STABILITY OF MEAN VALUES: APPLICATION OF THE BATES METHOD TO FIELD HOCKEY

Melissa Penn[1], Kevin Ball[1], Damian Farrow[1]
Institute of Sport, Exercise and Active Living (ISEAL), Victoria University, Melbourne, Australia.

A limitation within biomechanics research is an insufficient number of trials are analysed. Conjecture exists over the minimum number of trials required to achieve a stable mean. This study was conducted to identify the minimum number of trials necessary for mean values of selected kinematic variables to stabilise, using the progressive standard deviation method adapted from Bates et al. (1983). Three-dimensional kinematic data of the field hockey hit was collected using a 10-camera Vicon motion analysis system and analysed using Visual 3D (C-Motion). Mean values for selected parameters were calculated and the progressive change in standard deviation assessed. Results showed the number of trials needed for mean stabilisation is both parameter and task specific. The last threshold approach should be used to account for variability within parameters.

KEYWORDS: analysis, kinematics, stabilisation, biomechanics

INTRODUCTION: A common limitation within biomechanical research literature is an insufficient number of trials are analysed. As such, statistical power is low and results may be potentially unreliable (Bates et al., 1992). Moreover, conjecture exists over the minimum number of trials actually required to achieve a stable mean. For regression-type analysis of maximal tasks, the single best trial has been used by some authors (e.g. Ball, 2008) with the rationale that this is the trial of most interest and using an average value might mask important information. However for sub-maximal tasks or where group-based analyses are employed, values that represent a typical performance are necessary. In the case of these studies, it is important to identify the number of trials needed to attain this stable mean. For most biomechanical studies, the rationale behind the selection of trial numbers is not reported.

Of the authors who have reported the rationale behind selection of trial numbers, large differences exist between different tasks. For example, Taylor et al. (2013) conducted a sequential analysis of selected overarm throwing parameters, reporting a sample of twenty trials was required for an acceptable estimate of the mean. Bates et al. (1983) and James et al. (2007) reported that anywhere between three and eight trials are necessary for stability of ground reaction force (GRF) variables during running and landing tasks, respectively. In golf, Ball and Best (2007) found that 10 trials were necessary to ensure stable means were obtained for centre of pressure parameters. Clearly there is a need to evaluate how many trials are needed to obtain a stable mean on a task-specific basis.

Using the field hockey hit as a task exemplar, the aim of this study was to therefore identify the minimum number of trials necessary for the mean values of selected kinematic variables to stabilise. The progressive standard deviation method adapted from Bates et al. (1983) was used.

METHODS: Four female subjects participated in this study which was conducted indoors at the Victoria University (VU) Biomechanics laboratory. Testing was carried out in a simulated field hockey environment consisting of Federation of International Hockey (FIH) regulation-size goals and synthetic turf (TigerTurf, Aus). When asked to, participants took one step forward and hit a stationary hockey ball from the top of the goal circle toward the goal (14.63m away).

Prior to data collection a system of retro-reflective markers of 14 mm diameter was placed on specific anatomical landmarks, joint centres, the hockey stick and ball (Figure 1). A spatial model was created for three-dimensional (3D) analysis based on a series of anatomical model systems published previously and utilising the Calibrated Anatomical Systems Technique (CAST, Cappozzo et al. 1995). The shoulder segment was based on work by Lloyd, Alderson & Elliott (2007), the trunk by Brown, Selbie and Wallace (2013) and the CODA pelvis (Bell, Pedersen and Brand, 1989) was used. All other segments were based on ISB recommendations (Wu et al. 2002, 2005). The markers were attached to the participant, stick and ball using non-allergenic double-sided tape. To assist in marker application and joint-centre identification, participants were instructed to wear dark coloured clothing and tight-fitting bike shorts and singlet. Following marker placement all participants underwent a standardised warm-up and completed five to ten familiarisation hits. Each participant then completed 15 trials.

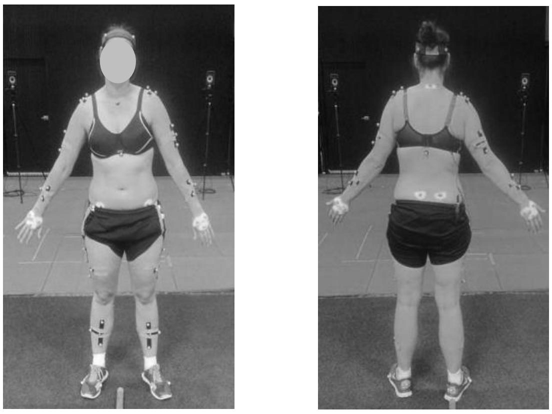

Figure 1 Marker placement

Three-dimensional (3D) kinematic data was collected using a 10-camera Vicon Motion Analysis system capturing at 500Hz using Vicon Nexus software (Vicon Motion Systems Inc, Centennial CO). A 3D spatial model of the body and stick was created and analysed using Visual3D software (C-Motion Inc.).
Body landmark and temporal data was filtered using two separate datasets: one before and one after stick-ball impact at 10Hz using a Butterworth filter (4th order low-pass). The two dataset analysis procedure was used to avoid distortion issues associated with smoothing across impacts (Knudson and Bahamonde, 2001). The 10 Hz cut-off was chosen based on a combination of residual analysis, effect on parameter values using different cut-offs and on visual inspection with attention paid to maxima and minima. Stick and ball trajectory data was not smoothed due to the high frequency of the signal around impact and the quality of the signal.
Eight parameters were calculated (Table 2, results) including the maximum stick and ball velocities (ms^{-1}), back and down swing movement times (s), and step length (m).
To assess the stability of mean values of selected parameters, methods adapted from Bates et al. (1983) were used. For each parameter selected for analysis, the mean, standard deviation (*Overall SD*) and one quarter of the standard deviation (*Threshold SD*) were calculated for each participant individually. Using their own individual data, the mean of the first and second trials for each variable was calculated for each player. The third trial was then added and the mean re-calculated (termed *Floating Mean*). This continued until all trials were included, as shown in Table 1. The difference between each Floating Mean was then calculated. Stability for each variable was estimated to occur when the change in Floating Mean first dropped below the Threshold SD (i.e. below one-quarter of the overall SD). To account for potential variability within each parameter, the Bates et al (1983) method was adapted such that the process of assessing the change in Floating Mean continued until the last drop below the threshold.

RESULTS: Using the first threshold approach, the average number of trials required for the mean of selected parameters to stabilise was found to be between 3.5 and 4.3, with a maximum of 6 trials. Using the last threshold approach, mean values stabilised on average between 4.3 and 7.5 trials and a maximum of 9.

Table 1 Sample analysis (Maximum Stick Velocity, ms^{-1})

	Value	FLOATING MEAN	CHANGE IN FLOATING MEAN
Trial 1	27.982		
Trial 2	29.730	28.856	
Trial 3	29.518	29.077	0.221
Trial 4	29.722	29.238	0.161
Trial 5	29.709	29.332	0.094
Trial 6	30.679	29.557	0.225
Trial 7	29.778	29.588	0.032
Trial 8	28.858	29.497	0.091
Trial 9	30.885	29.651	0.154
Trial 10	30.041	29.690	0.039
Trial 11	30.621	29.775	0.085
Trial 12	30.530	29.838	0.063
Trial 13	31.133	29.938	0.100
MEAN	**29.938**		
OVERALL SD	**0.868**		
THRESHOLD SD	**0.217**		

Table 2 Stability analysis results for parameter mean values (n = 15)

	FIRST THRESHOLD		LAST THRESHOLD	
	Mean	**Max**	**MEAN**	**MAX**
MaxStickVel	4.0	6.0	5.8	7.0
MaxBallVel	3.5	4.0	5.0	7.0
BSMT	3.8	5.0	5.5	8.0
DSMT	4.3	5.0	7.5	9.0
TMT	4.0	5.0	6.0	9.0
% BS OF TMT	3.8	4.0	4.3	5.0
% DS of TMT	3.8	4.0	4.3	5.0
StepLength	4.3	5.0	6.3	9.0

A difference in trial numbers necessary for mean stabilisation was also observed between parameters, particularly the discrete kinematic parameters versus the temporal parameters (Table 2). For example mean values for the percentage of back and down swing relative to total movement time stabilised at a maximum of five trials. Step length on the other hand stabilised after nine trials.

DISCUSSION AND CONCLUSION: This study applied the Bates (et al., 1983) method to the identification of the minimum number of trials needed for mean stabilisation of selected parameters in field hockey. The number of trials needed for mean stabilisation is parameter-specific, particularly when analysing discrete kinematic parameters versus temporal parameters (Table 2). Also, the number of trials for mean stabilisation appears to be task-specific, as evidenced by the observed differences between the results of the current study and those previously reported (Bates et al., 1983, 1992; Ball and Best, 2007; James et al. 2007; Taylor et al. 2013). As such it is recommended that when applying the analysis used in this study, not only should the last threshold approach be used, it should also be applied on a task and parameter-specific basis.

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