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Original research

The influence of bowling velocity on movement variability in experienced older aged lawn bowlers

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ABSTRACT

Objectives: This project examined the movement strategies adopted by highly experienced older aged lawn bowlers when performing *Draw* and *Drive* deliveries.
Design: Cross-sectional.
Methods: Twenty five experienced (10.2 ± 7.8 years) older aged lawn bowlers (67.3 ± 7.0 years) who play lawn bowls at least once per week volunteered to participate in this study. Participants performed 10 *Draw* and *Drive* deliveries at a target positioned 23 m away while standing on two force platforms (600 Hz), while an infrared motion capture system (200 Hz) recorded phases times and both foot and bowl positioning. Normalised root mean square (NoRMS) analyses was used to assess the bowl path consistency during the delivery phase. Correlation analyses assessed for relationships between age and experience and the spatiotemporal variables, with paired t-tests and effect size (ES) analyses used to examine differences between delivery types.
Results: None of the spatiotemporal or NoRMS data achieved more than low correlations with either age or playing experience ($R^2 < 0.2$). Although bowl release velocities were significantly slower for the *Draw* 5.25 ± 0.72 m/s than for the *Drive* deliveries 6.40 ± 0.97 m/s ($p < 0.001$, $ES = 1.96$) there were limited changes in any of the spatiotemporal variables. NoRMS data remained largely unchanged between *Draw* (5.10 ± 1.65) and *Drive* (5.07 ± 1.49, $p = 0.925$, ES = 0.02) deliveries.
Conclusions: These highly experienced lawn bowlers are adapting their technique to the different task demands of the two delivery types without altering their specific movement strategies.

Practical implications

- The technique of the *Drive* delivery is basically a more rapid version of the slower *Draw* delivery and simply incorporates a slightly larger back-swing position.
- While a certain degree of movement variability in bowl delivery path was present during the *Draw* deliveries, this did not change for the more rapid *Drive* deliveries.
- These experienced lawn bowlers released the bowl in the same relative position (in relation to their stride foot), with the side-to-side orientation of the bowl at *Release* being more consistent than the forward-to-back.

1. Introduction

Lawn bowls is a popular sport and is played in at least 52 countries globally.[1] The sport enjoys particular popularity throughout British Commonwealth countries, with Australian statistics showing that during 2015 more than 620,000 Australians played lawn bowls in either formal club competition or recreationally.[2] Although most elite lawn bowlers are aged between 20 and 40 years, lawn bowls has the relatively unique characteristic of being particularly popular amongst older aged participants, with more than 58% of participants being at least 65 years of age.[3]

Lawn bowls is a target sport where players take turns to roll their bowls using an underarm delivery as close as possible to a small target bowl (called the *Jack*) that is positioned between 23–37 m away. Traditionally, it is played on highly manicured grass, although there are an increasing number of matches being played on artificial surfaces in indoor venues. The bowl itself is typically 115–130 mm in diameter, has a mass of 1.2–1.5 kg, and has the unique characteristic of being asymmetrically shaped with a slightly off-centre weight distribution that results in the bowl following an arc when

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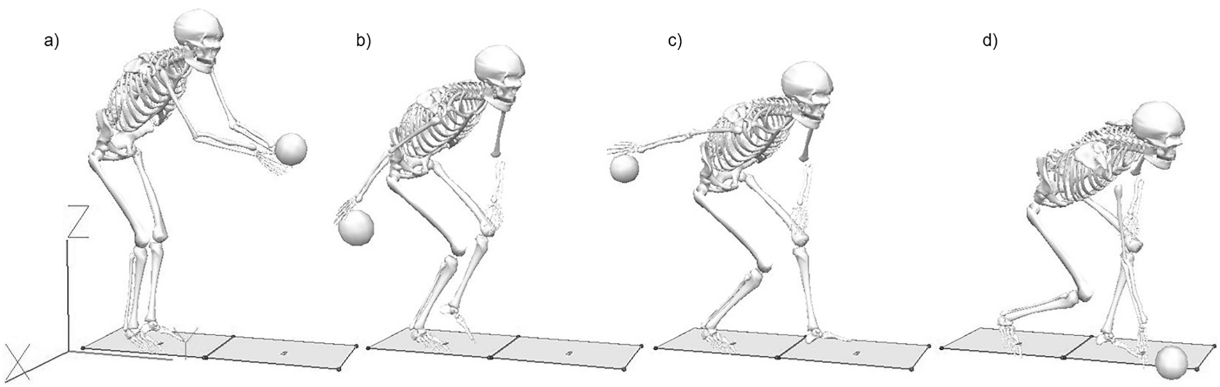

Fig. 1. Figure showing the main phases of the lawn bowls delivery action including the initial set-up position (a) and positions that designate the *Stride* (b–c) and *Delivery* (c–d) phases.

rolled. The standard *Draw* delivery commences with the bowler standing on a *Mat* (360 mm wide × 600 mm long), facing the target with the bowl supported in the dominant hand (Fig. 1). A right-handed player would then step forward with their left leg into a lunge position before releasing the bowl from their right hand as close to the ground as possible in a smooth under-arm action.[4] A variation on the *Draw* is the *Drive*, which although fundamentally similar in appearance involves considerably more power and has the explicit aim of striking the opponent's bowl(s) and/or the *Jack* in order to displace them.

Lawn bowls matches are contested by two teams of one, two, or four players over multiple rounds (*Ends*), with points awarded at the completion of each *End* by counting the number of bowls an individual or team has inside the closest bowl of the opposition. Uniquely, the winner of the previous *End* dictates the length over which the subsequent *End* is played. Additionally, the position of the *Jack* is not fixed during each *End* and so if it is struck by a bowl (hence moved) the players must adapt to this new position in their subsequent turns until the *End* is completed.

Clearly, the game poses numerous accuracy challenges with players having to adapt constantly to changes in both target length and location (and playing surface), which in turn influence the optimal bowl release velocity and hence the shape of the arc travelled by the bowl. However, despite both the popularity of the sport and its relatively unique technique challenges, biomechanical research on lawn bowls is published rarely in the scientific literature. At the time of this submission, only one paper reports data on biomechanical aspects of the delivery action, and that study focuses on the balance requirements of the release position in older aged participants.[5] Additionally, the potential speed-accuracy issues[6] imposed by *Draw* and *Drive* deliveries provides an ideal opportunity to explore this concept in a sport reported rarely in the scientific literature.

The need for lawn bowlers to adopt a technique that is adaptable is in line with research surrounding the concept of functional movement variability.[7,8] Researchers in this domain highlight that the movement patterns of highly skilled performers contain an innate level of movement variability, which enables them to adapt easily to variations in task demands without the need to modify fundamental aspects of the movement (see reviews by Refs.[8–10]). However, there is an obvious limit to the level of acceptable variability in an accuracy sport such as lawn bowls, with issues such as the variability of movements around the location and velocity of the bowl release point being likely to have a greater impact on outcome than any movement variability surrounding the backswing position. This concept has been demonstrated in both skilled table tennis players and golfers, where the variability in player's bat/club paths decreases approaching the point of ball contact.[11–13]

Assessing the role of functional movement variability in lawn bowls adds some interesting dimensions to this field, as participants must perform both finesse (*Draw*) and dynamic (*Drive*) movements using what fundamentally appears to be similar movement patterns. Additionally, examining these areas within a population typical in this sport can shed light on the technique strategies adopted by experienced older aged players (e.g. >65 years). The latter is particularly interesting, as research suggests that fine upper limb control and postural stability both decrease with age.[14–16] Accordingly, the aim of this project was to first examine the concept of function movement variability by examining consistency in bowl path, tempo and stride length in highly experienced older aged lawn bowlers when performing *Draw* deliveries. It was predicted that the more experienced players would exhibit more variability in these variables throughout the backswing phase of the delivery while also having a high level of consistency in the orientation of the bowl at the point of release (the most crucial point in the bowling action). The secondary aim for this project was to examine the influence of bowl release velocity on these variables by repeating the previous analysis for the *Drive* delivery.

2. Methods

Twenty five (13 males, 12 females) healthy older aged lawn bowlers volunteered to participate in this study, with written informed consent was obtained prior to all testing in accordance with the institutional Human Research Ethics Committee procedures. All participants were experienced players (12.2 ± 3.8 years), playing lawn bowls regularly (at least once per week) at local clubs on a year-round basis. Although some participants acknowledged they had some minor osteoarthritis, they all indicated that they were able to play lawn bowls 'pain free' at the time of testing. The mean age, height and body mass (BM) of the bowlers was 67.3 ± 7.0 years (males 68.7 ± 8.5 years, females 65.8 ± 4.6 years), 1.703 ± 0.078 m (males 1.765 ± 0.046 m, females 1.635 ± 0.038 m), and 77.9 ± 12.7 kg (males 85.4 ± 10.6 kg, females 69.7 ± 9.5 kg) respectively. Participants were excluded from testing if they reported suffering from conditions such as Parkinson's disease, stroke, or forms of vestibular disease at the time of testing.

After collecting standing height and BM data, 14 low mass, retro-reflective markers were attached bilaterally over the medial and lateral malleoli, the distal lateral edge of the 1st and 5th metatarsals, the tip of the 2nd toe and the base of the calcaneous. Two additional flat marker discs (10 mm) were positioned on either side of each participant's bowl. Next, a static capture was completed for each participant, with these data used during the modelling procedures. Participants were then permitted 5 min. warm-up and

Table 1
Data (mean ± 1SD) for the various consistency measures during *Draw* and *Drive* deliveries, with results from paired t-test and effect size (ES) analyses. The first row for each variable represents the mean (±1SD) of the mean data for each participant and delivery type. The second row represents the mean of the standard deviations for each participant for each delivery type (a measure of intra-individual variability).

Variable	Draw	Drive	*P*	*ES*
Stride phase time (s)	0.788 ± 0.185	0.747 ± 0.173	.002	0.70
	0.067 ± 0.033	0.081 ± 0.054	.137	0.31
Delivery phase time (s)	0.527 ± 0.087	0.501 ± 0.097	.004	0.63
	0.034 ± 0.021	0.035 ± 0.014	.851	0.04
Bowl tempo[a]	0.69 ± 0.13	0.69 ± 0.15	.920	0.02
Stride length (m)	0.600 ± 0.124	0.605 ± 0.109	.615	0.10
	0.045 ± 0.053	0.049 ± 0.039	.557	0.12
Stride width (m)	0.080 ± 0.045	0.059 ± 0.039	<.001	1.05
	0.017 ± 0.008	0.018 ± 0.006	.817	0.05
$Bowl_x$ position at *Backswing* (m)	0.013 ± 0.101	0.020 ± 0.099	.272	0.22
	0.020 ± 0.007	0.021 ± 0.007	.358	0.19
$Bowl_y$ position at *Backswing* (m)	−0.010 ± 0.163	−0.033 ± 0.166	.056	0.40
	0.042 ± 0.015	0.040 ± 0.010	.571	0.11
$Bowl_z$ position at *Backswing* (m)	0.591 ± 0.153	0.647 ± 0.163	<.001	1.26
	0.034 ± 0.012	0.037 ± 0.011	.299	0.21
$Bowl_x$ position at *Release* (m)	0.262 ± 0.056	0.243 ± 0.042	.008	0.58
	0.015 ± 0.006	0.019 ± 0.008	.007	0.58
$Bowl_y$ position at *Release* (m)	0.343 ± 0.104	0.412 ± 0.133	.005	0.62
	0.087 ± 0.021	0.100 ± 0.047	.213	0.26
NoRMS[a]	5.10 ± 1.65	5.07 ± 1.49	.925	0.02

[a] Data showing the mean in the standard deviations excluded.

10 min. of practice, before performing 20 bowls (10 *Draw* deliveries and 10 *Drives*) at a *Jack* positioned 23 m away. The delivery type order was randomised between participants and there was a short 1–2 min break between bowls to replicate standard conditions during competition.[17] Repetition number was consistent with previous studies examining movement variability in kinematic variables during discrete tasks.[9,18] Participants commenced each bowl standing on a force platform (Bertec Corporation, Columbus, USA) before stepping forward onto another during the delivery stride (sampling at 600 Hz). Marker locations were tracked using a motion capture system (Qualisys AB, Gothenburg, Sweden) sampling at 200 Hz. Data from the force platforms were inputted via an AD converter (BNC/USB/19 Rack, Qualisys AB, Gothenburg, Sweden) and synchronised with the kinematic data using the data acquisition software.

Marker trajectories were smoothed using a 2nd order low-pass digital filter with a cut off frequency of 6 Hz and two single segment foot models were developed using standard biomechanical software (Visual3D, C-Motion, Inc. Maryland, USA). A global reference system (GRS) was established with the positive y-axis directed towards the *Jack*, the x-axis perpendicular to the y (positive direction to the right) and the positive z-axis pointing vertically.

The foot kinematics and ground reaction force data were used to identify three time points and two phases during each delivery stride. The *Stride* was defined as having occurred from the point of lift-off of the stride foot through to ground contact with the second force platform. The *Delivery* was defined as occurring from the end of the *Stride* until the point of bowl release (Fig. 1). Stride length and width data were calculated based on the displacement of the segmental centre of mass of the stride foot, with these data combined with the duration of the *Stride* and *Delivery* phases as gross measures of spatiotemporal technique consistency. The 'tempo' of the bowling action was quantified as the ratio of the *Delivery* phase to the *Stride* phase. The orientation of the bowl centroid (a point mid-way between to the two bowl markers) at the beginning (*Backswing*) and end (*Release*) of the *Delivery* phase was determined in relation to the GRS and the stride foot respectively, with these data expressed in relation to the associated axes (i.e. $Bowl_x$, $Bowl_y$ and $Bowl_z$, respectively). The consistency in the orientation of the bowl at these two phases was determined from the standard deviation (SD) data,[19] with the consistency of bowl path during the entire bowling action quantified using normalised root mean squared (NoRMS) procedures.[20,21] When using this technique a higher NoRMS value represents increased variability in the path of the bowl over the 10 *Draw* or *Drive* deliveries.

All statistical analyses were conducted using the Statistical Package for the Social Sciences (Version 22.0 for Windows, SPSS Inc., USA). The relationships between the various kinematic measures and both age and playing experience were assessed via Pearson's Product Moment Correlation Coefficients, with paired sample t-tests and Cohen's Effect Size tests for related samples (*ES*) used to test for differences between variables across the two bowl delivery types. Non-normally distributed data (i.e. SD values) were log transformed prior to analyses. The relative magnitude of the *ES* values was expressed using the following subjective scale: 0–0.2 *trivial*, 0.2–0.6 *small*, 0.6–1.2 *moderate*, 1.2–2.0 *large*, >2.0 *very large*.[22] Due to the multiple statistical comparisons the significance level was set at $p < 0.01$ for all comparative analyses, with results presented as means ± 1SD.

3. Results

Although not assessed quantitatively, all participants showed high levels of accuracy that are typical of highly experienced players, finishing their bowl within less than 0.5 m of the *Jack* on all *Draw* deliveries and striking the *Jack* during nearly all *Drives*. None of the assessed spatiotemporal variables achieved more than *low*/*small* correlations[23] with either age or playing experience ($R^2 < 0.20$). The only significant correlations suggest that during *Drive* deliveries older aged players tending to take a shorter forward stride ($r = -0.405$, $p = 0.045$), have slightly reduced consistency in mediolateral stride foot placement ($r = 0.414$, $p = 0.040$) and have increased NoRMS values ($r = 0.443$, $p = 0.027$).

Not surprisingly, bowl release velocities were significantly slower for the *Draw* 5.25 ± 0.72 m/s than for the *Drive* deliveries 6.40 ± 0.97 m/s ($p < 0.001$, $ES = 1.96$). These differences were reflected in the *moderately* shorter overall *Stride* and *Delivery* phases times, although there were no differences in 'tempo' between delivery types (Table 1). Similarly, there were non-significant *trivial* differences in stride length between the two delivery types, although stride width was typically narrower during the *Drive* deliveries. The latter were also typified as having a more exaggerated *Backswing*, with the bowl being drawn back higher and

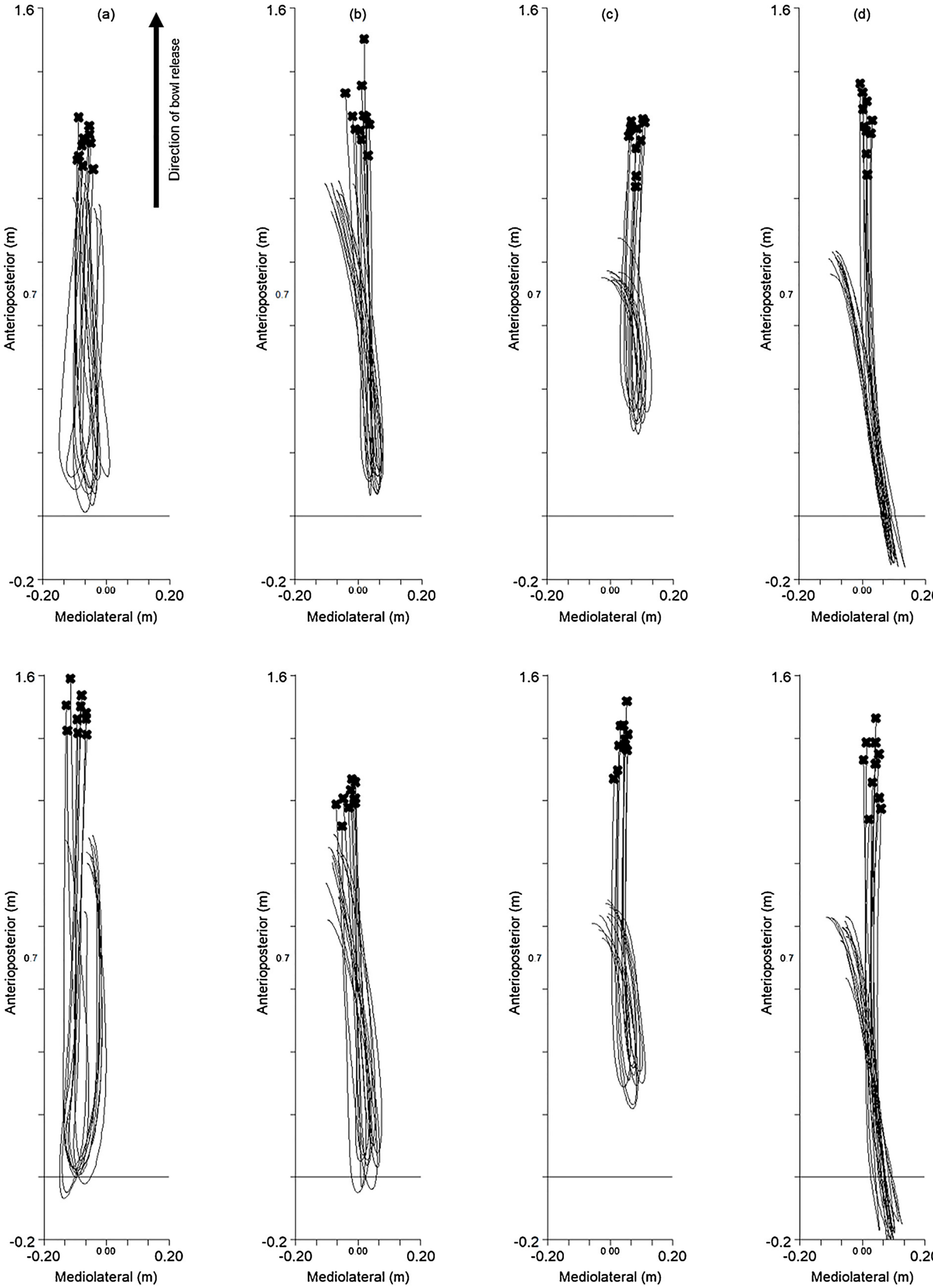

Fig. 2. Sample two-dimensional bowl path traces (plane form by the x and y-axes) for four participants for their ten *Draw* (top row) and *Drive* (bottom row) deliveries. Columns (a) and (b) are representative data two female competitors (62 and 70 years old respectively) who have 13 and 15 years lawn bowling experience respectively. Columns (c) and (d) are representative data two male competitors (76 and 65 years old respectively) who both have 12 years lawn bowling experience. The NoRMS these bowler's *Draw* deliveries were of 3.89, 5.79, 4.47 and 3.83 respectively, while the NoRMS for their *Drive* deliveries were 3.80, 7.25, 4.22 and 4.97 respectively. The arrow represents the direction of bowl travel during release, with the small "x" on the bowl path traces representing the point of bowl release.

slightly further back than during the *Draw* deliveries. During the *Drive* deliveries the bowl was released slightly closer (mediolaterally) and further in front (anteroposteriorly) of the stance foot than during *Draw* deliveries.

There were *trivial* to *small* increases in SD values from the *Draw* to the *Drive* deliveries, with the consistency of mediolateral bowl position the only variable to achieve statistical significance. This indicates that regardless of any differences in positioning of the stride foot or bowl between delivery types, participants achieved these positions with similar consistency. Accordingly, despite some slight inter individual differences in bowl path NoRMS data (Fig. 2), there were almost no differences in NoRMS data between bowl delivery types.

4. Discussion

This novel project examined the concept of function movement variability by assessing consistency in bowl path, tempo and stride length in highly experienced older aged lawn bowlers when performing *Draw* and *Drive* deliveries. The key finding in this project was that despite *large* significant differences in release velocities between the two delivery types, there were no concurrent changes in any typical measures of movement variability. For example, the typical technique adaptations for the *Drive* deliveries were centred on similar bowl swing paths to those adopted during the *Draw* deliveries. In order to generate the required additional bowl release velocities for the former, the bowlers simply withdrew the bowl further back in the *Backswing* and increased *Delivery* phase time. This approach is consistent with current theories on movement expertise, with experts demonstrating the capacity to modify their individual movement patterns to accommodate different task demands.[8,10,24]

It was anticipated that for these high accuracy tasks, participants would exhibit greater intra-individual variability in bowl position at the end of the *Backswing*, with very consistent bowl orientation at *Release*. This hypothesis is consistent with the concept of functional movement variability,[8–10] suggesting that the participants' expertise in lawn bowls enables them to compensate for any fluctuations in bowl position at the end of the *Backswing* with subtle changes in the bowl path during the *Downswing* phase. This hypothesis is consistent with research indicating that experienced golfers demonstrate greater SD values for the orientation of the putter at the end of the backswing compared to ball contact.[13] However, participants in this study had very consistent bowl positions at both *Backswing* and *Release* points during the *Draw* deliveries (i.e. small mean SD values), with the slightly greater anteroposterior mean SD values at *Release* probably being a reflection of the concomitant slight increases in stride length. The high level of intra-individual consistency in mediolateral bowl position at *Release* is noteworthy and no doubt a reflection of the importance this variable is likely to have on overall delivery accuracy. Similarly, while the high level of consistency in *Backswing* bowl orientation was not anticipated, it was a common feature in all participants and is probably simply a reflection of extensive practice. This is also reflected in the low NoRMS values, which show that all participants had highly consistent bowl swing paths.

In accordance with standard speed/accuracy concepts,[6] it was anticipated that the task demands of the *Drive* deliveries would result in concomitant increases in intra-individual positional variability in both *Backswing* and *Release* positions compared to the slower *Draw* deliveries. However, *trivial* non-significant differences in NoRMS and most mean SD data indicate that the *Delivery* phase was largely unaffected by increases in movement velocity associated with the different delivery types. The *small* intra-individual increases in mean SD values for stride time (0.014 s), and both mediolateral (4 mm) and anteroposterior (13 mm) bowl position at *Release* are of such small magnitude that they are unlikely to be practically meaningful. It would appear from these data that participants had obtained sufficient expertise in both delivery types that they were able to deliver the bowl consistently regardless of the different task demands.

The forward lunging action typical to lawn bowls deliveries requires players to control forces equivalent to their body mass (on the *Stride* leg) in a posture that compromises mediolateral balance.[5] Surprisingly, players tended to narrow their stride width during *Drive* deliveries with the reduced mediolateral base of support increasing the balance challenges associated with this position. This finding may be linked with the significant, albeit *small* negative correlation between stride length and age during these deliveries, suggesting older aged lawn bowlers may shorten stride length to help maintain balance control. Regardless, the high level of movement consistency exhibited by all participants is particularly noteworthy given previous research has linked reduced fine upper limb control and postural instability with advances in age.[14–16]

The current project did not attempt to assess lawn bowls skill, but all participants were experienced players and demonstrated high levels of accuracy during the testing. However, future projects should also assess novice players to see whether the results achieved in this study represent typical skill development for players of these age groups. In addition, movement analysis was limited to the quantification of bowl path, tempo and stride length and not whole-body kinematics per se and so generalisations to limb or joint movement variability should be undertaken with caution. Similarly, the limitations imposed by the dimensions of our motion analysis laboratory meant that we could not vary *End* length during testing (a crucial factor in *Draw* deliveries but probably less important during *Drives*). An important evolution of this research would be to assess how the movement strategies adopted by experience players are modified to fluctuations in *End* length. Finally, while the older age categories used in this project are representative of a large population of lawn bowlers, care should be taken before attempting to generalise these data with younger aged and/or elite level players.

5. Conclusions

This study has demonstrated how experienced older aged lawn bowlers are able to adapt their technique to the different task demands of the *Draw* and *Drive* delivery types without altering their specific movement strategies. This approach is consistent with current theories on movement expertise and suggests that participants were skilled at these tasks. The high level of movement consistency shown by these older aged participants suggests that the sport of lawn bowls has the potential to form a highly practical form of balance training.

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