DIFFERENCES IN THE MECHANICS OF ELITE TEN-PIN BOWLERS WHEN PERFORMING UNDER VARYING LEVELS OF ANXIETIES

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We explored the differences in the mechanics of elite ten-pin bowlers when performing under high-anxiety (HA) versus low-anxiety (LA) and when achieving strikes versus non-strikes. Eleven right-handed elite bowlers bowled 10 shots in HA versus LA. The Mental Readiness Form-3 was used to assess the bowlers' self-confidence, and somatic and cognitive anxieties, between the HA versus LA conditions. Selected bowling kinematics were analysed from the start of the fourth step to ball release. Bowlers reported significantly higher somatic and cognitive anxiety under HA compared with LA. HA was accompanied by a 1.4% increase in peak velocity of the left foot slide and a trend toward a 1.7% increase in right shoulder peak flexion velocities at the start of slide regardless of strikes or non-strikes. HA could have resulted in the bowlers rushing their shot.

KEY WORDS: ten-pin bowling, biomechanics, anxiety, expertise

INTRODUCTION: Skilled action in sport requires athletes to prospectively perceive what the environment affords (opportunities for action) and subsequently exercise appropriate motor control. This ability is referred to as perceptual-motor skill whereby visual-perception and motor actions interdependently constrain each other in a perception-action cycle (Jackson and Farrow, 2005).

Ten-pin bowling is a perceptual-motor skill that has a relatively long movement phase prior to ball release compared with sports like golf and darts whereby preparation to execution is concluded with a fast movement at the same spot. The goal of bowling is to produce strikes on every bowl by knocking down all ten pins. Because information regulates action (i.e. perception-action coupling), bowlers are likely to adjust their movement based on the affordances presented as the distance between them and the foul-line decreases during their approach to optimise ball-release in a bid to strike.

Our recent work in bowling (Goh, Lim, Wylde, Macnaughton, Chow, & Lee, 2018) highlighted that elite bowlers are less susceptible to high-anxiety (HA) compared with sub-elite athletes and focused on anecdotally more relevant areas of the bowling lane compared with sub-elite bowlers, albeit only after commencing on their approach instead of prior. Specifically, elite bowlers had their final fixation; gaze held on an object of interest for a minimum of 100 ms to allow for conscious information processing (Vickers, 1992); later into the five-step approach and fixated for longer compared with sub-elite bowlers. Our results suggest that attentional focus during the movement phase rather than pre-movement could be more pertinent in differentiating expertise during sporting tasks with a long movement phase such as bowling compared with other accuracy-based sport such as golf and darts. The motor skills involved in bowling, and how they are differentiated by expertise, anxiety and performance levels remain unknown.

The aim of this study was to investigate the 3D bowling biomechanics of elite ten-pin bowlers when performing under HA versus LA and when achieving strikes versus non-strikes.

METHODS: Eleven right-handed elite bowlers with 8.30±1.70 years of competitive experience were recruited. Seven of the bowlers are top 30 in the world while the other four are top 100. All procedures were approved by the institutional review board of the Singapore Sport Institute.

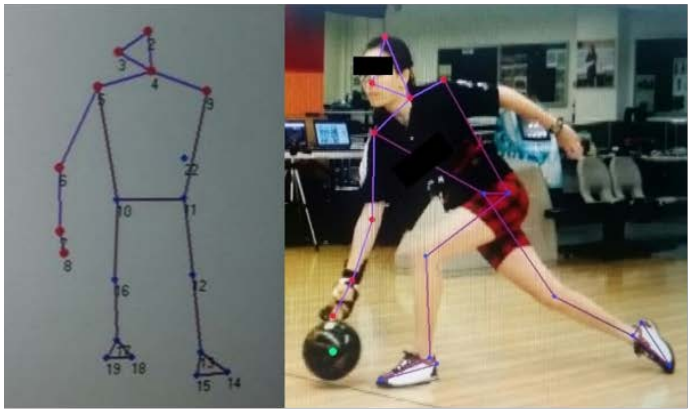
Participants were required to perform 10 shots using their own bowling balls on their preferred oiling conditions in low-anxiety (LA) and HA conditions that were counter-balanced between participants. The LA condition had no performance targets. The HA condition consisted of three manipulations. First, bowlers were required to achieve a target score of six strikes out of 10 bowls and achieve a minimum of 80 pin-falls out of a maximum of 100. These targets were approximated from past international competition results such as the World Men and Women Championships between 2008 – 2011 (World Bowling, 2014). The top athletes from those competitions achieved an average score of 240 out of 300 pin-falls in each game which corresponded with the targets. Second, all athletes were falsely informed that they had to perform an extra physical training session if they did not meet their targets; a challenge that would induce anxiety in the athletes according to their coaches. Third, a leader board with participants' names and scores was made visible to the participants to impose ego-threatening feedback for the elicitation of additional anxiety (Vine, Moore & Wilson, 2012). The bowlers' scores were always represented in the middle of the leader board so that they felt like they had a chance to catch up instead of feeling that they were too far off from the top.

Anxiety levels were monitored through the MRF-3 (MRF-3; Krane, 1994) that consists of three bipolar 11-point Likert scales that are anchored between not worried to worried for cognitive anxiety, not tense to tense for somatic anxiety, and not confident to confident for self-confidence. Three video cameras capturing at 50 Hz recorded the bowling action in the left-sagittal, right-sagittal, and frontal planes in a time-synchronized manner. A fourth camera was used to capture the number of pin-falls as a performance indicator.

Participants were informed of the task procedures before warming up. A familiarisation process consisting of five instead of ten trials were practised in both HA and LA, coupled with the completion of questionnaires. Under HA, only the leader board and target scores were implemented for familiarisation. After familiarisation, participants rested for five minutes before being instructed on the condition that they were commencing with and completed the MRF-3 for the first time. Participants then bowled the first 5 bowls. The MRF-3 was administered again. Thereafter, instructions related to the test condition (low-anxiety and high-anxiety) were reiterated before bowlers completed the last 5 bowls. The MRF-3 was administered for a third time. A five minute break was taken by the bowlers before the second condition was administered in a similar manner as the first condition. This is to minimise the effects of fatigue on their performance.

Digitisation was performed using Vicon Motus 10.0 (Contemplas, GMBH) on the footage of two strikes and two non-strikes that occurred in HA and LA respectively per participant. One strike and one non-strike were chosen at random from the first 5 trials and the last 5 trials in each condition. This counterbalance measure was done to prevent sequencing effects. To facilitate the reconstruction of 3-dimensional digitized coordinates, a calibration frame comprising 25 points of known three dimensional spatial locations (x, y, z) was filmed at the spot just before the foul line prior to and after each test. Direct linear transformation was utilized to obtain selected three-dimensional kinematic parameters from the start of the fourth step to ball release during the five-step approach. This required digitization of selected anatomical landmarks (Figure 1). The parameters were: peak ball height from ground, peak right hip flexion and knee flexion angles during peak ball height, peak velocity of the left foot slide, and velocities of the right shoulder flexion at the start and end of left foot slide and ball at release.

A paired t-test was used to compare the individual components on the MRF-3 regardless of strikes or non-strikes while a two-way (anxiety x performance) repeated measures Anova with Bonferroni correction was used to compare the biomechanical parameters between the HA versus LA conditions, and strikes versus non-strikes.



1	global	12	left knee
2	vertex	13	left ankle
3	nose	14	left toe
4	neck	15	left heel
5	right shoulder	16	right knee
6	right elbow	17	right ankle
7	right wrist	18	right toe
8	right finger	19	right heel
9	left shoulder	20	mid-point of hips
10	right hip	21	mid-point of shoulders
11	left hip	22	ball

Figure 1: Digitized landmarks for the calculation of 3D bowling biomechanics

RESULTS: The bowlers' exhibited significantly higher somatic [t(10) = 2.56, p=0.03] and cognitive [t(10) = 2.66, p = 0.02] anxiety in the HA compared with LA condition (Table 1). Anxiety exhibited a main effect for the biomechanical parameters assessed (p = 0.04, η2 = 0.93). Post-hoc comparisons revealed a 1.4% increase in peak velocity of the left foot slide in HA versus LA (p = 0.01, η2 = 0.470) and a trend toward a 1.7% increase in right shoulder peak flexion velocities at the start of slide (p = 0.07, η2 = 0.28) regardless of strikes or non-strikes (Table 2). The remaining biomechanical variables were not significantly different between anxiety levels and strikes versus non-strikes.

Table 1: Emotional States of Bowlers When Performing Under HA Versus LA

	Anxiety level	How worried bowler felt, from 0 = not worried to 11 = worried Mean ± SD	How tense bowler felt, from 0 = not tense to 11 = tense Mean ± SD	How confident bowler felt, from 0 = not confident to 11 = confident Mean ± SD
	LA	2.91±1.64	2.76±1.78	7.21±1.88
	HA	4.06±2.01	3.41±1.89	7.09±2.03
p-value		0.03*	0.02*	0.74

*Significantly different at P < 0.05.

Table 2: Mean peak ball height from ground, peak right hip flexion and knee flexion angles during peak ball height, peak left foot slide velocity, and velocities of the right shoulder flexion at the start[1] and end[2] of left foot slide and ball at release during HA versus LA and Strikes versus Non-strikes.

	Peak ball height from ground (m)	Right hip flexion (°)	Right knee flexion (°)	Peak left foot slide velocity (ms^{-1})	Peak right shoulder flexion velocity[1] (ms^{-1})	Peak right shoulder flexion velocity[2] (ms^{-1})	Ball velocity (ms^{-1})
LA	1.43±0.20	111.97±12.77	128.31±21.09	6.85±0.87	2.31±0.33	0.82±0.37	7.62±0.50
HA	1.42±0.20	111.34±12.91	127.53±20.31	6.94±0.88	2.35±0.31	0.85±0.43	7.53±0.65
P	0.46	0.18	0.52	0.01*	0.07#	0.54	0.37
Strikes	1.43±0.20	111.39±12.39	128.24±20.53	6.91±0.86	2.34±0.32	0.82±0.39	7.58±0.55
Non-strikes	1.42±0.20	111.93±13.3	127.60±20.86	6.88±0.89	2.31±0.32	0.85±0.41	7.58±0.60
P	0.082	0.36	0.39	0.477	0.50	0.53	0.98

Data are presented as mean ± SD unless otherwise stated.
*Significantly different at P < 0.05. #Approaching significantly different at 0.05 < P < 0.08.

DISCUSSION: The increased somatic and cognitive anxiety in the HA compared with LA condition could have resulted in the bowlers "rushing their shot". This is evidenced in the greater peak velocity of the left foot slide and higher velocity of the right shoulder flexion at the

start of foot slide. The null differences in the velocities of shoulder flexion at the end of left foot slide and ball at release between anxiety levels suggest that the bowler's slowed down the ball just prior to ball release. This abrupt braking action resulted in more non-strikes in HA (mean strike rate = 31%) compared with the strikes in LA (mean strike rate = 46%) across 10 bowls per participant. Further analyses of all 10 shots per participant to investigate the biomechanical differences across both LA and HA conditions, and strikes versus non-strikes would present greater insight into the parameters that contribute to successful versus less successful bowls. Understanding the biomechanical parameters that change when bowlers bowl under HA would enable coaches to be more targeted in training bowlers to improve their game during competition. Coaches could impart methods to their bowlers that would help them to better maintain consistency in their rhythm when experiencing increased anxiety. This is especially important in a target-based sport such as bowling as inconsistent techniques could lead to inconsistent ball releases and therefore, outcomes. Future research that aims to compare this data with those of sub-elite bowlers would bring about further insights into the biomechanical parameters that may be effected not just by anxiety levels and performance but also expertise.

CONCLUSION: This preliminary investigation found that elite ten-pin bowlers were susceptible to environmental stressors that increased their anxiety levels regardless of performance. Furthermore, the technique of these elite athletes was also affected by increased anxiety levels. Coaches could explore ways to help their athletes to maintain their rhythm, especially in the penultimate step when pushing off on step 4; whereby peak ball height in the backswing is achieved; into the slide on step 5 followed by ball release. This could result in the balls rolling down the lanes in more consistent paths which would improve performance scores.

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