ELBOW LOADING DURING THE BACKWARDS HANDSPRING: THE INFLUENCE OF HAND POSITION.

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This study aims to investigate the influence of hand position on the musculoskeletal loading at the elbow during the back handspring in female artistic gymnastics. Six 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 inverse dynamics analysis performed to calculate elbow joint kinetics. Increased vertical and medio-lateral joint forces and higher medio-lateral moments at the elbow joint during the outward and parallel hand position may lead to increased injury risk. When using the outward and parallel hand positions, the elbow joint is exposed to increased joint kinetics and biophysical loading that may lead to an increased injury risk when performing the back handspring.

KEY WORDS: Gymnastics, Injury Prevention, Elbow.

INTRODUCTION: The back handspring represents a fundamental skill within gymnastics and is performed by gymnasts in high volumes throughout their careers. The back handspring exposes the structures of the upper limb to high loading (Farana, Jandacka, Uchytil, Zahradník, and Irwin, 2014; Farana, Jandacka, Uchytil, Zahradník and Irwin, 2017), notably at the wrist and elbow joints. Gymnasts have been reported to experience on average, more than 100 impacts per training session on the upper limbs (Daly, Rich, Klein, and Bass, 1999) with peak magnitudes of force reaching 3.6 time body weight. The elbow joint is among those reported as a common injury site (Bradshaw and Hume, 2012) and given the high frequency at which the back handspring is performed, this may be a significant contributing factor when considering injury potential. Technique selection has been previously researched by Farana *et al*. (2014) who investigated technique selection during the round off and found that in the parallel hand position technique, the wrist joint of the second contact limb is exposed to higher axial compression load. External forces and internal wrist kinetics during the backward handspring under “parallel”, “outwards” and “inwards” hand positions have been explored (Needham *et al.*, 2016), where significantly greater internal joint forces (vertical and medio-lateral) and significantly greater longitudinal moments at the wrist were reported for the outward hand position suggesting that selection of this technique may be associated with greater injury risk at the wrist. However, kinetic loading at the elbow joint has not yet been considered. The aim of this study was to investigate the influence of hand position on the musculoskeletal loading at the elbow during the back handspring in female artistic gymnastics. The overall purpose was to gain insight into injury risk and provide information for athletes, coaches and clinicians to make informed decisions when selecting techniques.

METHODS: Participants: Six national level female artistic gymnasts were recruited. Mean (± *SD)* age was 20 ± 1.75 years; body mass 60.81 ± 6.11 kg and height 1.65 ± 0.03 m. All participants were free from injury at the time of data collection and written informed consent was sought. Landing mats were used in the performance area ensuring participant safety throughout testing. Two gymnastic floor mats were secured over both force plates in order to imitate the surface of the gymnastics floor in accordance with Farana *et al*. (2016). All gymnasts performed five back handspring trials from a hurdle step round off using each hand position (Figure 1). Trials were completed in a randomised order with maximal exertion. The hand position was controlled by observation from a qualified coach.

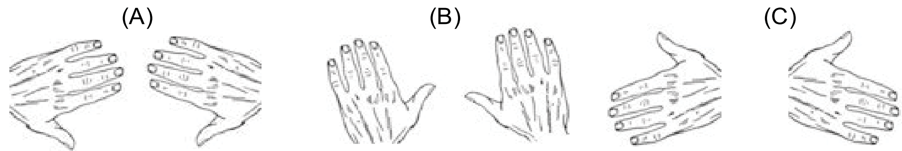

Figure 1. Hand positions: (A) inward (B) parallel (C) outward.

Data Collection & Processing: Three dimensional 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. Retro-reflective markers were placed on the upper limbs and trunk in accordance with Farana *et al*. (2014).

Data Analysis: Data were processed using Visual 3D (C-Motion, Rockville, MD, USA). Static calibration was conducted in accordance with Farana *et al.* (2014). Analyses centred on the support phase of both left and right hands during the back handspring. As bi-lateral differences were not the focus of this research, left and right hand data were grouped for each participant. Support phase was defined using a 20 N vertical force threshold. Key variables included elbow flexion-extension angle (θ), vertical (F_{v}) and medio-lateral elbow joint forces (F_{ml}) and medio-lateral joint moments (T_{ml}). Kinetic and kinematics data were match filtered (Bisseling & Hof, 2006) using a low-pass Butterworth filter with a 12 Hz cut-off frequency. Data were normalised to body mass (Bm) to allow comparison between participants. Statistical tests were performed at both group and individual levels. A Shapiro-Wilk test confirmed that data was not normally distributed. Statistical nonparametric mapping (SnPM) (Nichols and Holmes, 2002) was used to statically compare between hand positions. Specifically, a one-way ANOVA with post hoc test was used (α=0.05). Where the scalar output statistic, SnPM{f}, exceeded the critical threshold (f*) differences between conditions were deemed significant. f* is the value above which differences are significant at the specified alpha level. It is calculated as the 100(1-α)th percentile of the permutation distribution of the maximal statistic (Nichols and Holmes, 2002). Post hoc testing was conducted using SnPM independent t-test to provide the scalar output statistic, SnPM{t}. Critical thresholds (t*) were adjusted using a Bonferroni procedure. All SnPM analyses were implemented using open-source spm1d code (v.04, www.smp1d.org) in Matlab (R2016b, The Mathwords Inc, Natick, USA).

RESULTS: Group level statistical analysis revealed no significant differences between conditions for any variable. However, at an individual level differences were present. For all participants outward and parallel θ were significantly greater than inward position θ throughout support (Figure 3). Outward and parallel F_{v} were significantly greater than inward positions, between 20-65% of support for all but P2 who presented significantly higher F_{v} for inward and parallel between 0 - 65% of support (Figure 4).

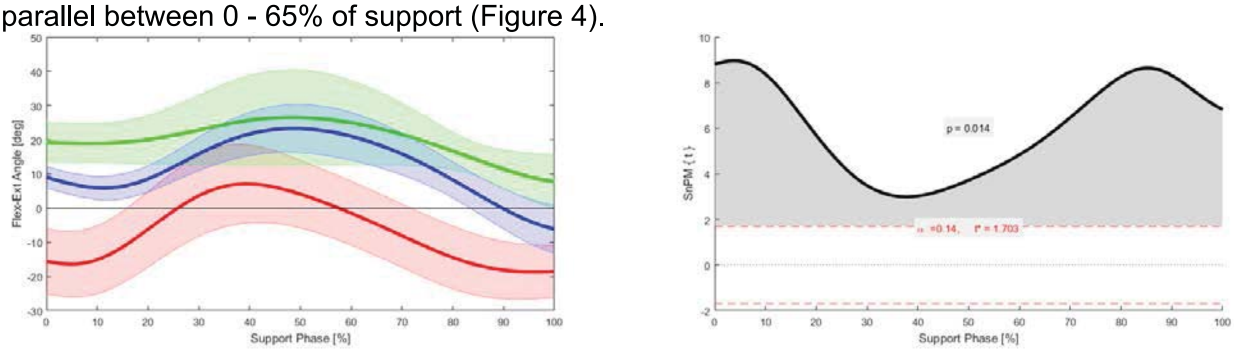

Figure 3. Left – Mean elbow angle (± SD) for each condition for P2. Red = Inward, Green = Outward, Blue = Parallel. Right – Example SnPM{t} output – Post hoc Inward-Outward elbow angle differences. P = p-value for supra-threshold cluster (grey area).

The outward hand position displayed F_{v} ranging from -2.78 BM (P3) to -14.21 BM (P1), parallel ranged from -5.73 BM (P3) to -11.50 BM (P1) and inward ranged between -5.59 BM (P1) and -9.11 BM (P4). This trend was also present for elbow joint F_{ml}, whereby the outward and parallel hand position displayed lower values (ranging from 1.38 BM (P1) to 6.02 BM (P4) and 2.96 BM (P3) to 5.36 BM (P4) respectively) when compared to the inward technique (ranging from 2.09 BM (P1) to 4.95 BM (P4)). Under the outward position, P1 presented significantly higher F_{ml} than the inward position. For all other participants both outward and parallel position F_{ml} were significantly higher, generally between 25-75% of support. T_{ml} responses were split across the group where half (P1, P4 and P6) presented no significant differences between hand propositions.

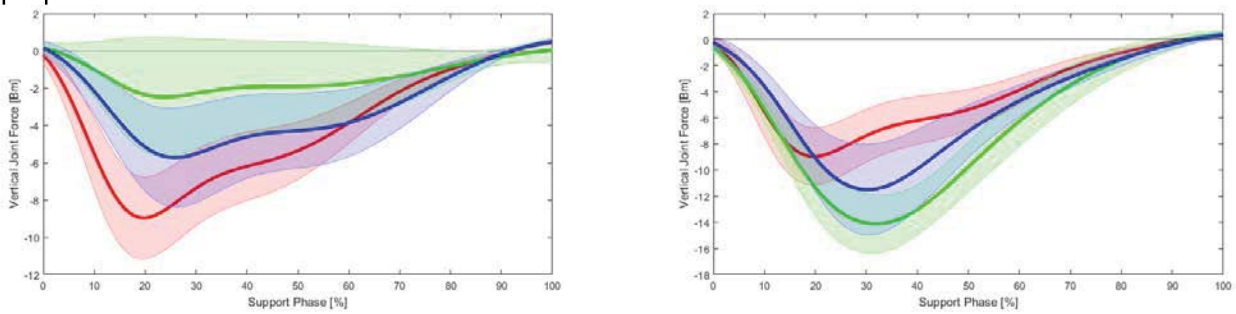

Figure 4. Mean Vertical Joint Force (± SD) for each condition. Red = Inward, Green = Outward, Blue = Parallel. Left example – P3. Right example – P2.

The other half (P2, P3 and P5), show significantly greater T_{ml} for outward and parallel hand positions when compared to the inward hand position. Statistically significant differences occurred for up to 100% of support phase.

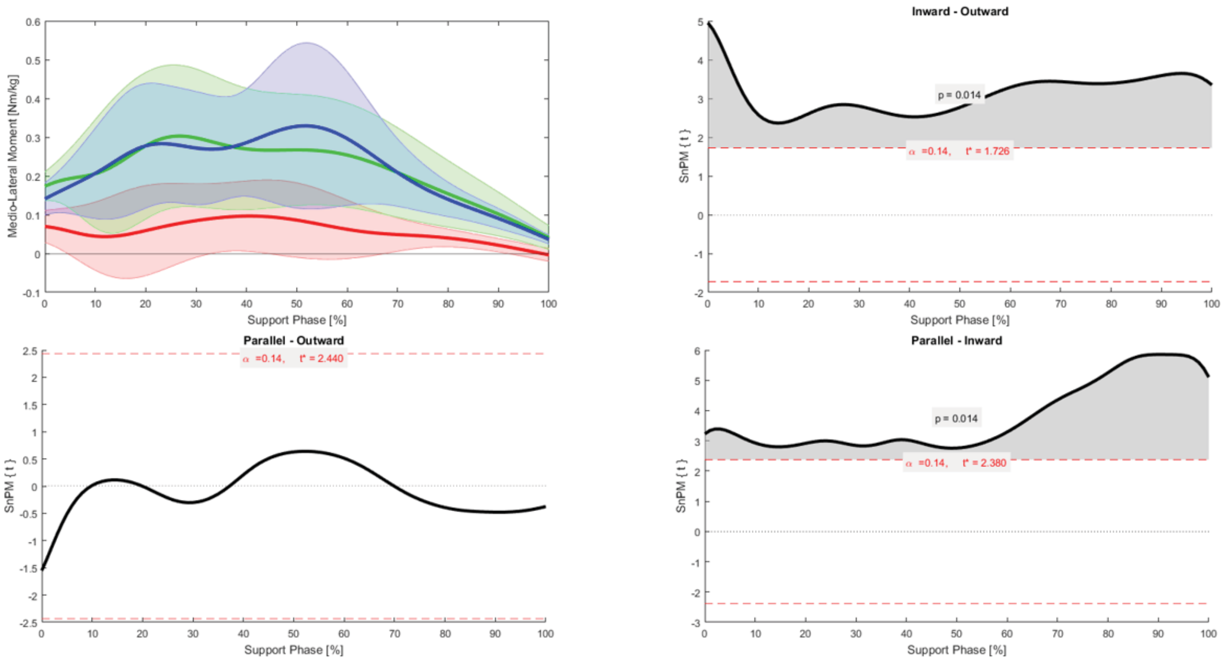

Figure 5. Figure 3. Top Left – Mean medio-lateral moment (± SD) for each condition. Red = Inward, Green = Outward, Blue = Parallel. Others - SnPM{t} output – Post hoc differences for each condition. P = p-value for supra-threshold cluster (grey area).

DISCUSSION: The aim of this study was to investigate the influence of hand position on the musculoskeletal loading at the elbow during the back handspring in female artistic gymnastics. This study has offered an insight into the injury risk at the elbow joint, offering valuable information for athletes, coaches and clinicians to make informed decisions when selecting techniques.

In the current study, θ was greater when performing the outward and parallel hand positions. Whereas when performing the back handspring with an inward hand position, most gymnasts tended to hyperextend at the elbow throughout early and late support phase. The technique displayed when employing the inward hand position is in line with current coaching methods for the back handspring, whereby gymnasts are encouraged to "block" the floor with outstretched, straight arms (Readhead, 1997). Koh, Grabiner and Weiker (1992) highlighted that increased elbow flexion during the back handspring may protect the elbow from large joint moments. This may suggest that the gymnasts employed higher elbow flexion when using the parallel and outward hand position to help manage the larger joint force magnitudes experienced when using these techniques. Although this may also indicate that the performers cannot produce a large enough extension moment to resist the observed elbow flexion under load, and therefore has implications in performance.

In the current study, larger magnitudes of elbow F_v were generally recorded during the outward and parallel hand positions when compared to the inward hand position. This trend

was also present for elbow joint for F_{ml} and indicates that the elbow was experiencing lowest stress when the hands were placed inwards. These findings concur with the comments of Sands and McNeal (2006), who suggested that by turning the hands inward during a flic-flac the female gymnast reduces the risk of injuring the elbow. The excessive joint force observed during the outward and parallel technique, combined with external rotation of the upper limbs (observed when using the outward technique) and multiple repetitions of the back handspring element, may increase the occurrence of lateral compression injuries of the elbow (e.g. osteochondritis dissecans of the capitellum) (Koh, Grabiner and Weiker, 1992).
Half of the gymnasts in this sample displayed significantly larger T_{ml} when using the outward and parallel hand position. This implies that the internal stability of the elbow joint may be compromised when utilising these techniques during the back handspring. Farana *et al.* (2014) stated that excessive repetition of skill may have a substantial impact upon injury risk during the more basic gymnastics elements. Given that this fundamental skill is performed on multiple occasions throughout training and competition, enduring repeated large elbow joint force and moments will increase the repetitive stress of the elbow joint, exposing the gymnast to higher injury risk potential when performing the back handspring.
The findings from the current study concur with results from Needham *et al*. (2016) suggesting that the outward and parallel hand positions within the back handspring expose the performer to an increased injury risk potential at the wrist joint. However, the current study displays higher magnitudes of joint force and moments within the elbow joint. This begins to offer a more holistic assessment of the upper limb movement for the back handspring. Conclusions drawn from the current study must be considered in regards to sample size. This limitation reduces the wider application of these results. Although, these initial findings provide a foundation to investigate this area further, with differing performance levels and learning stages of gymnasts, and other upper limb joints such as the wrist to provide a more holistic assessment factors that may influence injury occurrence during the back handspring.

CONCLUSION: The main conclusions from this study state that when using the outward and parallel hand positions during the back handspring, the elbow joint is exposed to increased joint biophysical loading that may increase injury risk. The inward hand position may lower injury risk in the back handspring due to lower internal forces and moments occurring at the elbow joint. These implications may offer valuable information for coaches, in terms of technique selection and to aid clinicians in identifying injury risk.

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