KINEMATIC CHARACTERISTICS OF ALIGNMENT IN ACROBATIC ATHLETES

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The purpose of this study was to determine if an underlying structure defining an 'aligned' body could be identified in acrobatic athletes, and to assess extreme examples of this structure for specific kinematic differences. Twenty-five male and female competitive gymnasts and divers were assessed for body segment alignment in a straight-standing position. Passive reflective markers were placed on the skin surface covering a variety of anatomical landmarks along the appendages and torso, including the spine. Athletes were instructed to assume the 'straightest body position possible' with their arms overhead and eyes forward. An HD digital camcorder recorded this position for approximately 5s. The video was digitized for various angular positions of the upper and lower extremities and the torso. Hierarchical cluster analyses revealed 4 clusters of athletes based on the kinematic variables. Athletes comprising the two most distant clusters (labelled 'best' and 'worst' with regard to alignment variables) were selected for further comparison. Discriminant and logistic regression identified pelvic tilt relative to vertical and forward head angle as the variables accounting for the most variance between the two groups. Independent t-tests revealed that athletes from the 'best' cluster were characterized by a more vertically aligned trunk, upper extremity-sternum, upper extremity-trunk, lower limb, and pelvic tilt, a more forward head position and smaller cervicothoracic angle. Identification of kinematic characteristics associated with an aligned body can help direct coaching and talent identification efforts for achievement of this position.

KEY WORDS: gymnastics, diving, posture, spine, performance.

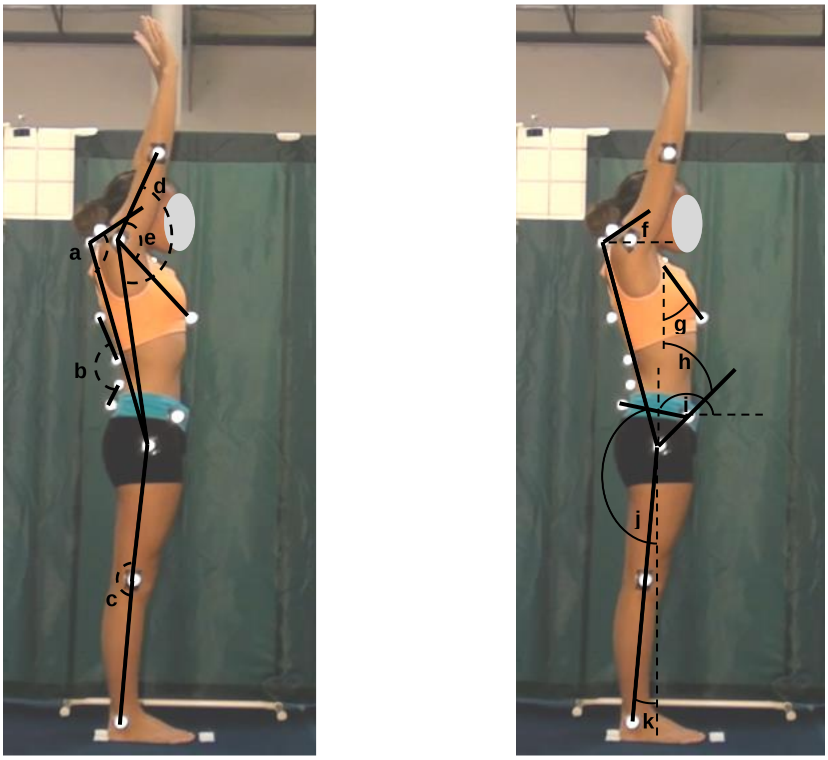
INTRODUCTION: The attainment of straight-body posture is a cornerstone of technical and aesthetic excellence in acrobatic sports such as diving and gymnastics (Arkaev & Suchlin, 2004; Malina & Gabriel 2007; Miller, 2000; O'Brien, 2003; Qian et al., 2010; USA Gymnastics, 2009). This sport-specific, straight-body posture is also thought to be better for reducing the chance of injury which may result from force imparted on a body that is out of alignment during impacts with equipment or water (Badman & Rechtine, 2004; Qian et al., 2010). Competitive scores in acrobatic sports partially depend on this straight-body position (Qian et al., 2010; USA Gymnastics, 2009) in which the arms are straight overhead, the head is neutral, the spine exhibits minimal sagittal curvature, and angles of flexion/extension of the limbs are minimized (O'Brien, 2003). This aligned position is so essential in diving that athletes perform 'line-ups' as a regular part of daily training (Badman & Rechtine, 2004; Malina & Gabriel, 2007; O'Brien, 2003). Although coaches prescribe many drills and exercises to their athletes in the hopes of improving this posture, there are no objective data from which to make evidence-based training decisions. The purpose of this study was to determine if an underlying structure defining an 'aligned' body could be identified in acrobatic athletes, and to assess extreme examples of this structure for specific kinematic differences.

METHODS: Sixteen divers and 9 gymnasts with an average training age of 5.0 ± 2.7 y comprised the sample. Four males (age 14.0 ± 5.8 y; stature 157.8 ± 17.0 cm; mass 47.7 ± 17.8 kg) and 21 females (age 14.0 ± 2.4 y; stature 154.5 ± 9.9 cm; mass 49.1 ± 11.5 kg) performed a single, stationary standing position with arms overhead, and their position video-recorded (Sanyo HD Xacti FH1A) in the sagittal plane. Spherical, retro-reflective markers (12.7, and 19 mm) placed on the subject's right side identified 14 anatomical landmarks from which the following 11 alignment angles were calculated (Figure 1): lordosis, cervicothoracic (Perry, Smith, Straker, coleman, & O'Sullivan, 2008), vertically referenced pelvic tilt (VPT;

Perry et al.), horizontally referenced pelvic tilt (HPT; Crowel, Cummings, Walker, & Tillman, 1994), sternal angle (Belli, Chaves, deOliveira, & Grossi, 2009), knee, trunk (McEvoy & Grimmer, 2005), forward head (Perry et al.), upper extremity-sternum, upper extremity-trunk, and lower limb (McEvoy & Grimmer, 2005).

Marker digitization was accomplished primarily using automatic marker identification (PeakMotus, v 9.0) with manual digitization in the event of failed auto-location. The average position for each angle across 4-6 consecutive video frames was calculated, and hierarchical cluster analysis was performed on the resulting means (SPSS v 20). Cluster analysis identified a four-cluster solution. Athletes comprising the two most divergent clusters were labelled as the 'best' (*n*=6) or 'worst' (*n*=9) with regard to alignment, based on a theoretical 'ideal' alignment being more vertically oriented with fewer deviations from a straight line (O'Brien, 2003). Discriminant analysis and logistic regression were used to determine the most critical variable(s) in differentiating between group membership. Finally, individual kinematic variables were assessed for differences between groups using independent t-tests. Alpha for all statistical tests was set at $p \leq 0.05$, and statistical control for family-wise error rate inflation was not implemented due to the exploratory nature of this investigation.

Figure 1: Angle Descriptions



Note: relative angles a) cervicothoracic, b) lordosis, c) knee, d) upper extremity-trunk, e) upper extremity-sternum; absolute angles f) forward head, g) sternal, h) vertically referenced pelvic tilt, i) horizontally referenced pelvic tilt, j) trunk, and k) lower limb

RESULTS: Table 1 displays the means and standard deviations for each variable between the 'best' and 'worst' aligned subjects. Discriminant function analysis determined VPT and forward head as distinguishing between the two groups, and this was supported by results from logistic regression. Independent t-tests revealed that the 'best' acrobats had a more vertically aligned trunk (t = 3.6, p = 0.003), upper extremity-sternum (t = 4.05, p = 0.001), upper extremity-trunk (t = 3.8, p = 0.002), lower limb (t = -2.2, p = 0.046), VPT (t = -5.4, p < 0.001), a more forward head position (t = -4.7, p < 0.001), and smaller cervicothoracic angle (t = -2.2, p = 0.048), than the 'worst'. There were no differences between groups for sternal angle, knee, lordosis, or HPT (all p > 0.05).

Table 1
Angular Position Characteristics of 'Best' and 'Worst' Aligned Acrobats

Item	'Best' *n* = 6 (mean ± SD)		'Worst' *n* = 9 (mean ± SD)	
vertical pelvic tilt	31.5	3.7	42.4	3.9
forward head	35.0	2.6	45.3	4.9
upper extremity-sternum	136.7	8.5	122.1	5.6
upper extremity-trunk	166.4	4.7	158.3	3.5
trunk	348.7	1.6	344.4	2.6
lower limb	5.7	0.7	2.9	0.9
cervicothoracic	119.9	4.1	125.5	5.3
sternal angle	21.9	5.5	26.0	2.9
lordosis	161.7	6.9	168.2	10.5
horizontal pelvic tilt	174.3	3.3	173.3	1.8
knee	181.7	3.6	178.0	6.9

DISCUSSION AND CONCLUSION: This is the first report in the literature of the combined effect of various kinematic positions for identifying athlete subgroups based on sagittal body alignment. Smith, O'Sullivan, and Straker (2008) measured three sagittal thoarocolumbar angles in adolescents and identified four clusters, which the authors termed 'neutral', 'hyperlordotic', 'flat', and 'sway'. Comparisons with our groups is difficult due to our investigation including kinematic variables other than those describing the spine. Comparing only the components of the thoracolumbar segment, the 'best' group in our investigation was characterized by a more vertically aligned pelvis and trunk. This is similar to the 'flat' group described by Smith et al. The authors also reported that a higher proportion of adolescents in the 'neutral' subgroup had never experienced back pain compared to the other subgroups. While attempts have been made to link back pain with spinal alignment (Cho, 2008; Hall, 1986; Kruse & Lemmen, 2009; Mitchell, O'Sullivan, Burnett, Straker, & Smith, 2008; Steele & White, 1986; Tsai & Wredmark, 1993; Widhe, 2001; Youdas, Garrett, Egan, & Therneau, 2000), research results have been mixed. Our current investigation did not include athletes with current back pain, and therefore conclusions cannot be made with regard to the contribution of body alignment variables and pain or injury.

Attempts have been made to relate normal standing posture to lack of flexibility, strength, skeletal characteristics, and training time (Emery et al., 2009; Hein, 1999; Li et al., 1996; Steele & White, 1986; Tsai & Wredmark, 1993; Wojtys et al., 2000) to name a few. Results have been variable, leading to uncertainty and confusion with regard to what interventions may be most useful in improving body alignment variables, as well as reducing pain and injury believed to result from 'poor' posture. Past investigations looked only at a relaxed standing body position, as opposed to the active aligned position more specific to acrobatic performance. Our contribution to this literature demonstrates that the specific straight-body aligned posture prized by acrobatic athletes can be identified by certain kinematic variables. Specific kinematic differences between 'best' and 'worst' aligned subjects warrant further description and investigation to determine how these positions might relate to performance and injury occurrence, and if these positions are trainable and to what degree they may be useful in a selection process.

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