a cricket coach. Measures of bowling intensity included a subjective measure of prescribed effort, bowling velocity and outputs from wearable microtechnology.

Methodology

Bowling Intensity – Ball Velocity

Ball velocity was measured for each delivery using a high performance sports radar gun accurate to ± 3% (Stalker Pro, Stalker Sports Radar, Piano, Texas) positioned at the batters end of the cricket pitch.[13] No bowling velocity feedback was provided to the bowlers. A relative ball velocity score was calculated as a percentage of the individual bowlers peak ball velocity across the 24 balls bowled.

Bowling Intensity – Microtechnology

Data from the accelerometers and gyroscopes embedded in the microtechnology device (MinimaxX S4, Catapult Innovations, Melbourne, Australia) were extracted from the commercially available software (Sprint Version 5.0.9.2, Catapult Innovations, Melbourne, Australia) for each ball bowled. Both the accelerometers and gyroscopes collected data at 100 Hz. PlayerLoad^{TM} and the resultant accelerometer vector were calculated from each of the X, Y and Z vectors. In this study, PlayerLoad^{TM} was calculated as the square root of the sum of the squared instantaneous rate of change in acceleration in each of the three vectors (X, Y and Z axis) and divided by 100.[9,11] The resultant accelerometer was calculated as

$r = (x^2 + y^2 + z^2)^{0.5}$. Roll (x-axis – lateral flexion during bowling) and yaw (z-axis – rotation at the thoracic spine during the bowling action) gyroscope velocity outputs were collected from the microtechnology device for each ball bowled. Peak measures of PlayerLoad^{TM}, accelerometer resultant, yaw velocity and roll velocity during the delivery stride were used for analysis of each ball. A percentage relative to the individual bowlers peak score across the 24 balls bowled was calculated for each ball across all variables. Measures of roll have previously been used to distinguish fast bowling events within cricket practice and competition.[12]

Statistical Analyses

Data were tested for normality prior to analysis using a Shapiro-Wilk test. The relationship between the microtechnology outputs and both prescribed effort and ball velocity were analyzed using polynomial regression in SPSS (IBM Corp, Armonk, USA) and expressed as R. These relationships were described as trivial (0.0 – 0.1), small (0.1 – 0.3), moderate (0.3 – 0.5), large (0.5 – 0.7), very large (0.7 – 0.9) or nearly perfect (0.9 – 1.0).[14] A custom Microsoft Excel spreadsheet (Microsoft, Redmond, USA) was used to calculate both between and within subject coefficient of variation (CV) with 90% confidence intervals to describe the variability across intensity levels.

Results

Peak PlayerLoad^{TM} showed very large relationships (R = 0.83 ± 0.19) with prescribed effort for each ball bowled (Table 1, Figure 1). Relative ball velocity was also associated with peak PlayerLoad^{TM} (R = 0.82 ± 0.20) for each ball bowled (Table 1, Figure 1). Table 1 shows the large to very large relationships of both peak yaw (R = 0.58 ± 0.36), roll (R = 0.73 ± 0.27) and resultant accelerometer (R = 0.64 ± 0.33) for each ball bowled.

<<<< **Insert Table 1 here** >>>>

<<<< **Insert Figure 1 here** >>>>

Table 2 demonstrates that as bowling effort increased, measures of intensity began to stabilize. Measures of CV in Peak PlayerLoad^{TM} were calculated as 19.0% (17.0 – 23.0), 14.0% (12.0 – 16.0), 9.6% (8.4 – 11.0) and 7.3% (6.4 – 8.5) across the prescribed 60% (warm up), 70% (light intensity), 85% (match-play) and 100% (maximal effort) bowling intensities (Table 2). Relative ball velocity followed the similar trend across prescribed bowling intensities with CV of 6.6% (5.8 – 7.7), 3.8% (3.4 – 4.4), 3.6% (3.2 – 4.2) and 2.6% (2.3 – 3.0) across the four prescribed bowling intensities (Table 2). Measures of CV were shown to be higher when observing absolute data (Table 3). Additionally, the peak PlayerLoad^{TM} and resultant accelerometer data had higher measures of CV in the 100% effort band when compared to the 85% effort band.

<<<< **Insert Table 2 here** >>>>

<<<< **Insert Table 3 here** >>>>

Table 4 demonstrates that ball velocity had the best measure of within subject CV. Measures of within subject CV followed similar trends, with CV results reducing as intensity increased. The measures of within subject CV in Peak PlayerLoad^{TM} were calculated as 11.2% (9.9 – 13.0), 8.0% (7.1 – 9.3), 7.4% (6.5 – 8.6) and 6.8% (6.0-7.8) across the prescribed intensities (Table 4).

No bowler was required to re-bowl any balls due to no balls, wide deliveries or failure to bowl at the predetermined intensity.

<<<< **Insert Table 4 here** >>>>

Discussion

This study (1) examined the relationship between prescribed bowling effort, bowling velocity and the outputs from a microtechnology device, and (2) ascertain whether the technology could provide a more refined measure of bowling workload and intensity compared the routine method of counting balls bowled only. The results of this study demonstrate a good relationship between prescribed bowling effort and both bowling velocity and PlayerLoad™ results. Data were reported as percentages relative to maximal efforts of individual fast bowlers, which accounts for individual variations in technique and bowling velocities, and is easily processed by cricket coaches. Practically, calibrating the percentage effort of each ball to a recent effort within a significant competitive match provides both context and meaningful data for coaches and support staff.

To date, the measurement of bowling workload in cricket literature and practice has been limited to the simple method of bowling counts in training and competition.[3,4,12] This presents a simple definition of total workload, but may not account for the variability and significance of higher effort bowling from one training session/game to another. Intuitively, the intensity of individual bowling sessions will have a significant influence on the bowler's workload status, and may have an influence on the physical status and fatigue of bowlers. As such, bowling intensity is likely to influence the preparation of fast bowlers for various levels of competition or returning from injury.[5] Fast bowlers returning from injury likely have to build up bowling intensity and grouping lower intensity bowling may not reflect the match bowling in

The large variability in the microtechnology metrics at sub maximal intensities can be explained by the greater scope for variability at lower or submaximal intensities (Table 2). Importantly, the ball velocity, measured with a routinely used radar gun, also exhibited an increased variability at lower intensities. We acknowledge that the microtechnology output exhibit greater variability than ball velocity and should be considered a limitation of the technology. However, this may be explained by the ability of elite fast bowlers to find efficiency in maintaining stable ball velocity across bowling intensities despite the likelihood of subtle changes in bowling technique at lower bowling velocities. Ball velocity was measured as greater than 80% across all four intensities. This is likely explained by the fact that bowling "effort" is not the only component contributing to ball velocity in elite fast bowlers. The bowling technique of elite fast bowlers has a large influence on ball velocities,[15] and despite the aim of bowling at lower intensities, technically the bowlers were still able to maintain a higher level of ball velocity. Given the bowlers in this study were elite performing fast bowlers and only bowled two overs at high intensity, we believe that fatigue would have limited influence on the results of this study.

Within subject CV showed that ball velocity provided the most stable output. In addition, the within subject CV for ball velocity decreased as intensity increased. Absolute microtechnology outputs demonstrated greater variability than relative values, although absolute ball velocity had similar variability to relative ball velocity. This is explained by the fact that between the bowlers, each performed with slightly different actions impacting the microtechnology outputs.

Based on this finding, we suggest that microtechnology outputs in cricket fast bowlers should be observed relative to the individual. Although this may be considered a limitation of microtechnology as an indication of bowling intensity, using microtechnology to record bowling workload and intensity provides a much more practical solution than the use of radar guns when applied across large populations of fast bowlers and over many training sessions and competitions.

Measures of roll and PlayerLoad™ provided the strongest relationships with both prescribed intensity and ball velocity (Table 1). The gyroscope measure of roll represents the velocity of lateral trunk flexion. As opposed to yaw (thoracic rotation velocity), lateral trunk flexion velocity may be a more stable trait within the side-on, front-on or mixed bowling techniques used amongst fast bowlers. Both the peak resultant and peak PlayerLoad™ variables rely on the tri-axial accelerometers housed within the wearable unit. The resultant accelerometer combines the raw outputs from all three accelerometer axes. Treating the raw accelerometer data with a filter may be required to improve the relationship between prescribed intensities and ball velocity.

This study did not include match-play data, and consequently we were unable to relate bowling intensity to a pre-determined maximum competition output. Further research is required to establish the validity and reliability of the microtechnology outputs during cricket match-play. Measuring bowling intensity may potentially provide a novel method of monitoring elite cricket fast bowlers. The paucity in literature around bowling intensity and injury outcome can largely be attributed to the difficulty in measuring fast bowling intensity. We propose that microtechnology outputs may provide a practical method of monitoring bowling intensity in fast bowlers.

A relationship between fast bowling workload and injury has been widely reported.[1,3,4] More specifically, researchers have demonstrated increased injury risk with both under- and over-bowling[3] while others have shown a delayed effect of increased injury risk after bouts of increased acute bowling workload.[1,4] Previous researchers have studied the relationship between chronic (fitness) and acute (fatigue) bowling workloads and injury risk in cricket fast bowlers.[4] They identified that the injury likelihood of fast bowlers increased significantly in the week following a “spike” in acute workload relative to chronic workload.[4] Systematic increases in chronic bowling workloads decreased injury likelihood.[4] With this in mind, the findings presented in this study provide the scope for cricket researchers to establish measures of fast bowling intensity and help generate chronic bowling workloads relative to the match-play demands of the individual fast bowler. It is likely that in some cases, chronic workloads have been inflated with the inclusion of balls bowled at lower intensities, which may be misleading when identifying the preparedness of the bowler. Further research is required to explore if excluding lower intensity balls influences the acute:chronic workload ratio in fast bowlers.

Practically, there are many factors that play a role in prescribing bowling workloads to fast bowlers. These may include, but are not limited to; return from injury, competition restrictions, competition strategy, and playing conditions.[16] To a degree, these factors can largely be controlled. However, there are other factors that are much more difficult to account for when preparing fast bowlers, including; the time between bowling innings in multi-day cricket and, the workload 'flow-on' effect amongst the bowlers within the team when one bowler sustains an injury in a competitive match. With this in mind, controlling bowling workloads prior to and after competition is vital in the preparation and management of fast bowlers from both a skill acquisition and injury prevention perspective. This integration of routinely used monitoring systems such as microtechnology to provide specific and meaningful data for coaches, rehabilitation and strength and conditioning staff in cricket would provide both a novel and practical solution in monitoring bowling intensity.

Practical Applications

Outputs from the microtechnology unit worn by cricket fast bowlers provide good insight into bowling intensity. The use of this technology provides a more practical method of measuring and recording bowling intensity than measuring ball velocity. This information provides a method of improved overall workload monitoring, particularly where varying bowling intensities are performed by the bowler. The use of wearable microtechnology to determine bowling intensity provides additional meaningful information apart from the routinely reported data outputs of GPS in cricket match-play and training. Additionally, this data provides workload information for the coach from numerous players who may be competing or training in various locations at any one time that to date has been difficult to objectively quantify. Finally, implementing intensity into the current acute and chronic workload monitoring system may provide a clearer indication of the preparedness of the fast bowler to tolerate high workloads.

Conclusions

In conclusion, we found a large to very large relationship between microtechnology outputs and both prescribed intensity and ball velocity. The large standard deviations at lower intensities can be explained by both the inability of the athlete to adhere to submaximal intensities and greater scope for variability at lower intensities. While further validation in varying competition and training settings is required, our findings demonstrate that microtechnology devices offer both a practical and adequate tool for prescribing and monitoring bowling intensity and workload in elite fast bowlers.

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Table 1. Relationship between bowling effort and microtechnology outputs.

Prescribed Effort Relationship	*R*	*Ball Velocity Relationship*	*R*
Resultant max %	0.71 ± 0.28 *Very Large*	Resultant max %	0.64 ± 0.33 *Large*
PlayerLoad^{TM} max %	0.83 ± 0.19 *Very Large*	PlayerLoad max %	0.82 ± 0.20 *Very Large*
Roll max %	0.80 ± 0.21 *Very Large*	Roll max %	0.73 ± 0.27 *Very Large*
Yaw max %	0.56 ± 0.37 *Large*	Yaw max %	0.58 ± 0.36 *Large*

Polynomial regression ± 90% confidence intervals and descriptor.

Table 2. Mean and coefficient of variation for *relative data* across prescribed bowling intensities.

		Bowling Intensity %			
Variable		60%	70%	85%	100%
Peak Roll %	*Mean*	64.4%	74.9%	88.0%	93.2%
	CV (%)	16.0 (14.0 – 18.0)	11.0 (10.0 – 13.0)	11.0 (9.3.0 – 12.0)	6.1 (5.4 - 7.1)
Peak Accelerometer resultant %	*Mean*	57.0%	72.2%	81.0%	86.4%
	CV (%)	21.0 (19.0 – 24.0)	17.0 (15.0 – 19.0)	12.0 (10.0 – 13.0)	12.0 (10.0 – 13.0)
Peak PlayerLoad^{TM} %	*Mean*	56.7%	68.8%	81.4%	92.1%
	CV (%)	19.0 (17.0 – 23.0)	14.0 (12.0 – 16.0)	9.6 (8.4 – 11.0)	7.3 (6.4 - 8.5)
Peak Yaw %	*Mean*	72.8%	82.6%	91.2%	93.3%
	CV (%)	22.0 (19.0 – 26.0)	16.0 (14.0 – 18.0)	10.0 (9.1 – 12.0)	8.4 (7.4 - 9.7)
Relative Ball Velocity %	*Mean*	81.9%	89.2%	93.5%	97.2%
	CV (%)	6.6 (5.8 - 7.7)	3.8 (3.4 - 4.4)	3.6 (3.2 - 4.2)	2.6 (2.3 – 3.0)

Coefficient of variation (CV%) and 90% confidence interval.

Table 3. Mean and coefficient of variation for *absolute data* across prescribed bowling intensities.

		Bowling Intensity %			
Variable		60%	70%	85%	100%
Peak Roll (deg/sec)	*Mean*	764.83	890.3	1042.6	1090.5
	CV (%)	29.7 (26.0 – 34.0)	27.3 (24.0 – 32.0)	27.6 (24.0 – 32.0)	23.8 (21.0 – 28.0)
Peak Accelerometer resultant (g)	*Mean*	8.8	11.1	12.4	13.3
	CV (%)	28.4 (25.0 – 33.0)	22.8 (20.0 – 27.0)	16.0 (14.0 – 19.0)	19.2 (17.0 – 22.0)
Peak PlayerLoad™ (AU)	*Mean*	4.0	4.9	5.7	6.5
	CV (%)	24.4 (22.0 – 28.0)	18.1 (16.0 – 21.0)	14.7 (13.0 – 17.0)	17.8 (16.0 – 21.0)
Peak Yaw (deg/sec)	*Mean*	933.0	1055.7	1169.8	1196.4
	CV (%)	27.1 (27.0 – 31.0)	21.1 (19.0 – 24.0)	17.9 (16.0 – 21.0)	16.6 (15.0 – 19.0)
Ball Velocity (km/h)	*Mean*	100.7	109.6	115.0	119.7
	CV (%)	7.9 (6.9 – 9.1)	4.0 (3.5 – 4.6)	4.0 (3.5 – 4.7)	4.3 (3.8 – 5.0)

Coefficient of variation (CV%) and 90% confidence interval.

Table 4. Within subject coefficient of variation across prescribed bowling intensities.

		Bowling Intensity %			
Variable		60%	70%	85%	100%
Peak Roll (deg/sec)	*CV (%)*	7.6 (6.7 – 8.8)	6.1 (5.3 – 7.0)	6.9 (6.1 – 8.0)	5.9 (5.2 – 6.9)
Peak Accelerometer resultant (g)	*CV (%)*	15.3 (13.0 – 18.0)	10.4 (9.1 – 12.0)	9.4 (8.3 – 11.0)	10.5 (9.3 – 12.0)
Peak PlayerLoad^{TM} (AU)	*CV (%)*	11.2 (9.9 – 13.0)	8.0 (7.1 – 9.3)	7.4 (6.5 – 8.6)	6.8 (6.0 – 7.8)
Peak Yaw (deg/sec)	*CV (%)*	9.6 (8.4 – 11.0)	7.6 (6.7 – 8.9)	8.0 (7.0 – 9.2)	6.2 (5.4 – 7.1)
Ball Velocity (km/h)	*CV (%)*	3.8 (3.3 – 4.4)	2.6 (2.3 – 3.0)	2.8 (2.5 – 3.2)	2.5 (2.2 – 2.9)

Coefficient of variation (CV%) and 90% confidence interval.

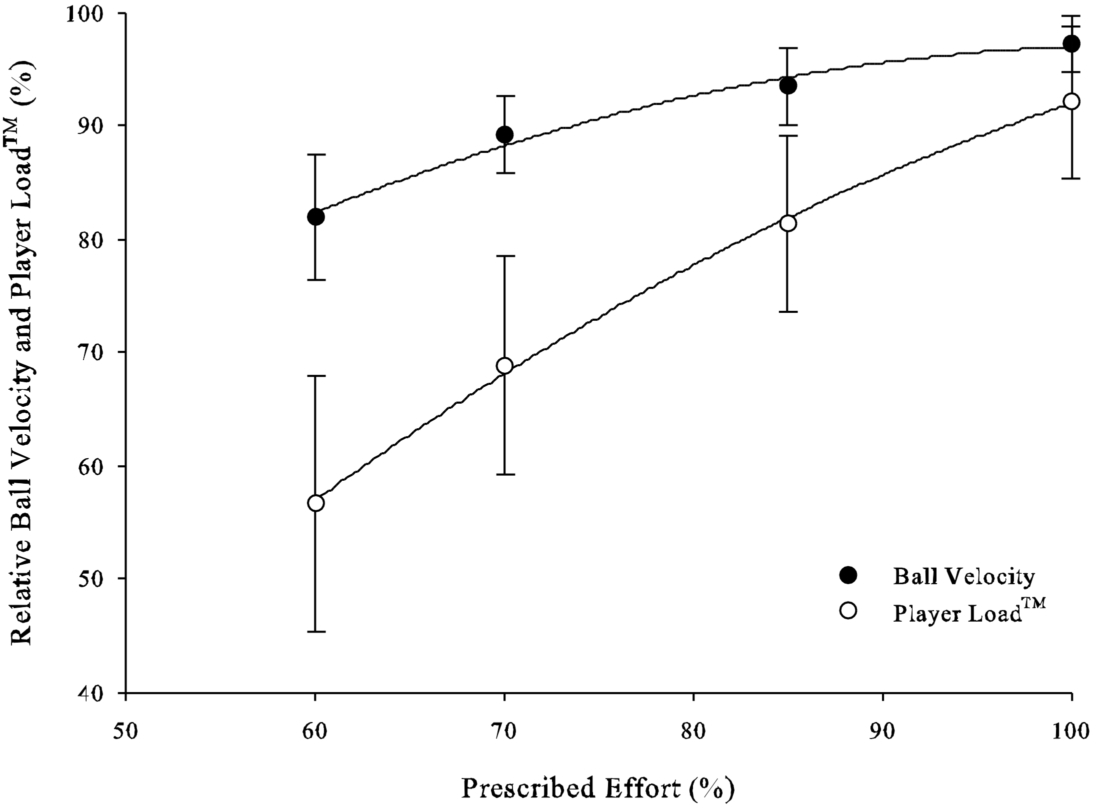

Figure 1. Mean ± Standard Deviation of Relative Ball Velocity and Relative PlayerLoad™ vs. Prescribed Effort.