Journal of Sports Sciences

ISSN: 0264-0414 (Print) 1466-447X (Online) Journal homepage: www.tandfonline.com/journals/rjsp20

Trackman 4: Within and between-session reliability and inter-relationships of launch monitor metrics during indoor testing in high-level golfers

Chris Bishop, Jack Wells, Alex Ehlert, Anthony Turner, Daniel Coughlan, Noah Sachs & Andrew Murray

To cite this article: Chris Bishop, Jack Wells, Alex Ehlert, Anthony Turner, Daniel Coughlan, Noah Sachs & Andrew Murray (2023) Trackman 4: Within and between-session reliability and inter-relationships of launch monitor metrics during indoor testing in high-level golfers, Journal of Sports Sciences, 41:23, 2138-2143, DOI: 10.1080/02640414.2024.2314864

To link to this article: https://doi.org/10.1080/02640414.2024.2314864

Published online: 08 Feb 2024.

JOURNAL OF SPORTS SCIENCES
2023, VOL. 41, NO. 23, 2138–2143
https://doi.org/10.1080/02640414.2024.2314864

Routledge
Taylor & Francis Group

SPORTS MEDICINE AND BIOMECHANICS

OPEN ACCESS Check for updates

Trackman 4: Within and between-session reliability and inter-relationships of launch monitor metrics during indoor testing in high-level golfers

Chris Bishop [a,b,c], Jack Wells[d], Alex Ehlert[e], Anthony Turner[a], Daniel Coughlan[b,c,d,f], Noah Sachs[g] and Andrew Murray[b,c]

[a]London Sport Institute, Middlesex University, London, UK; [b]Medical Department, Ladies European Tour, Uxbridge, UK; [c]European Tour Performance Institute, Surrey, UK; [d]The Professional Golfers' Association, National Training Academy, Sutton Coldfield, UK; [e]Independent Researcher, Knightdale, NC, USA; [f]England Golf, Lincolnshire, Woodhall Spa, UK; [g]Independent Researcher, Frisco, TX, USA

ABSTRACT

The aims of the present study were to: 1) investigate the within and between-session reliability of the Trackman 4 launch monitor system, and 2) determine the inter-relationships of some of these commonly used metrics. Golfers attended two test sessions at an indoor golf academy and performed 10 shots using their own driver. Results showed excellent within and between-session reliability for CHS (ICC = 0.99; SEM = 1.64–1.67 mph), ball speed (ICC = 0.97–0.99; SEM = 2.46–4.42 mph) and carry distance (ICC = 0.91–0.97; SEM = 7.80–14.21 mph). In contrast, spin rate showed the worst reliability (ICC = 0.02–0.60; SEM = 240.93–454.62 °/s) and also exhibited significant differences between test sessions (g = −0.41; $p < 0.05$), as did smash factor ($g = 0.47$; $p < 0.05$) and dynamic loft (g = −0.21; $p < 0.05$). Near perfect associations were evident in both test sessions between CHS and ball speed ($r = 0.98$–0.99), CHS and carry distance (r = 0.94–0.95), ball speed and carry distance ($r = 0.97$–0.98), and launch angle and dynamic loft ($r = 0.98$–0.99). Collectively, CHS, ball speed and carry distance serve as the most consistently reliable metrics making them excellent choices for practitioners working with golfers.

ARTICLE HISTORY
Received 8 March 2023
Accepted 30 January 2024

KEYWORDS
Golf; data; radar; technology

Introduction

Recent years have seen a growing interest in physical preparation for golf, both in the day-to-day practice of how players plan their training and through research in the sport (Ehlert, 2020). When aiming to quantify performance, historically, golf has always placed a key emphasis on a player's gross score (Brennan et al., 2023), which seems obvious given this is how players are ranked during competition. However, seminal work from Broadie (2014) used a large database of data from the PGA Tour™ to determine how likely players are to "hole out" from different positions on the course, referred to as "Strokes Gained". For example, this work has highlighted that if a player can achieve an extra 20 yards in distance, they will gain 0.75 strokes on average against their competitors, per round (Broadie, 2014). By comparing expected performance from a given position (based on benchmark scores from the same position) to actual performance, strokes gained analysis allows for a more in-depth insight into the performance of individual shots and quantification of the potential performance benefit of changes in shot performance. Consequently, this type of information has resulted in elite and high-level players placing an increased emphasis on hitting the ball further, which has fed into a greater interest in physical preparation and using data from launch monitor technologies to gain insights into current performance and track progress over time.

Naturally then, practitioners must have confidence that any technology they use is both valid and reliable. However, to the best of the authors' knowledge, only one peer-reviewed and published study has directly compared launch monitor systems to a criterion method. Leach et al. (2017) compared the "Trackman Pro IIIe" and the "Foresight GC2 + HMT" launch monitors with a high-speed video camera system (criterion method), consisting of four cameras each operating at 5400 Hz. Although both launch monitors showed significant differences when compared to the camera system for some variables, it's worth noting that for commonly used metrics in golf such as clubhead speed (CHS), ball speed, and launch angle, median differences for the Trackman were −0.4 mph, 0.2 mph, and 0.0º, respectively. Thus, it was deemed that this launch monitor system was both accurate and valid to use in the field. However, reliability data was not reported. With this in mind, and to the best of the authors' knowledge, only one study has specifically investigated the reliability of any kind of launch monitor system (Villarrasa-Sapina et al., 2022), with one other reporting reliability data as a secondary aim (Read et al., 2013). Read et al. (2013) investigated the association between commonly measured strength and power field-based tests and their association with CHS, using a Flightscope launch monitor. However, from a reliability standpoint, the authors only reported the metric of CHS, which showed an intraclass correlation coefficient (ICC) of 0.87. Villarrasa-Sapina et al. (2022) investigated the test-retest reliability of multiple metrics from the Flightscope Mevo+ launch monitor, an upgraded system from the one used by Read et al. (2013). A total of 15 metrics were analysed with a driver and 6-iron, with the driver showing ICC values ranging from 0.08 (lateral distance) to 0.98 (CHS),

CONTACT Chris Bishop C.Bishop@mdx.ac.uk London Sport Institute, Middlesex University, StoneX Stadium, Greenlands Lane, London NW4 1RL, UK

and the 6-iron showing similar results ranging from −0.11 (launch direction) to 0.97 (carry and total distance). Thus, from the limited body of evidence, it seems that the Trackman launch monitor system is accurate and that some data from cheaper systems such as Flightscope are highly reliable. However, Trackman have now produced a newer model (Trackman 4) meaning the evidence to date has been conducted on an older model and reliability only investigated for more affordable launch monitors (Flightscope). Thus, robust test-retest study designs investigating the within and between-session reliability of the Trackman 4 seems warranted, as this would enable practitioners to better comprehend which metrics can be confidently used to monitor progress and help guide decision-making in golf.

Although the ability of these launch monitors to provide instantaneous feedback for multiple metrics can be seen as a useful and positive step when incorporating data analysis in golf, to the best of our knowledge, no study has investigated the inter-relationships of these metrics. Understanding the magnitude of these inter-relationships may enable golf practitioners to group certain metrics together in the ongoing monitoring process. Although specific to jump testing, a recent opinion piece outlined that when metrics from a test are linked together, there is a greater ability to concurrently use all of the data, without any metrics contradicting each other (Bishop, Turner, et al., 2022). Thus, a combination of knowing the day-to-day reliability of these launch monitor metrics and their inter-relationships may provide a strong justification for which metrics to monitor when tracking a golfer's current performance and progress over time.

Therefore, the present study had two aims: 1) investigate the within and between-session reliability of the Trackman 4 launch monitor system, and 2) determine the inter-relationships of some of these commonly used metrics. Although the evidence is limited, it was hypothesised that some metrics would show excellent reliability, with others showing much greater variability. In addition, it was also hypothesised that the more reliable metrics would exhibit stronger inter-relationships with one another.

Methods

Experimental design

This study used a repeated measures design where golfers attended two test sessions at an indoor golf academy, for the purpose of assessing within and between-session reliability of the Trackman 4 launch monitor. Participants performed a self-selected warm-up specific to their own golf routine, before 10 shots were performed with their own driver in each test session. Specifically, participants were instructed to hit the ball off the tee as they normally would, when playing a tee shot during a par 5 hole, with no obvious hazards ahead of them (e.g., water or bunkers).

Participants

Thirteen male golfers, consisting of 10 amateurs and three professionals (age: 33.0 ± 7.8 years; height: 176.4 ± 7.7 cm; body mass: 72.8 ± 12.7 kg; handicap: 7.6 ± 7.5) volunteered to participate in this study. Sample size estimation was conducted based on the work of Walter et al. (1998), which estimates the sample required for reliability studies. In the present study, which used a test-retest design, a sample of nine was required for a minimal acceptable ICC value of 0.5 and an estimated ICC of 0.8. All players participated in golf a minimum of twice per week, had a minimum playing history of seven years, and did not undertake any physical activity (including golf) in the preceding 24 h before testing. No injuries were reported for any players at the time of testing. Informed consent was provided by all participants, and this study was approved by the London Sport Institute research and ethics committee.

Procedures

Both testing sessions took place in an indoor driving range using a Trackman 4 launch monitor, which was set up as per the manufacturer's instructions. Specifically, it is suggested that the Trackman be set in "normalised" mode and be placed between 2–3 m directly behind the ball; thus, it was positioned 2.5 m behind the ball for all participants, in line with a pre-determined target (i.e., a flag on the driving range in the distance on a virtual screen). Test sessions were separated by a maximum of seven days for each player, with all Trackman variables and their associated definitions displayed in Table 1. Each session took the same format with players conducting their own self-selected golfing warm-up routine, which lasted between 10–15 min. Specifically, this usually consisted of a number of practice shots with short irons (e.g., pitching or gap wedge), mid irons (e.g., 6 or 7-iron), and escalating intensity shots with their driver. Once players were ready to start data collection, they were asked to complete 10 driver shots, with an average of all trials used for further analysis. No further or specific instructions were provided, as testing was

Table 1. Description of launch monitor metrics, as defined by Brennan et al. (2023).

Launch Monitor Metric	Metric Definition
Clubhead speed (mph)	Linear speed of the club's geometric centre just before contact with the ball.
Ball speed (mph)	Speed of the ball's centre of gravity immediately post separation from the clubface.
Carry distance (yards)	Total distance travelled by the ball between point of shot and where it initially lands.
Smash factor	A ratio metric calculated as: ball speed/clubhead speed.
Spin rate (°/s)	Rate of ball rotation around the resulting rotational axis immediately after the ball separates from the clubface.
Launch angle (°)	Vertical angle relative to the horizon of the ball's centre of gravity movement immediately after leaving the clubface.
Attack angle (°)	Vertical direction of the clubhead's geometric centre movement at maximal compression of the ball.
Dynamic loft (°)	Vertical clubface orientation at centre point of contact between clubface and ball at the time of maximal compression.

mph = miles per hour; °/s = degrees per second; ° = degrees.

conducted indoors, with no risk of the ball landing in a hazard, which serves as a potential risk in competition.

Statistical analysis

Mean and standard deviation (SD) were computed for all metrics, and normality was checked and confirmed using the Shapiro-Wilk test ($p > 0.05$). Both within and between-session reliability were calculated using a two-way random effects intraclass correlation coefficient (ICC) with 95% confidence intervals (CI) and the standard error of the measurement (SEM), calculated as: SD*(√1-ICC). ICC values were interpreted in accordance with Koo and Li (2016), where values < 0.5 = poor, 0.5–0.74 = moderate, 0.75–0.9 = good, and > 0.9 = excellent. Systematic bias was assessed between test sessions, using paired samples *t*-tests with statistical significance set at $p < 0.05$. Practical differences were also determined using Hedges *g* effect sizes with 95% CI. Finally, inter-relationships between launch monitor metrics were established using Pearson's *r* for both test sessions, with magnitudes interpreted as follows: < 0.1 = trivial, 0.1–0.29 = small, 0.3–0.49 = moderate, 0.5–0.69 = large, 0.7–0.9 = very large, > 0.9 = nearly perfect (Hopkins et al., 2009).

Results

Table 2 shows within-session reliability data for each test session. SEM values ranged from 0.03 (smash factor) to 454.62 °/s (spin rate) in test session one and 0.02 (smash factor) to 240.93 °/s (spin rate) in test session two. ICC values ranged from moderate to excellent in test session one (0.60 to 0.99), but poor to excellent in session two (–0.02 to 1.00). Between-session reliability data and Hedges *g* effect sizes are shown in Table 3. SEM values ranged from 0.03 (smash factor) to 443.90 °/s (spin rate), and ICC values ranged from poor to excellent (0.15 to 0.99). When assessing systematic bias, significant differences were evident between test sessions for: smash factor ($g = 0.47$ [0.22, 0.72]), spin rate ($g = -0.41$ [−0.64, −0.18]), and dynamic loft ($g = -0.21$ [−0.38, −0.04]).

Inter-relationships between launch monitor metrics were established for both test sessions and are presented in Tables 4 and 5. In both test sessions, relationships ranged from trivial to nearly perfect (session 1: −0.04 to 0.98; session 2: 0.02 to 0.99), with the largest relationships being consistent between both test sessions. Specifically, *r* values were nearly perfect in both test sessions between CHS and ball speed ($r = 0.98$–0.99), CHS and carry distance ($r = 0.94$–0.95), ball speed and carry distance ($r = 0.97$–0.98), and launch angle and dynamic loft ($r = 0.98$–0.99). Despite the near perfect relationships of launch angle and dynamic loft, the usability of these metrics must be questioned, owing to the poor levels of reliability for both metrics (Table 1). Thus, a graphical representation of the association between CHS and ball speed, and CHS and carry distance are presented in Figure 1.

Discussion

The aims of the present study were to: 1) investigate the within and between-session reliability of the Trackman 4 launch monitor system, and 2) determine the inter-relationships of some of these commonly used metrics. Both within and between-session results showed that CHS, ball speed and carry distance exhibited the strongest reliability, whilst spin rate, launch angle

Table 2. Within-session reliability data using the standard error of the measurement (SEM) and intraclass correlation coefficients (ICC) with 95% confidence intervals (CI) of launch monitor metrics from the trackman 4.

	Session 1		Session 2	
Trackman Launch Monitor Metrics	*SEM*	*ICC (95% CI)*	*SEM*	*ICC (95% CI)*
Clubhead speed (mph)	1.67	0.99 (0.98, 1.00)	1.64	0.99 (0.98, 1.00)
Ball speed (mph)	4.42	0.97 (0.93, 0.99)	2.46	0.99 (0.98, 1.00)
Carry distance (yards)	14.21	0.91 (0.83, 0.96)	10.65	0.94 (0.87, 0.97)
Smash factor	0.03	0.70 (0.49, 0.86)	0.02	0.52 (0.26, 0.76)
Spin rate (°/s)	454.62	0.60 (0.35, 0.80)	240.93	0.02 (−0.16, 0.33)
Launch angle (°)	1.20	0.67 (0.44, 0.84)	1.52	0.43 (0.17, 0.70)
Attack angle (°)	1.02	0.82 (0.67, 0.92)	0.93	0.82 (0.67, 0.92)
Dynamic loft (°)	1.62	0.63 (0.40, 0.83)	1.63	0.47 (0.20, 0.72)

mph = miles per hour; °/s = degrees per second; ° = degrees.

Table 3. Mean data and standard deviations (SD) for both test sessions ($n = 13$), with Hedges *g* effect sizes with 95% confidence intervals (CI) and between-session reliability data using the standard error of the measurement (SEM) and intraclass correlation coefficient (ICC) with 95% CI.

Trackman Launch Monitor Metrics	Mean ± SD (Session 1)	Mean ± SD (Session 2)	Hedges *g* (95% CI)	SEM	ICC (95% CI)
Clubhead speed (mph)	101.19 ± 16.75	101.26 ± 16.42	0.00 (−0.14, 0.15)	1.66	0.99 (0.97, 1.00)
Ball speed (mph)	145.63 ± 25.97	147.44 ± 24.55	0.07 (−0.08, 0.21)	3.54	0.98 (0.95, 0.99)
Carry distance (yards)	229.54 ± 47.35	233.39 ± 44.37	0.08 (−0.07, 0.23)	7.80	0.97 (0.91, 0.99)
Smash factor	1.44 ± 0.06	1.46 ± 0.02	**0.47 (0.22, 0.72)**	0.03	0.47 (0.02, 0.76)
Spin rate (°/s)	2838.38 ± 721.62	2628.73 ± 243.37	**−0.41 (−0.64, −0.18)**	443.90	0.15 (−0.33, 0.57)
Launch angle (°)	13.50 ± 2.11	13.18 ± 2.03	−0.14 (−0.30, 0.01)	1.37	0.57 (0.15, 0.81)
Attack angle (°)	2.31 ± 2.42	2.71 ± 2.20	0.15 (−0.01, 0.31)	0.83	0.87 (0.68, 0.95)
Dynamic loft (°)	15.44 ± 2.65	14.90 ± 2.24	**−0.21 (−0.38, −0.04)**	1.66	0.54 (0.11, 0.80)

mph = miles per hour; °/s = degrees per second; ° = degrees.
Hedges g values in bold denote statistical significance ($p < 0.05$).

Table 4. Pearson's *r* correlations between launch monitor metrics for test session 1.

	Clubhead Speed	Ball Speed	Carry Distance	Smash Factor	Spin Rate	Launch Angle	Attack Angle	Dynamic Loft
Clubhead Speed	1	0.98	0.94	0.23	−0.04	−0.55	0.52	−0.57
Ball Speed	-	1	0.98	0.41	−0.19	−0.64	0.63	−0.68
Carry Distance	-	-	1	0.49	−0.26	−0.57	0.68	−0.64
Smash Factor	-	-	-	1	−0.83	−0.60	0.78	−0.72
Spin Rate	-	-	-	-	1	0.39	−0.67	0.56
Launch Angle	-	-	-	-	-	1	−0.51	0.98
Attack Angle	-	-	-	-	-	-	1	−0.65
Dynamic Loft	-	-	-	-	-	-	-	1

Table 5. Pearson's *r* correlations between launch monitor metrics for test session 2.

	Clubhead Speed	Ball Speed	Carry Distance	Smash Factor	Spin Rate	Launch Angle	Attack Angle	Dynamic Loft
Clubhead Speed	1	0.99	0.95	0.24	−0.27	−0.54	0.49	−0.65
Ball Speed	-	1	0.97	0.33	−0.29	−0.53	0.54	−0.63
Carry Distance	-	-	1	0.47	−0.32	−0.36	0.59	−0.48
Smash Factor	-	-	-	1	−0.26	0.03	0.69	−0.04
Spin Rate	-	-	-	-	1	−0.12	−0.43	0.02
Launch Angle	-	-	-	-	-	1	0.07	0.99
Attack Angle	-	-	-	-	-	-	1	−0.05
Dynamic Loft	-	-	-	-	-	-	-	1

and dynamic loft, exhibiting the poorest reliability. When investigating inter-relationships between launch monitor metrics, the strongest (near perfect) associations were evident between CHS, ball speed and carry distance.

When considering the primary aim, our findings showed that within-session reliability (as measured by the ICC) was moderate to excellent for all eight metrics in session one, but in session two, notable reductions were evident for spin rate, launch angle and dynamic loft, with each of these exhibiting ICC values < 0.50. From a consistency standpoint, CHS, ball speed, and carry distance showed the strongest reliability (ICC range = 0.91–0.99) demonstrating excellent reliability across both test sessions. Given the distinct lack of comparable data for the majority of these metrics using a Trackman, drawing upon previous reliability research cannot be done. However, previous literature has outlined that there is a "sweet spot" in terms of which values likely produce the most desirable outcome for metrics such as spin rate, launch angle, attack angle and dynamic loft (Brennan et al. 2023; Wallace et al., 2007). For example, Wallace et al. (2007) showed that when aiming to optimise drive distance, the optimal spin rate is likely to be between 2280 and 2640 degrees per second. Thus, when the desirable outcome of a metric is not always the larger value (like for CHS, ball speed or carry distance), fluctuations either side of that optimal range are likely to affect reliability in a detrimental way. To use spin rate as an example, our data supports this notion given the ICC was 0.60 in session one, but drastically reduced to 0.02 in sessions two. However, in an attempt to somewhat explain this, metrics such as spin rate, launch angle, attack angle and dynamic loft, have all been described as strategy-based metrics during the golf swing (Brennan et al. 2023), which partly describe the process of how distance is achieved, and are somewhat likely to be more variable.

When assessing the between-session reliability data, our findings followed a similar trend as within-session, with ICC values often appearing to be somewhere in-between the two within-session values, especially for metrics which showcased lower reliability. However, when trying to relate our between-session findings to previous research, comparable reliability data can only be done from one study that used a different (Flightscope Mevo+) launch monitor device. Villarrasa-Sapina et al. (2022) reported similar ICC data to the present study with CHS, ball speed, carry distance and smash factor showing values ranging from 0.86 to 0.98, with only smash factor in the present study exhibiting a noticeably lower between-session ICC value of 0.47, but a small SEM of 0.03. Furthermore, less reliable metrics in the present study such as launch angle (ICC = 0.57) also showed poor reliability when using the Flightscope Mevo+ (ICC = 0.43) (Villarrasa-Sapina et al., 2022). Consequently, and regardless of which launch monitor device is used, it seems that the most reliable launch

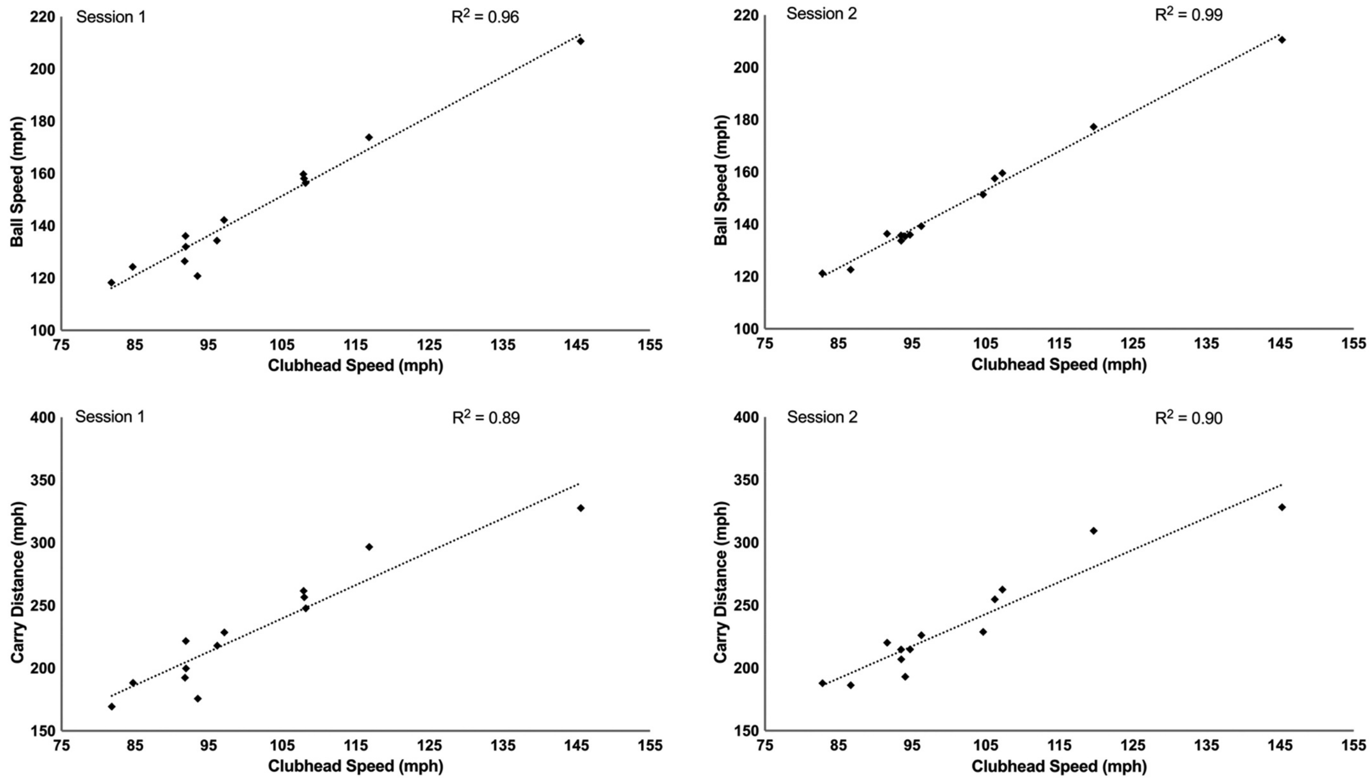

Figure 1. Pearson's *r* correlations between clubhead speed and ball speed, and clubhead speed and carry distance, for both test sessions.

monitor metrics are CHS, ball speed and carry distance, and potentially smash factor if the SEM is considered.

However, it's worth acknowledging that smash factor is a ratio metric (i.e., made up of two component parts: ball speed and CHS) and previous research has outlined many problems with monitoring ratio data when tracking changes in data over time (Bishop et al., 2023). Specifically, practitioners may wish to be mindful that changes in smash factor can occur from more than one source (i.e., changes in CHS or ball speed) and thus, when being used, must be done in conjunction with both component parts. In addition to this, smash factor was one of the metrics which showed significant differences between test sessions ($g = 0.47$). Although somewhat anecdotal, we do not consider this to be a positive finding, given this study employed a test-retest design, with a maximum of 1-week between test sessions. Put simply, this does not provide enough time to showcase any meaningful adaptations in performance; thus, we would potentially expect greater consistency between test sessions for this metric. With that in mind, despite its small SEM, practitioners may wish to consider using smash factor with some level of caution. Other metrics exhibiting significant differences between test sessions included: spin rate ($g = -0.41$) and dynamic loft ($g = -0.21$), and when each of these metrics' poor reliability is also considered, it becomes challenging to suggest that practitioners should include these as part of the ongoing monitoring process.

Our secondary aim focused on the inter-relationships of these launch monitor metrics, which to the best of our knowledge, has not been investigated before. Given our test-retest design focus, the correlations which exhibited near perfect relationships, consistently across both sessions, are the ones of most importance. Specifically, CHS and ball speed ($r = 0.98$–0.99), CHS and carry distance ($r = 0.94$–0.95), ball speed and carry distance ($r = 0.97$–0.98), and launch angle and dynamic loft ($r = 0.98$–0.99) were the most consistent and important associations found. Naturally, it stands to reason that CHS, ball speed and carry distance are so closely related, as carry distance will primarily be determined by the speed of the ball, which in turn, is determined by how much force and speed is produced during the swing (Bishop, Ehlert, et al., 2022; Brennan et al. 2023; Ehlert, 2020). In addition, it stands to reason that there was such a strong relationship between launch angle and dynamic loft. Put simply, the more lofted the club (i.e., a pitching wedge vs. a 4-iron), the easier it will be to quickly elevate a shot at a sharper angle (Betzler et al., 2014; Wallace et al., 2007). However, despite the strength of this relationship, practitioners are reminded that both launch angle and dynamic loft exhibit questionable reliability, and if they are to be used in the monitoring process, must be done so knowing that they are likely to exhibit greater variability than metrics such as CHS, ball speed and carry distance.

There are a few limitations to the present study which must be acknowledged. Firstly, our sample size was small; however, it did exceed the number required to expect a minimum acceptable ICC value of 0.5. Second, we only used a driver to assess launch monitor data, with previous research using multiple clubs (e.g., driver, mid-iron and short-iron) (Leach et al., 2017; Villarrasa-Sapina et al., 2022). However, with Trackman being considered one of (if not the) gold standard launch monitor systems, this study does represent one of the first of its kind and is useful in aiding a practitioner's understanding of how usable some of the data is, in day-to-day practice. Thirdly, the current study adopted to measure launch monitor data indoors (which was unavoidable). However, given Trackman utilises radar technology (which is trying to track objects flying through the air), it is believed that utilising this technology outdoors is more appropriate because ball flights can be tracked from impact to landing. Future research should aim to conduct both indoor and outdoor testing with a highly-skilled group of players in an attempt to better understand how the data is affected. Finally, the participants were a mix of professional and amateur golfers resulting in a mean handicap of 7.6, and it is possible that the reliability of some metrics would be improved if a more homogenous sample was used (e.g., elite amateurs with handicap < 5), which should be strived for in future investigations. However, it is also worth acknowledging that the variation in skill-level could also be deemed a strength of this investigation, when considering the inter-relationships. Specifically, the magnitude of associations between CHS, ball speed and carry distance, shows that regardless of skill-level, these relationships are both consistent and near perfect, which should provide practitioners with confidence in their use for ongoing monitoring purposes.

Practical applications

Since this investigation has provided data on the day-to-day reliability of the launch monitor metrics, practitioners are now in a position to consider how to use these values to set target scores for players. Specifically, the SEM typically accounts for 67% of the normal distribution in a given test or metric, whilst 2*SEM accounts for 95%, enabling much greater confidence that any change outside this is greater than the error of the test. To provide a specific example, if a player produces a CHS of 101 mph with a SEM of 1.66 mph, we would first multiply 1.66 by 2, resulting in a value of 3.32 mph. The next step is to add this value to our test score of 101 mph, resulting in a target score of 104.32 mph. Put simply, when aiming to determine whether changes in CHS are real, practitioners would need to see an improvement greater than 104.32 mph to be confident that the change is greater than the measurement error. This process could then be applied using the SEM value for all metrics (especially those with good or excellent ICC values), enabling us to differentiate between the signal and the noise, when using launch monitor systems.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The author(s) reported there is no funding associated with the work featured in this article.

ORCID

Chris Bishop http://orcid.org/0000-0002-1505-1287

References

Betzler, N., Monk, S., Wallace, E., & Otto, S. (2014). The relationships between driver clubhead presentation characteristics, ball launch conditions and golf shot outcomes. *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering & Technology*, *228*(4), 242–249. https://doi.org/10.1177/1754337114541884

Bishop, C., Ehlert, A., Wells, J., Brearley, S., Brennan, A., & Coughlan, D. (2022). Strength and conditioning for golf athletes: Biomechanics, common injuries and physical requirements. *Professional Strength and Conditioning*, (63), 7–12.

Bishop, C., Shrier, I., & Jordan, M. (2023). Ratio data: Understanding pitfalls and knowing when to standardise. *Symmetry*, *15*(2), 1–6. https://doi.org/10.3390/sym15020318

Bishop, C., Turner, A., Jordan, M., Harry, J., Loturco, I., Lake, J., & Comfort, P. (2022). A framework to guide practitioners for selecting metrics during the countermovement and drop jump tests. *Strength & Conditioning Journal*, *44*(4), 95–103. https://doi.org/10.1519/SSC.0000000000000677

Brennan, A., Ehlert, A., Wells, J., Broadie, M., Coughlan, D., Turner, A., & Bishop, C. (2023). Monitoring performance in golf: More than just clubhead speed. *Strength & Conditioning Journal*, *45*(6), 631–641. https://doi.org/10.1519/SSC.0000000000000764

Broadie, M. (2014). Every shot counts: Using the revolutionary strokes gained approach to improve your golf performance and strategy. *Avery*, 20–48.

Ehlert, A. (2020). The effects of strength and conditioning interventions on golf performance: A systematic review. *Journal of Sports Sciences*, *38*(23), 2720–2731. https://doi.org/10.1080/02640414.2020.1796470

Hopkins, W., Marshall, S., Batterham, A., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise*, *41*(1), 3–12. https://doi.org/10.1249/MSS.0b013e31818cb278

Koo, T., & Li, M. (2016). A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *Journal of Chiropractic Medicine*, *15*(2), 155–163. https://doi.org/10.1016/j.jcm.2016.02.012

Leach, R., Forrester, S., Mears, A., & Roberts, J. (2017). How valid and accurate are measurements of golf impact parameters obtained using commercially available radar and stereoscopic optical launch monitors? *Measurement*, *112*, 125–136. https://doi.org/10.1016/j.measurement.2017.08.009

Read, P., Lloyd, R., De Ste Croix, M., & Oliver, J. (2013). Relationships between field-based measures of strength and power and golf club head speed. *Journal of Strength & Conditioning Research*, *27*(10), 2708–2713. https://doi.org/10.1519/JSC.0b013e318280ca00

Villarrasa-Sapina, I., Ortega-Benavent, N., Monfort-Torres, G., Ramon-Llin, J., & Garcia-Masso, X. (2022). Test–retest reliability of task performance for golf swings of medium- to high-handicap players. *Sensors*, *22*(23), 1–11. https://doi.org/10.3390/s22239069

Wallace, E., Otto, S., & Nevill, A. (2007). Ball launch conditions for skilled golfers using drivers of different lengths in an indoor testing facility. *Journal of Sports Sciences*, *25*(7), 731–737. https://doi.org/10.1080/02640410601113221

Walter, S., Eliasziw, M., & Donner, A. (1998). Sample size and optimal designs for reliability studies. *Statistics in Medicine*, *17*(1), 101–110. https://doi.org/10.1002/(SICI)1097-0258(19980115)17:1<101:AID-SIM727>3.0.CO;2-E