WRIST-ELBOW COORDINATION IN TECHNIQUE SELECTION: INFLUENCE OF HAND POSITION DURING THE BACK HANDSPRING.

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This study aims to investigate the influence of hand position on elbow and wrist joint coordination and variability during the back handspring in female gymnastics. Five national level female gymnasts performed five back handspring trials with “inward”, “parallel” and “outward” hand positions. Synchronised three-dimensional kinematic and kinetic data were collected and modified vector coding techniques were used to calculate wrist-elbow coordination. Self-organised coordination patterns were observed for the three hand positions. The “inward” displayed highest coordination variability (24.6^{o} up to 60.5^{o}) with the “parallel” displaying lowest variability (10.8^{o} to 28.3^{o}). Lower variability within the parallel technique may be more suited to gymnastics performance, with the “inward” contributing more towards overuse injury reduction.

KEY WORDS: upper limb, self-organisation, variability.

INTRODUCTION: Technique selection of fundamental skills is important within artistic gymnastics. The same elements can be executed with various techniques within the restrictions imposed by the Fédération Internationale de Gymnastique (FIG, 2017). Coaches thus face the challenge of determining which individual techniques will suit the gymnast, reduce injury risk and optimise performance with the aim of making gymnastics skills more safe, efficient and effective. The back handspring is a fundamental skill used to accelerate the gymnast for subsequent tumbling movements. There are three main hand positions that are commonly observed during the back handspring performance (Figure 1). The Code of Points (FIG, 2017) does not currently provide a restriction for hand position during this skill; therefore, gymnasts are free to use any of the techniques during performance. Technique selection may have an impact on injury risk potential and the evolution of the skill therefore is an important area for research (Farana, Uchytil Irwin, Jandacka, and Mullineaux., 2015). The identification of factors that may influence biological failure within gymnastics is important from a biomechanical perspective. Farana, Jandacka, Uchytil, Zahradnik and Irwin (2017) highlighted the absence of examination regarding the interaction between impacting upper limbs in sports such as gymnastics. Throughout training and competition gymnasts frequently touch down with the hands during routine tumbling, and with reports of up to 42% of gymnastics injuries located at the upper extremities (Singh, Smith, Fields and McKenzie, 2008), analysis of the upper limbs during fundamental skills is imperative to inform to understand both performance and injury risk factors. Providing an initial insight into the nature of coordination patterns of the upper limbs during these skills may subsequently allow for applicable and effective skill selection techniques, that will enhance performance and provide useful information regarding injury risk (Farana *et al.,* 2015). Holistic perspectives of technique have been used to understand technique through coordination and variability analysis (Irwin and Kerwin, 2009). Movement variability is essential in skills where the adjustments of complex motor patterns are necessary to allow performers to alter both internal and external influences to correct the motor pattern, thereby reducing the possibility of acute injury (Button, Davids and Schollhorn, 2006). Although, the back handspring involves firm task constraints imposed by FIG, therefore coordination variability of the upper limbs may be seen as detrimental to performance, although perhaps functional to the reduction of injury risk potential. Knowledge of upper limb coordination is useful for coaches and clinicians in relation to performance and the reduction of injury risk.
The aim of this study was to investigate the influence of hand position on elbow and wrist joint coordination and variability during the back handspring in female gymnastics. The purpose was to inform practitioners regarding the influence of hand position on performance and injury risk potential within technique selection.

METHODS: Participants: All participants were proficient when using all three hand positions during back handspring performance, although preferred hand position was noted.

The ability to perform all three hand positions was checked with the national coach to reduce selection bias.
Five national level female artistic gymnasts were randomly selected for this study. Mean (± SD) age was 20 ± 1.67 years; body mass 59.66 ± 5.79 kg and height 1.65 ± 0.03 m. Participants were free from injury at the time of data collection and written informed consent was sought in accordance with the Ethics Committee of Cardiff Metropolitan University. Two gymnastic floor mats were secured over both force plates to imitate the surface of the gymnastics floor; this protocol was successfully used by Farana *et al*. (2017).
Following practice trials, all gymnasts performed five back handspring trials from a hurdle step round off using each hand position (Figure 1). All trials were completed in a randomised order with maximal exertion and were separated by sufficient rest. The hand position was controlled by observation from a qualified national coach.

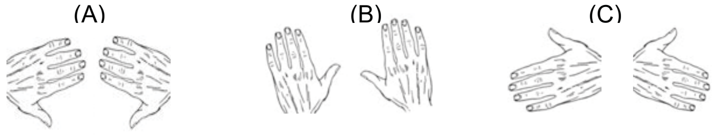

Figure 1. Hand positions: (A) inward (B) parallel (C) outward.

Data Collection: 3D kinetic and kinematic data were collected using a 15 camera Vicon Vantage motion capture system (Vicon, UK) synchronised with two force plates. Force plates (Kistler, 9287BA, Switzerland) were embedded into the ground sampling at 1000 Hz while camera data were sampled at 250 Hz. Global coordinates were defined so the x-axis represented the antero-posterior, the y-axis represented the medio-lateral and the z-axis represented the vertical direction. Retro-reflective markers were placed on the upper limbs and trunk in accordance with Farana *et al*. (2015).
Data Analysis: Data were processed using Visual 3D (C-Motion, Rockville, MD, USA). Analyses centred on the support phase of both left and right hands during the back handspring. Support phase was defined using a 20 N vertical force threshold. Each segment's local coordinate system (LCS) was defined using a static trial in accordance with Farana *et al.* (2015). Joint angular displacement of the distal relative to the proximal LCS was described by an XYZ Cardan sequence. For the elbow and wrist joints, data were extracted for the support phase and normalised to 101 data points. Kinematic data were filtered using a low-pass Butterworth filter with a 12 Hz cut-off frequency. Coupling at the elbow and wrist joint was quantified using a modified vector coding procedure (Chang, van Emmerik and Hamill, 2008; Needham, Naemi and Chockalingam, 2014) in the x, y and z planes. Elbow and wrist coupling was used due to the functional role of the upper limbs during the back handspring support phase (Needham *et al.,* 2016). Mean coupling angles and coordination variability were calculated using directional statistics. The mean standard deviation between trials across the support phase was determined for each coupling angle. Coupling angles were classified into one of four coordination patterns (Chang *et al.,* 2008). These coordination patterns were 1) elbow-phase, 2) wrist-phase: where only the elbow or wrist was moving, respectively, 3) in-phase: where segments moved in the same direction, 4) anti-phase: where segments moved in opposite directions. Due to the limited number of skilled participants and research design of this initial study only a descriptive analysis was performed for each participant, as previously published by Irwin and Kerwin (2009).

RESULTS: Within-participants the "outward" and "parallel" hand positions displayed similar wrist-elbow coupling angles throughout support when compared to the inward position (Figure 2). Between-participant variation was high with each participant presenting a unique coordination pattern (see Table 1). For all participants the inward hand position displayed highest coordination variability (ranging from 24.6^{o} up to 60.5^{o}) with the parallel hand position displaying lowest coordination variability (ranging from 10.8^{o} up to 28.3^{o}).

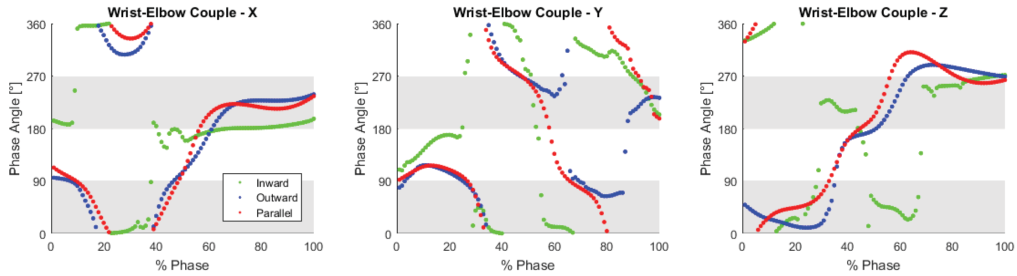

Figure 2. An example of mean coupling angle for the wrist and elbow for each condition. (P1).

Table 1. Upper limb coordination pattern frequency data for the X, Y and Z plane. Values are shown in percentage distribution of phase angle.

X		**Inward**				**Parallel**				**Outward**		
P	**E**	**W**	**I**	**A**	**E**	**W**	**I**	**A**	**E**	**W**	**I**	**A**
1	31	25	27	17	33	21	22	24	44	5	26	25
2	10	50	32	8	39	27	19	15	50	1	23	26
3	1	94	2	3	19	20	51	10	20	13	44	23
4	10	78	7	5	10	21	59	10	25	18	37	20
5	26	28	23	23	23	25	30	22	30	21	21	28
Y		**Inward**				**Parallel**				**Outward**		
P	**E**	**W**	**I**	**A**	**E**	**W**	**I**	**A**	**E**	**W**	**I**	**A**
1	20	32	14	34	13	28	12	47	8	9	3	80
2	45	9	15	31	40	11	8	41	20	9	13	58
3	14	38	14	34	49	10	15	26	53	4	29	14
4	14	30	19	37	53	14	27	6	51	8	22	19
5	10	36	19	35	17	67	1	15	26	35	5	34
Z		**Inward**				**Parallel**				**Outward**		
P	**E**	**W**	**I**	**A**	**E**	**W**	**I**	**A**	**E**	**W**	**I**	**A**
1	67	4	8	21	75	0	1	24	55	11	10	24
2	61	14	14	11	39	16	23	22	19	55	20	6
3	32	18	43	7	36	17	26	21	41	35	20	4
4	38	8	50	4	16	34	26	24	29	35	29	7
5	58	12	11	19	30	14	25	31	35	7	17	41

Key: **P** = participant **E** = elbow-phase **W** = wrist-phase **I** = in-phase **A** = anti-phase.

DISCUSSION: The aim of this study was to investigate the influence of hand position on elbow and wrist joint coordination and variability during the back handspring in female gymnastics. This current study has offered information regarding upper limb coordination during the fundamental gymnastics skill, providing initial insight into performance enhancement and injury risk potential within technique selection for coaches and clinicians. Gymnasts self-organised to achieve this skill, this is observed through the unique coordination patterns despite participants performing the same constrained task (Table 1). Manipulation of the task domain yielded similar within-participant coordination patterns for outward and parallel positions, while inward generally differed for all participants (Figure 2). This finding aligns with that of Needham *et al*. (2016), where external kinetics and internal kinetics of the wrist were higher for the outward and parallel positions, thus providing further insight into the unique intrinsic dynamics of each technique. Evidence of movement degeneracy is demonstrated by the individual organisation of coordination patterns in achieving successful performance (Seifert, Button and Davids, 2012). All trials presented here were deemed successful and each participant's coordination pattern allows them to satisfy the demands of the task. It is interesting that these differences emerge despite the strict task constraints imposed upon the gymnast. The current study found that the inward hand position displayed highest upper limb coordination variability for all participants (25° - 61°), with the parallel hand position showing least variability (11° - 28°). While variability within gymnastics is often viewed as detrimental to performance, dynamical systems constructs view variability as essential in inducing a coordination change and to establish a combination of stability and flexibility of movement (Hamill, van Emmerik, Heiderscheit and Li, 1999). As evidenced by the findings of this study, variability is still present despite all trials being deemed successful. Between-condition differences in coordination variability may be linked to skill level, as variability was lowest for all participants, in all planes, during the parallel position. However, all participants favoured the parallel hand position and therefore possessed the greatest levels of task familiarity for this position. This familiarity of the parallel hand position within the back handspring may have contributed to the reduced coordination variability observed. Although, all gymnasts were deemed proficient when using all three hand positions during the back handspring by a national gymnastics coach. In contrast, the high levels of coordination variability in the inward position may be associated with reduced injury risk (Hamill *et al.,* 1999) and healthy function. Farana *et al.* (2015) recorded higher variability within elbow kinematics of the round off and suggested a broader load distribution among the upper limbs, potentially decreasing the load experienced at the upper limb joints, thereby reducing the injury risk potential. The higher coordination variability observed in this current study when employing the inward hand position during the back handspring may therefore allow flexibility for the performer to correct both internal and external influences, reducing upper limb injury risk. However, skilled gymnasts often exhibit a reduced variability in the mechanically significant features of the performance (Farana *et al.,* 2015). From this perspective, this study would suggest that the parallel hand position during the back handspring might be attributed to enhanced performance, due to lower upper limb coordination variability displayed. Coaches thus face the challenge of determining which individual techniques will suit the gymnast. The differences in coordination patterns and variability associated with individual gymnasts in this research concur with previous proposals that the functionality of variability may not be suitable to generalise, and that many differing techniques can be employed to accomplish the same, successful performance (Preatoni *et al.,* 2013). Future work will aim to investigate these three techniques in a sample of gymnasts from differing training groups who favour different hand positions and employ inferential statistics (parametric/non-parametric) in order to make generalisations about the findings.

CONCLUSION: This study concludes that the gymnasts in this sample present highly individual upper limb coordination patterns. The lower coordination variability displayed within the parallel hand position may be product of task familiarity, however the inward hand position may be appropriate for overuse injury reduction purposes. These findings provide an insight into upper limb coordination during the fundamental gymnastics skill and consistency of gymnast's performance for each hand position during the back handspring**,** offering valuable technique information for athletes, coaches and clinicians.

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