TRANSITION TO A HEAVIER BALL IN TEN-PIN BOWLING

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This study investigated how developmental ten-pin bowlers can better transit to a heavier ball by comparing differences in performance outcomes and movement execution between two ball weights. Eight pre-transited bowlers bowled 10 first-frame trials each in two ball weight conditions: normal (NB) and heavy (HB); of which 3 trials were analysed. Full body joint kinematics were recorded via a 3D motion capture system. Paired sample t-test on performance outcome, joint kinematics and kinetics was conducted. No differences in performance outcome and peak joint velocities were found (p>0.05). Bowling with the HB resulted in higher peak elbow extension moment and quicker third step, with differences in left shoulder rotation and ankles abduction during the movement (p<0.05). Results suggest strengthening of the musculature around the shoulder and arm to prepare for the transition.

KEYWORDS: ten-pin bowling, kinematics, kinetics.

INTRODUCTION: Ten-pin bowling is a self-paced abstract target sport that involves swinging <16pound ball in a 4-5 step approach to generate optimal speed and revolution down an 18m oiled lane to knock down 10 pins. Faster ball release velocity (BR_{vel}) was significantly correlated to average bowling score, peak foot velocity, acceleration, deceleration and duration in the final step known as the front foot slide (FFS) (Razman, Abas, & Othman, 2010). Seiferheld et al (2023) found that over repeated bowls, male elite bowlers decreased BR_{vel}, but increased wrist and elbow flexion and pronation angles during ball release for higher rotational energy to compensate for changes in ball and lane traction. All professional bowlers use 15 to 16-pound ball (Lee, Harmony, Jamal-Azmi, Gunasagaran, & Ahmad, 2021) as a heavier ball can lead to more pin action, increasing the strike probability; provided that the acceleration can be maintained (F=ma). Hence every developmental bowler goes through a transition from a lighter 12 to 14-pound to the heavier ball. However, the transition is done based on coaches' experience and qualitative judgement as there are no known research in this area. If the transition is not managed properly, injury risk may be higher with increased load over time; especially at the more commonly injured bowling wrist and fingers (ring, middle fingers, and thumb) which are in contact with the ball (Lee et al., 2021). Past research in other skills such as golf swing, tennis serve and baseball pitching provide reference points. Heavier golf clubs did not change club head speed but ball speed, trunk and wrist kinematics were different (Joyce, Burnett, Cochrane, & Reyes, 2016). Increase in racket weight resulted in decreases in peak shoulder internal rotation and wrist flexion velocities during the forwardswing of elite adolescent female tennis players while maintaining the ball speed as with a normal racket (Whiteside, Elliott, Lay & Reid, 2014). Pitching overweight balls correlated with decreased ball velocity, shoulder and elbow joint torques and forces (Fleisig, Diffendaffer, Aune, Ivey, & Laughlin, 2016). Therefore, to better understand how to manage this transition in developmental bowlers, this study investigated the differences in performance outcomes and movement execution when the ball weight increased. Bowling with a heavier ball was hypothesized to (1) result in worse performance outcomes in terms of BR_{vel} and score (2) smaller and slower joint and movement kinematics (3) higher peak moments in the shoulder, elbow, and wrist of the bowling arm.

METHODS: Eight pre-transited right-handed bowlers bowled 10 first-frame trials each in two ball weight conditions: normal (NB) and heavy (HB). This means that spares were not played and pins reset to the full set if there was no strike in the previous bowl. This ensures all participants have the same task goal of hitting 10 pins rather than having varied pin positions during the second frame when spares happen. Participants were told to bowl to the best of their ability and to score as many pin-falls as possible. Order of the two conditions were alternated between participants. Scores (pin-falls) were recorded per shot and bowlers answered a questionnaire regarding bowling with the heavier ball for a qualitative perspective.

Full body joint kinematics were recorded via a 12-camera 3D motion capture system (Vicon Motion Systems, UK) operating at 250 Hz and processed using modified versions of the UWA upper body, lower body, and ball models (Whiteside et al., 2014), filtered using a fourth-order low-pass Butterworth filter at a cut-off frequency of 6Hz for the marker trajectories. The movement was divided into three phases: downswing, backswing and forwardswing, defined by events based on the ball swing: start, bottom (BOS) and top of swing (TOS), and ball release (BR) (Figure 1), with the carpal marker position on the bowling hand as reference. Onset, duration, and length of each step were also measured to analyse the 5-step approach. The onset was normalised to allow comparisons across individuals. Start and end of each step were defined as when the heel marker exceeds 100mm/s in the vertical (Z) axis and lowest Z-value of the heel marker respectively. End of slide was defined as the instance that heel marker front-back (Y) velocity goes below 100mm/s. Three best trials from each condition based on score, of each bowler were selected for analysis. Joint angles of the trunk, shoulders, elbows, wrists, hip, knees, and ankles at ball swing events were compared. Paired sample t-test was performed on performance outcomes, step data, joint kinematics with alpha significance level at 0.05. Peak joint angular velocities and moments of the right shoulder, elbow, and wrist were compared with non-parametric Wilcoxon sign ranked test due to normality violation.

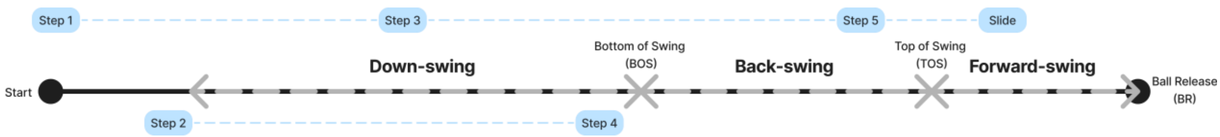

Figure 1: Events and phases breakdown of a bowling trial.

RESULTS: No significant differences in performance outcomes (Table 1) and peak joint velocities (Table 2) were found between the two ball weights, although the bowlers scored slightly better with the HB and recorded slower peak joint velocities in all except thorax lateral flexion. Peak elbow extension moment was significantly lower in NB than HB (Table 3). Step 3 length and duration were longer in NB than HB. At BOS, the left ankle was more abducted, and right ankle more flexed, in NB than HB. At TOS, the left shoulder was more internally rotated in NB than HB. At BR, the left ankle was more abducted in NB than HB.

Table 1: Performance outcome results.

	NB	HB	*t*	*p*
Score	8.22 ± 0.80	8.39 ± 0.50	-0.44	0.68
BR_{vel} (m/s)	7.90 ± 0.89	7.90 ± 0.97	0.06	0.95

Table 2: Peak joint velocities results.

	NB		HB		
Peak Angular Velocity (°/s)	**Mean**	**SD**	**Mean**	**SD**	***p***
Right Shoulder Abduction	395.3	242.1	277.8	76.3	1.00
Right Shoulder Rotation	402.0	229.4	310.7	166.7	0.29
Right Shoulder Flexion	875.5	266.4	797.5	242.5	0.59
Right Elbow Pronation	230.5	141.4	228.6	126.1	0.29
Right Elbow Flexion	335.1	184.1	328.3	205.7	1.00
Right Wrist Abduction	210.8	133.5	151.0	89.4	0.59

Right Wrist Extension	380.2	335.4	218.1	58.3	0.59

Table 3: Peak upper limb joint moments results.

	NB		HB		
Peak Moments (Nm)	**Mean**	**SD**	**Mean**	**SD**	***p***
Right Shoulder Adduction	162.2	325.6	180.7	363.8	0.18
Right Shoulder Internal Rotation	34.2	44.0	75.5	128.9	0.18
Right Shoulder Extension	82.8	126.1	80.2	128.2	0.42
Right Elbow Pronation	39.2	113.0	101.4	272.3	0.18
Right Elbow Extension *	55.8	127.6	180.9	511.9	0.05
Right Wrist Adduction	85.3	263.2	116.9	311.1	0.16
Right Wrist Extension	52.6	153.9	217.8	644.2	0.25

*$p \leq 0.05$

Table 4: Paired samples t-test results.

	NB	HB	*t*	*p*	% difference (NB - HB)
General					
Step 3 Length (m) *	0.64 ± 0.08	0.61 ± 0.11	2.65	0.03	5%
Step 3 Duration (%) *	20.2 ± 4.44	19.4 ± 4.05	3	0.02	4%
BOS					
RAnkleFlexion (°) *	14.6 ± 10.2	13.3 ± 10.1	2.44	0.05	9%
LAnkleAbduction (°) *	-3.07 ± 10.2	-3.93 ± 10.5	2.58	0.04	-28%
TOS					
LShldInternalRot (°) *	5.71 ± 48.4	2.77 ± 46.9	2.36	0.05	51%
BR					
LAnkleAbduction (°) *	-2.59 ± 12.1	-2.45 ± 12.1	2.81	0.03	5%

*$p \leq 0.05$

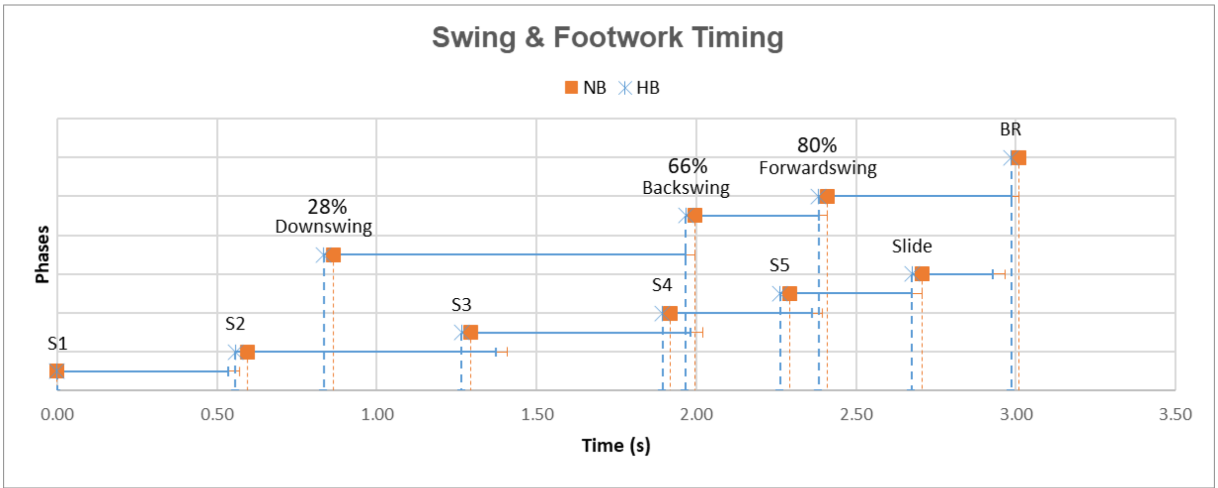

Figure 2: Breakdown of phases of a bowling movement.

DISCUSSION: The progression to a HB is one that every competitive bowler will undergo as assuming one is able to impart the same acceleration to both NB and HB at release, the HB will be able to hit the pins with greater force and momentum, increasing the possibility of a strike. There is still however, little consensus on how this transition should take place, especially at the initial early stages as injury risks could be higher with throwing a less familiar ball weight repeatedly. Hence, the aim of this study was to understand this transition better by first investigating differences in performance outcomes and movement execution when ball weight increased.

Bowling with the HB was hypothesised to (1) result in lower BR_{vel} and score from (2) slower and more controlled movement execution with (3) greater torques acting through the joints of the bowling arm, but these were generally unsupported. BR_{vel} and score were similar between the NB and HB. This was unexpected, considering that the ball weight increment is 0.45kg; a relatively large weight compared with other common sport implements (Schorah et al., 2012). Serving with a heavier tennis racket also did not change ball speed, but there were decreases in peak shoulder internal rotation and wrist flexion velocities (Whiteside et al., 2014). Swinging heavier and differently shafted golf clubs did not change club head speed but trunk and wrist kinematics were different (Joyce et al., 2016). In contrast, no bowling arm kinematics were found to differentiate the two ball weights; although mean peak angular velocity values were generally slower for HB (Table 2). Instead, the significant kinematic variables are more related to footwork (third step timing and ankles angles) and the non-throwing shoulder; which were not previously found to relate with bowling performance. While higher mean peak joint moments were recorded, only elbow extension moment was significantly more for HB vs NB.

A quicker third step when bowling with HB may mean a faster tempo but without other findings; especially on the slide, it is difficult to ascertain the reason behind and its effect on bowling performance. BOS generally corresponds with the end of the third (left foot) step and start of the fourth (right foot) step (Figure 2). This means the left foot is on the lane, while the right foot is about to leave the lane. Hence, a more abducted left ankle at BOS suggests an attempt to better balance the HB by spreading the foot laterally. A less flexed right ankle may mean that that the foot is at different phase of the step as it leaves the lane. This can happen because each bowler’s timing of footwork and step is different. TOS occurs at peak ball height and may represent the most unstable point during the approach. The left arm acts as the counter-balance, hence a less internally rotated left shoulder suggests that the bowlers may be less comfortable to further rotate to prioritise stability instead of generating more force with the HB. Moreover, HB resulted in higher peak elbow extension moment which occurred around TOS. This means more force is needed to bring the HB up to TOS and control the drop during the forward swing, hence strengthening of the elbow extensors is important. At BR, only the left foot is in contact with the lane from which the bowlers pivot about when releasing the ball and it also absorbs the force and acts as a stabiliser similar to in an overarm throwing motion (Chu, Jayabalan, Kibler, & Press, 2016). A less abducted left ankle means the foot is pointing straighter towards the pins, which might have helped in releasing the HB with more precision.

CONCLUSION: Pre-transited developmental bowlers achieved similar performance outcomes when bowling with the HB, with minimal differences in movement execution. Non-significant slower joint angular velocities and higher peak torques in the throwing arm suggest that more work is needed to better understand the mechanics behind bowling with a HB. Future research could investigate time-continuous or longitudinal data with an intra-individual approach. More importantly, this study provides a first insight into the ball transition in bowling and strengthening of the elbow extensors may be important aspect in the preparation.

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ACKNOWLEDGEMENTS: The authors would like to thank Singapore Bowling Federation for their partnership and support.