DO SOME ATHLETE'S INERTIAL PROPERTIES GIVE THEM A NATURAL ADVANTAGE WHEN PERFORMING PURE SOMERSAULTS?

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The paper defines the relative difficulty of a posture as the transverse moment of inertia of the body in that posture, divided by the transverse moment of inertia when in a layout posture. Its value and range was compared across inertial property data sets compiled from estimates on current athletes and from the literature. Some data sets show that some athletes have a considerable natural advantage in terms of inertial properties alone when performing somersaults. No simple index showed promise to identify such athletes, and so each athlete's inertial properties would have to be individually determined. Males and females were found to represent distinct sub-populations, with males being at a natural disadvantage. Athletes aged 12 years or under were also found to be a distinct sub-population and were at a natural disadvantage.

INTRODUCTION: Training allows an athlete to improve strength, power, and even flexibility, but it does not allow them healthily to alter their height or body proportions. Thus, they have minimal control over their inertial properties. If an athlete's body is such that they possess desirable inertial properties then they will have a natural advantage over other athletes. This paper evaluates a range of inertial properties using a model of the human body in various somersault postures to determine if some athletes will have a practically significant natural advantage. Basic characteristics of the athletes are then considered to determine which categories of athletes, or if any of the ratios and indices previously used in biomechanics to categorise athletes correlate with those athletes having a natural advantage. In a pure somersault an athlete rotates only around their anatomical transverse (y) axis, which remains horizontal. In sports such as gymnastics and diving the dominant posture held during the somersault defines the skill and sets the difficulty score. The y-axis moment of inertia I_{yy} for the posture is the constant of proportionality between angular velocity ω and angular momentum H. The I_{yy} value is determined by the inertial properties of the athlete and their posture (joint angles). Differences in segmental inertial properties between athletes will result in different I_{yy} values for the same postures. The relative difficulty τ_r of a posture is defined here as the ratio of the number of layout somersaults that may be completed in the same time, and with the same angular momentum, as in the current posture. While holding a posture the athlete is quasi-rigid, so $H \approx I_{yy}\omega$. Thus, relative difficulty τ_r becomes I_{yy}/I_{yy_Layout}. The layout somersault is used as the 'reference' since it is common on entry and exit, and is the posture with the highest difficulty score in diving and gymnastics. It also has been used previously to normalize angular momentum requirements (Vieten & Riehle 1992). For any posture a lower τ_r compared to other athletes will mean that the somersault is relatively easier to perform, thus giving that athlete a natural advantage. A high range in τ_r across all postures τ_{r_range} will also indicate a natural advantage whereby an athlete performing multiple somersaults will have the ability to 'pick-up' considerable speed as they change shape. Athletes with a lower τ_{r_range} will benefit less from changing shape. To gain difficulty it would be advisable to focus on somersaults in a layout posture (or twisting somersaults, which use more laid-out postures) to gain difficulty points. It is expected that these athletes will learn their first somersault more slowly but then more quickly progress to more open postures.

METHODS: Postures: Twenty sport-specific postures were evaluated: 'layout' (L), 'arch' (A), 'just layout' (JL), 'entry pike' (EP), 'open pike' (OP), 'pike' (P), 'tight pike' (TP), 'tuck' (T), 'front tuck' (FT) and 'back tuck' (BT), which differ in torso curvature due to initiation and sighting considerations, 'tight tuck' (TT), 'cowboy tuck' (CT), 'lateral hip flexion' (LHF), 'L with arms up' (LAU), 'L with arms lateral and outstretched' (LAP), 'L with one arm up and one down' (L1U1D), 'L with one arm in high V and the other in low V' (LHVLV), L1U1D with both arms bent 90°' (L1U1DB), L1U1DB with lateral hip flexion' (L1U1DBLF), and 'puck' (PU).

Inertial property data sets: Inertial property data sets that were used for calculation of τ_r were extracted from the literature and generated from estimates made on current athletes. From the literature inertial properties intended to represent average or a specific percentile person were found in Anthropology Research Project (1988), Nikolova & Toshev (2007), Huston (2009) and Nikolova & Toshev (2010a, 2010b). This gave nine male and six female data sets. Estimates of inertial properties of current gymnast/diver were made using the methods described in Mikl (2013), the geometric model in Nikolova & Toshev (2007), and the regression equations in Finch (1985), Shan & Bohn (2003), and Ma et al. (2011) but using actual body segment lengths rather than regression lengths. Estimates that produced negative values, moments of inertia such that the sum of two was not greater than the third, or a total body mass or expected segment lengths differing from the measured by more than 20% were discarded. Recruitment of athletes was through the NSW Institute of Sport, with the only criteria being current participation in diving or gymnastics. Thirty-four athletes participated: Table 1 gives the 'squad' and gender distribution while Figure 1 shows the spread of heights and weights of the athletes.

Table 1: Athlete descriptors

Squad	M	F	Total
12yr-or-under	7	5	12
Teen (13-16yr)	4	6	10
Senior	4	2	6
Master	1	5	6
Total current athletes	16	18	**34**

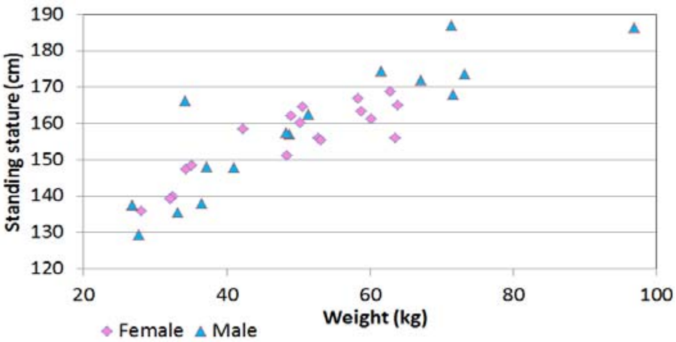

Figure 1: Scatter plot of athlete mass and height

Indices/ratios: It would be desirable to find a single index or ratio to identify athletes with a high value of τ_{r_range}, rather than needing to determine their inertial properties specifically. The following indices and ratios were considered: BMI, Rohrer, Ponderal and Androgyny indices and V-ratio, sitting height-, arm- and leg-length to stature ratios (Park et al., 2007; Stewart & Sutton, 2012; Bradshaw & Rossignol, 2004). The proportion of variability, R^2, (Phipps & Quine, 2001) between τ_{r_range} and each index or ratio was determined.

Equivalent somersaults: The variation in τ_r that is practically significant is not immediately clear, and it is not necessarily the same for all postures. The concept of equivalent somersaults was used to translate difference in τ_r to something a coach or athlete could readily interpret as an advantage or disadvantage. The number 'equivalent somersaults' was defined as the median value for τ_r across all athletes for the posture of interest divided by the τ_r specific to an athlete for that posture. For example, if the median τ_r for a tuck was found to be 0.46 (see Table 2 later). If for a particular athlete their τ_r for tuck was 0.51 then their equivalent somersaults for tuck would be 0.46/0.51 = 0.90. Which means that compared to the median for that posture, for the same relative difficulty they would only achieve 0.9 of their tuck somersault, making them 360*(1-0.9) = 36° under-rotated.

Box-Plots: Box-plots presented here illustrate the five figure summary: minimum, lower quartile, median, upper quartile and maximum (Phipps & Quine, 2001).

RESULTS and DISCUSSION: Table 2 gives the median values of τ_r for each posture. The postures are ordered by the median of τ_r and, when this was equal, by the mean of τ_r. The order of the postures does reflect the general expectation that τ_r decreases with the more compact postures that are associated with lower difficulty scores.

Equivalent somersaults: Figure 2 gives box plots for the equivalent somersaults of each posture. It is clear that some athletes have a natural advantage.

Table 2: τ_r for each posture ordered by its value

LAU	LAP	1U 1D	HV LV	1U 1D B	1U 1D BLF	L	A	LHF	Pu	JL	EP	OP	P	T	BT	TP	FT	TT	CT
1.16	1.07	1.07	1.06	1.05	1.02	1.00	0.96	0.94	0.92	0.88	0.82	0.70	0.49	0.46	0.41	0.41	0.41	0.34	0.35

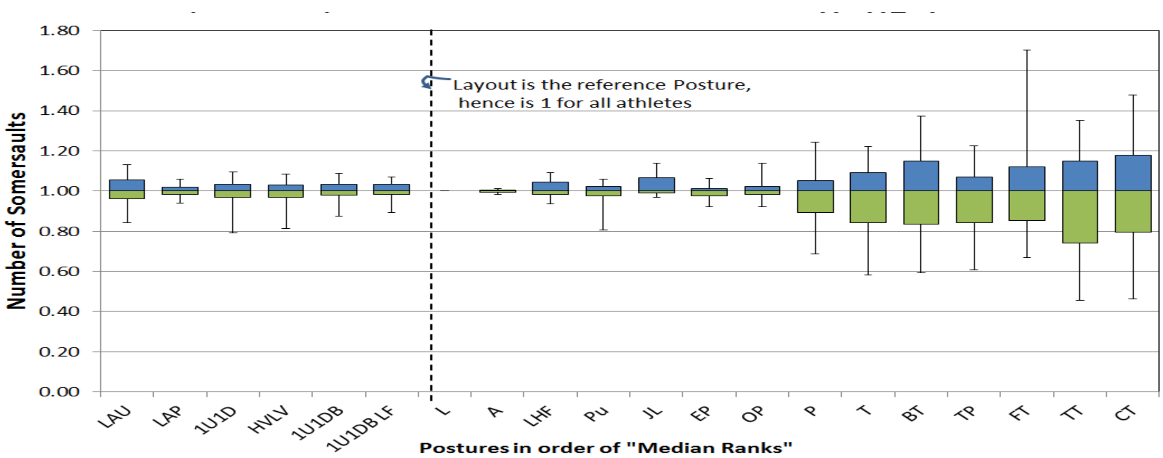

Figure 2: Equivalent somersaults

Imagine being the lower quartile athlete who is short by ~40° in your pike somersault while your upper quartile counterpart can over-rotate by 20° for the same relative difficulty! The difference in achievement multiplies with the number of somersaults: an upper quartile athlete using CT for the same relative difficulty exceeds the median by 0.18 after one, 0.36 after two and 0.54 after three somersaults. This conclusion differs from Vieten & Riehle (1992) who found only “insignificant changes for all individuals”. The difference may be because Vieten & Riehle only looked at the magnitude of τ_r and not at equivalent somersaults. Their group consisted only of adults, and used a Hanavan method (presumably Hanavan-BP). The Hanavan-BP “Senior” and “Master” inertial property data sets in the current study show similar standard deviations in τ_r (0.017 for “Senior” and 0.036 for “Master”) to Vieten & Riehle’s trampolinists (0.024 for “top trampolinists” and 0.031 for “semi-trained adults”). These seem small, yet the range of equivalent somersaults for these athletes is practically significant: for example, a range of 0.21 in P, 0.32 in T and 0.42 in CT.

Sub-populations and indices: Sub-populations and indices were compared using τ_{r_range}. A large range would indicate a natural advantage. Figure 3 shows the spread of τ_{r_range}, grouped by each of the categories in Table 1. The “12yr-or-under” and “teen” categories were the larger groups and showed moderate spread so were also split by gender. The non-parametric median test (Freund, Gray & Simon, 1997) was used to compare categories. The probability p given below is the probability that the null hypothesis (that the medians of the categories being compared are equal) is true. It is important to recall that category size and the difference in the medians alters p. Males and females differ significantly: the male median falls below and the female median above the “all” median, both at $p<0.05$. This is an interesting finding, since it is traditionally males who push the bounds of difficulty in terms of the number of somersaults achieved. This indicates that even though an athlete may be at a natural disadvantage in terms of inertial properties, other factors, such as the ability to generate angular momentum, are important when considering their actual achievement. The “12yr-or-under” median was significantly lower than “all” ($p<0.01$) making it a distinct sub-population with a significantly lower τ_{r_range} than other age groups. The male “12yr-or-under” median was significantly lower than “all” ($p<0.01$) but the female “12yr-or-under” did not reach statistical significance ($p=0.21$). The male and female “12yr-or-under” medians were not significantly different ($p>0.15$), indicating that this sample is too small to split by gender when using the non-parametric median test. The “teen” group was not significantly different from the “all” median. Male and female teens showed moderate difference to each other (p<0.12). All the data sets from the literature were well above the “all” median with a quite a small range. The literature data is clearly distinct from the athlete data generated for this paper. It is unclear, however, which characteristics of the literature data (e.g. how it was collected; the people who were sampled) make it a distinct population.

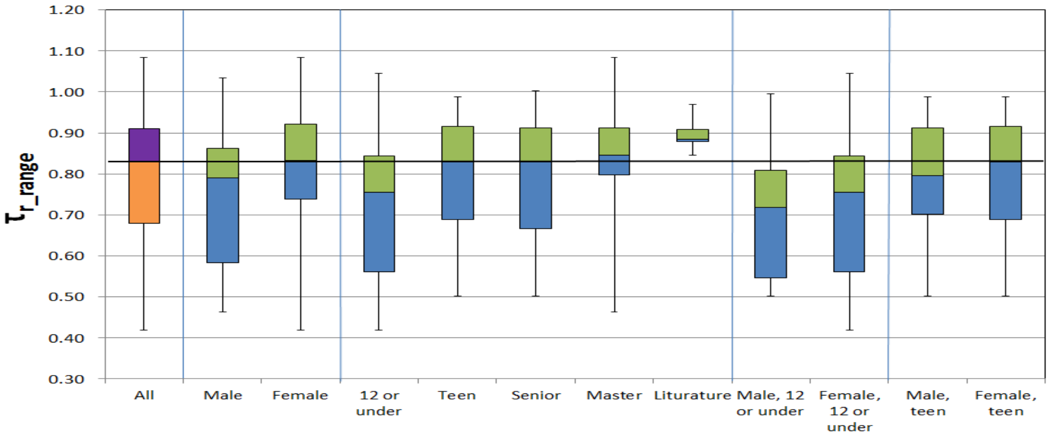

Figure 3: Spread of τ_{r_range} grouped by sub-population

None of the indices showed potential for use in classifying athletes. R^2 between τ_{r_range} and each index was <0.1. Restricting the inertial property data sets to Hanavan-BP estimates, which had only one rejection, R^2 was predominantly <0.5, or the number of athletes was too small to extract meaning from R^2. Males did, however, show an $R^2 = 0.75$, and males under 12 an $R^2 = 0.82$ for BMI, with scatter reasonably about the linear regression line.

CONCLUSIONS: Differences in segmental inertial properties give some athletes a natural advantage in somersaulting. No index showed potential for predicting which athletes would have a natural advantage and so an athlete’s inertial properties would need to be individually determined to identify favourable inertial properties. The genders were found to be distinct sub-populations with males having less favourable inertial properties. The “12yr-or-under” athletes were also a distinct sub-population which tended to have a lower τ_{r_range}. This is somewhat fortunate since it is expected that as they grow and seek to learn higher difficulty skills the changes in their inertial properties will assist rather than hinder their progression.

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