Fluctuating Asymmetry as a Predictor for Rowing Ergometer Performance

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Abstract

Fluctuating asymmetry (FA) can be defined as an organism's deviation from perfect bilateral symmetry. FA has been of interest to evolutionary biologists as it may be indicative of the ability of an individual to express its genotype in a stable manner. Asymmetry has been shown to correlate with success in both intra- and inter-sexual selection in various species, including humans. A growing body of knowledge is emerging concerning the relationship between asymmetry and sporting ability. This study seeks to expand upon understanding of developmental stability and athletics by investigating the association between asymmetry and performance in rowers. Both male and female competitors from a range of abilities were tested (76 males and 70 females), with asymmetry being determined through bilateral digit measurements and performance through personal best time over 2000m on the Concept 2 indoor rowing ergometer. Significant negative correlations were observed between asymmetry and 2000m ergometer performance in both males and females. The relationship remained significant after adjustment for rowing experience and height. These results suggest that asymmetry may serve as a predictor of potential ability in the sport of rowing. The cause for the association between asymmetry and sporting performance has yet to be identified.

Introduction

Fluctuating asymmetry (FA) has been defined as "random deviation from perfect bilateral symmetry in a morphological trait for which differences between the right and left sides have a mean of zero and are normally distributed" [23]. FA is of interest to a range of academic disciplines as it allows researchers to investigate the ability of a genotype to achieve stable development of a phenotype under given environmental conditions [19]. FA is therefore an indicator of developmental stability.

The capacity of an individual to withstand the effects of environmental stress is dependent upon his or her genetic basis. Since the same genetic code is responsible for both sides of any bilateral trait, the degree of asymmetry is very informative of the individual's ability to develop in a stable manner when exposed to stress. FA is therefore indicative of how well-adapted an individual is to their environment. There are numerous factors which can increase fluctuating asymmetry, including infection by parasites [14],

growth rate [24], mutations [18], unusual temperature conditions, environmental pollutants, increased maternal age and radioactivity [15]. Digit ratio will also be considered through reference to earlier work [7]. The ratio of second to fourth digit ratio has been shown to vary with prenatal androgen exposure, which is in turn correlated to performance in various sports including rowing.

Fluctuating asymmetry, energetic and sporting ability

Individuals successful in intra-sexual selection and many sporting and athletic disciplines share several attributes, including strength, endurance, speed and enhanced visual and spatial awareness. If fluctuating asymmetry is related to fitness in an evolutionary context, it follows that it might also be related to fitness in a sporting context.

Symmetry has been linked to efficiency of energy utilisation across species. It has been [2, 16, 17, 20] revealed that damage to the tail feathers of barn swallows (Hirundo rustica) has important conse-

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Leverhulme Centre for Human Evolutionary Studies University of Cambridge Fitzwilliam Street Cambridge United Kingdom CB2 1QH Tel.: +44/077/733 149 14 dannylongman@gmail.com quences for flight performance. If a tail streamer is damaged and asymmetry is introduced, the power required for flight at low speeds is increased, as is the energy expenditure for straight flight. Poorer turning performance through affects on the distribution of lift across the aerodynamic surface may also impose energetic costs.

Energetic inefficiency as a result of asymmetry has also been demonstrated in humans [11]. In males, asymmetry is positively correlated with resting metabolic rate. This may be because males with increased developmental stability are better able to withstand the stress of sexual selection than males of lower phenotypic quality relative to a given sport. The use of "energy thrifty genotypes" allows individuals with energetically favourable genes to allocate more energy to growth (beneficial in male-male competition) and reducing asymmetry (beneficial in mate choice). Energetic inefficiencies arising from high fluctuating asymmetry would be detrimental in a sporting arena.

An early study concerning the relationship between FA and athletic performance considered racehorses [9]. A calculation of the relative asymmetry of several bilateral traits (right measurement minus left, divided by the mean of the right and left character measurements), was combined with the use of handicappers' racing ability estimates, to observe a negative correlation between fluctuating asymmetry and racing ability; symmetrical horses were faster. This implied that fluctuating asymmetry could be an indicator of future performances in young horses. Importantly, the asymmetry was in the face not the legs, hence it was not a direct mechanical asymmetry, but more likely indexed developmental stability.

The relationship between FA and athletic performance among humans has been investigated among middle distance runners [12]. They considered deviations from perfect bilateral symmetry and ranked subjects based on their reported personal best times for the 800 m and 1 500 m distances. It was found that the more symmetric subjects had faster times over 800 m, 1 500 m and a combination of the 2 times. This suggested further possibilities for the use of FA in talent identification projects.

The previously discussed investigations highlight the benefits of having low fluctuating asymmetry in these activities. Gauvreau et al. [3] found that performance in racing horses may be enhanced by well developed aerobic and anaerobic capacities, and middle distance running relies on both the aerobic and anaerobic energy production systems.

Manning [10] found a negative correlation between fluctuating asymmetry and body weight in males. This is consistent with the hypothesis that body weight in human males is a sexually selected character. It would therefore follow that as low fluctuating asymmetry is related to body mass it may also enhance physical strength [1], adding to a prospective rower's anaerobic abilities. It has been demonstrated that to reach an elite level, a rower must exhibit outstanding aerobic and anaerobic capacities [4] (70–75% aerobic energy release for men, 60–65% aerobic for women, with the remainder of the energy being anaerobically released [6]). The authors hypothesized that both of these characteristics may benefit from low fluctuating asymmetry for the reasons outlined above.

Based upon the evidence from these previous studies of runners, we would predict that a more symmetric individual may be at an advantage in the sport of rowing, as he/she may benefit from more highly efficient aerobic and anaerobic systems associated with developmental stability than would be found among the more asymmetric individual.

Aims of the Study

7

The purpose of this study was to investigate the association between fluctuating asymmetry and rowing ability. This would lend further predictive power to coaches and those involved in the identification of sporting prowess.

Methods

The participants in the study were 76 male and 70 female student rowers from the University of Cambridge, with testing being carried out in Cambridge, UK. Ethical approval was given by the University of Cambridge Human Biology Ethics Committee, and all testing was in accordance with IJSM ethical standards [5].

4 bilaterally symmetrical characters were measured for each subject [13] in order to determine their fluctuating asymmetry. Each subject was asked to place their hands on a flat surface, straightening their fingers with the palm facing upwards. Measurements were taken from each hand in accordance with the methods of [22], from the centre of the digit crease proximal to the palm to the finger tip using Mitutoyo vernier callipers [8] accurate to 0.01 mm. Such measurements were taken for the second, third, fourth and fifth digits. Each measurement was taken blind (the measurer was unable to see the digital display on the callipers) twice, with the mean average of the two being used for analysis. The relative FA of each participant was calculated by subtracting the left measurement from the right, and dividing this value by the mean of the left and right measurement. The modulus of the left minus the right measurement was used so positive and negative asymmetries across traits do not cancel out. Each individual was then assigned a fluctuating asymmetry value by finding the sum of the relative asymmetries for each trait and dividing by 4 as follows [21]:

Fluctuating asymmetry = $\{\Sigma \mid R_i - L_i \mid /[(0.5 (R_i + L_i))]\}/4$

The simplest and most accurate metric to use when assessing rowing potential is the Concept 2 ergometer (manufactured by Concept 2, Vermont, USA). This device is used for the standard fitness test over 2000 m and is ubiquitous throughout the rowing world, including the various boat clubs of the University of Cambridge. The ergometer's popularity arose from its facilitation of training when it is not possible to row on water, and because it provides a controllable and reproducible tool in the assessment of rowing performance. It was for these reasons that personal best score over 2000 m (as reported by rowers' coaches, to the nearest 0.1 s, and with a drag factor of 130-135 - variance within this range is deemed insignificant by coaches) was used as the metric by which rowing ability was assessed in this study. This does, however, assume that the machines provide identical output data for a given input performance, an assumption which was impossible to test in practice.

In addition to digit lengths and 2000 m performance, participants' age, height and consecutive years rowed were also recorded. This was because these factors were considered to be possible contributors to 2000 m ergometer performance.

	M		Females (n=70)			
	Mean	SD	Range	Mean	SD	Range
2 000 m time (s)	413	30.4	363-501	496	31.7	458-571
height	186	5.45	172–197	171	6.94	151–195
years rowed	2.92	1.89	1-10	2.10	1.50	1–9
age	21.7	3.29	18-39	20.7	3.08	19–33
FA	0.079	0.0336	0.0183-0.152	0.132	0.0409	0.0264-0.237



Fig. 1 Fluctuating asymmetry and male ergometer time.

Results ▼

The first and second measurements of each digit length were strongly correlated for each subject ($r \ge 0.95$). These associations allowed confidence in the reliability of the measurements of fluctuating asymmetry, and therefore in the conclusions reached.

A description of the male and female cohorts is given in **• Table 1**. Males were significantly taller, but did not differ from females in age or years of rowing experience. Both male and female subcohorts shared a similar range of ability.

Male rowers

Among the male subsample there was a significant positive correlation between fluctuating asymmetry and 2000m time (r=0.44, p<0.001; see **•** Fig. 1).

There were significant differences between the mean fluctuating asymmetries of the top 30 and bottom 30 2000 m performers (p<0.05), and between the mean heights of the top 30 and bottom 30 2000 m performers (p<0.001). In addition there was a negative correlation between height and 2000 m time (r = -0.33, p = 0.003), and a negative correlation between years rowed and 2000 m time (r = -0.47, p < 0.001).

Regression analysis, controlling for body size (height) and experience, revealed that for every standard deviation increase in fluctuating asymmetry the 2000 m time increased by 7.3 s, with 9.5% of variance in ergometer performance being explained by fluctuating asymmetry (r-squared=0.095, p <0.01). When right hand digit ratio data is incorporated [7] alongside fluctuating asymmetry, height and years rowed, it is revealed that 51.5% of variance in 2000m time can be explained by these factors (r-squared=0.515). Colinearity has been tested for and no significant relationships were found.

The standard error of the estimate, 21.7867, shows that the regression equation can be used to predict an individual's



Fig. 2 Fluctuating asymmetry and female ergometer time.

0.000 0.025 0.050 0.075 0.100 0.125 0.150 0.175 0.200 0.225 0.250

Fluctuating asymmetry

Female rowers

575

550

525

500

475

450

425

Ergo time (s)

Among the female subsample there was a significant positive correlation between fluctuating asymmetry and 2000m time (r=0.45, p<0.001; see • Fig. 2).

As with the male subsample, there were significant differences between the mean fluctuating asymmetries of the top 30 and bottom 30 2000 m performers (p<0.001), and between the mean heights of the top 30 and bottom 30 2000 m performers (p<0.001). In addition there was a negative correlation between height and 2000 m time (r = -0.51, p<0.001), and a negative correlation between years rowed and 2000 m time (r = -0.29, p<0.05).

Regression analysis, controlling for body size (height) and experience, revealed that for every standard deviation increase in fluctuating asymmetry the 2000m time increased by 10.2s, with 14.2% of variance in ergometer performance being explained by fluctuating asymmetry (r-squared = 0.095). When digit ratio data is incorporated (Longman, Stock & Wells, 2010) alongside fluctuating asymmetry, height and years rowed, it is revealed that 41.8% of variance in 2000m time can be explained by these factors (r-squared = 0.418).

The standard error of the estimate, 24.8 (3sf), shows that the equation can be used to predict an individual's 2000 m ergometer performance within a 95% confidence interval of \pm 49.5 s (\pm 2*SEE).

Discussion

This study revealed significant inverse correlations between fluctuating asymmetry and 2000 m ergometer performance in both males and females, i.e., more symmetrical individuals tended to perform to a higher level. The magnitude of the variance in 2000 m performance being explained by fluctuating asymmetry (9.5% and 14.2% in males and females, respectively) and the significant improvement of 2000 m performance associated with a standard deviation decrease of fluctuating asymmetry (7.3 s and 10.2 s for males and females, respectively) suggests a potential use for fluctuating asymmetry measurement as part of the talent identification programs run by various national sporting bodies. When used in conjunction with measurements of digit ratio [7] the predictive power is further increased.

This study has therefore shown that FA, when controlled for body size and different levels of experience, is significantly and negatively correlated with levels of attainment in a discipline requiring significant energetic contributions from both aerobic and anaerobic systems. This supports the previously reported associations between FA and sporting ability in disciplines with similar energetic demands [13–15, 17]. However, it is not known if it is the aerobic, the anaerobic, or both the aerobic and anaerobic energy systems that are important in the link to fluctuating asymmetry. Further study in this area is necessary to gain a greater understanding of which characteristics are linked to an individual's fluctuating asymmetry. Investigations comparing essentially aerobic sports with anaerobic sports would be meritorious.

One possible explanation for the relationship between FA and ability in rowing could derive from efficiency of movement [22]. It has been reported that legs have shown higher developmental stability (and therefore lower FA) than other morphometric traits, and that this may be a result of selection for mechanical efficiency. Asymmetry as observed in finger lengths could be indicative of external imbalances elsewhere in the body, for example in leg or arm length. If this were so, the individual would have to expend energy making slight changes in his or her stroke to correct for the imbalance. Over the course of 2000 m, these small extra energy expenditures could summate to produce poorer performances. This could be tested by taking further anthropological measurements throughout the body to see if asymmetry is consistent.

Alternatively, it may be that observed asymmetry in finger lengths may be indicative of internal developmental instabilities elsewhere in the body, for instance tissues such as muscles, tendons and internal organs. An imbalance may cause inefficiency at high outputs, such as the strenuous effort required to complete 2000 m on the rowing ergometer. This could be tested in a number of ways. If fluctuating asymmetry were inversely correlated with maximal muscle strength, for example, it would provide support for a relationship between power and developmental stability of the musculo-skeletal system. In order to test for developmental abnormalities in the respiratory or cardiovascular system, the correlation between fluctuating asymmetry and subjects' VO₂ Max could be tested. A negative correlation here could indicate that it is the respiratory and/or cardiovascular systems that are affected by increased fluctuating asymmetry. Once an association has been detected, further tests could then be carried out to narrow down the affected system or systems (as it may be a general imbalance rather than one tissue in particular).

Unfortunately, the evidence for a correspondence between symmetry, developmental stability and rowing performance identified here, does not allow for further explorations of the ultimate causes of this correlation. The main limitation of this study arose from the use of personal best times achieved using different machines. Although it was not practically possible to ensure each machine would give an identical output time for a given level of input performance, the Concept 2 rowing ergometer is manufactured with a high quality, and is ubiquitous in the training regimes of Olympic squads throughout the world. We are confident that the results of the study were not significantly affected by such possible variation.

In conclusion, this investigation has shown that fluctuating asymmetry has for the first time been significantly and positively correlated with the sport of rowing in both males and females. This suggests a potential use of fluctuating asymmetry in talent identification programs. Future research should attempt to further delineate the relationship among fluctuating asymmetry, developmental stability and both power and endurance in sport.

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