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†This paper is based on thesis Evaluation of the connection among the body measurements and the flying speed in a racing pigeon population written by Steven Mercieca, a Maltese student at the Szent István University, Faculty of Veterinary Science, Budapest, Hungary 2013.

Dates: Received: 16 December, 2016; **Accepted:** 09 March, 2017; **Published:** 10 March, 2017

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Keywords: Racing pigeon; Breeding value for flying speed; Conformation; Temperature-humidity index

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Research Article

Connection among Body Measurements and Flying Speed of Racing Pigeon†

Abstract

The ability of racing pigeons to navigate and to find their way home is determined by many factors. The aim of this investigation was to prove the outer and inner environmental impacts on the flying performances of racing pigeon flock. The fieldwork consisted of taking down of various body measurements of 49 birds, which was improved by collection of racing-, meteorological-, geographical-, and pedigree data.

According to the age corrected body measurements the birds of actual flock were longer in wing length, narrower in wing width and lighter in body weight than birds in Horn's study.

The breeding value for flying speed (BV speed) was calculated by an individual animal model taking the proven environmental effects (fixed: year of race, wind direction, rain fall, reproductive status; covariates: distance, temperature-humidity index) into consideration next to the genetic relatedness.

The BV speed showed significant association with the real flying speed only ($r=0.71$), and there were no statistically proven correlations with the body measurements and the body condition loss as well. While the wing length stayed in a closer negative connection ($r=-0.40$, $p<0.05$) to the loss in body condition.

Association of traits was further evaluated by use of factor analysis, from which it is concluded that the measurement responsible for body capacity, the measurements contributing the wing surface area, and the speed of bird are belonging to different determining groups (factors).

Over and above, from the investigation it can be concluded that the flying speed of the racing pigeon is not clearly determined by their body measurements, by their live weights and condition losses. However, the contribution of the body weight, chest depth (as breast muscle volume), and wing length to the flying success is strongly imaginable, which needs further research.

Introduction and Aim

The homing pigeon (a variety of domesticated pigeon, *Columba livia domestica*) has long been known for its impressive ability to navigate through various terrains and find its way home, with speed being essential for a quick return when racing. Several adaptations make birds solid and strong, yet at the same time lightweight 'flying machines' [1]. Many external factors are believed to have an effect on the flying speed and thus racing performance of pigeons whereas others may not affect speed or do so to a lesser extent. Such factors include prevailing wind direction and speed, rainfall, sun visibility, temperature-humidity index, temperature, health, disease, husbandry and nutrition, training, familiarity and geography of landscape.

The essence of a homing pigeon is its ability to navigate

and return home in the quickest manner and from distant unfamiliar locations. Racing pigeons have long been used as models for navigational studies and their homing ability has intrigued many throughout the ages [2]. Besides the need for good muscle functioning, a great variety of other factors, including the wing quality, are present which determine the suitability of a bird for racing according to speed. The wing structure and characteristics are important in defining the racing capacity of a bird, along with various other anatomical traits. The speed of a pigeon is a critical part of the homing ability together with overcoming many possible obstacles. Both internal and external factors may influence the speed and resultant performance of a bird and external ones include meteorological, geographical and environmental factors whereas internal factors include health, innate homing ability, and stage of reproduction and body condition.

Once flight is initiated, different speeds may be attributed to various flight modes. A free flying pigeon is capable of differing flight modes including ascending, descending, turning, gliding, horizontal flight, take-off and landing [3].

Pigeons are able to breed from the age of 6 months and can do so all year, being most prolific in the spring and summer months. They are monogamous and build flimsy nests in which 1–2 white eggs are laid after 10–15 days of pairing and these are incubated for 17–19 days with the parents alternating incubation once daily. After hatching, the parents raise the squabs and these fledge after 30 days or so. A second clutch is usually laid during the rearing period of the first pair of squabs [4]. Racing of birds when they are in pre-breeding, incubation or rearing reproductive stages has been postulated to affect their speed and racing performance [5].

According to a study by Murton et al. [6], male birds are thought to undergo behavioural changes as a result of changing hormonal basis. Courtship is believed to be dependent on high levels of FSH/androgen resulting in aggressive components of the behaviour. The next phase is the nest demonstration and higher oestrogen levels dominate it. At the end of this phase, FSH dominated once more and results in nest building. Ball and Balthazart [7] believe that ovarian oestrogens activate female sexual behaviour and that parental care is hormonally initiated by synergistic actions of sexual steroids and prolactin in females, and by a response to the female's signals in males.

The muscles are needed for wing movement, the chest depth of a bird can be taken as the breast muscle volume. The attachment of the *m. pectoralis superficialis* (aka *m. pectoralis major*) is from the ribs, clavicle and lateral sternum to the crest of the lateral tuberosity on the humours [8]. Its contraction on the outside causes the wing to move downwards (downstroke, Figure 1). The contraction of the *m. pectoralis profundus* (aka *m. pectoralis minor* or *m. supracoracoideus*) will move the wing upwards (upstroke, Figure 2). The tendon of this muscle runs through a channel called the foramen triosseum formed by the coracoid, scapula and clavicle allowing a pulley effect to be achieved. The *m. pectoralis major* is rich in myoglobin and muscle fibres and also lipid droplets (most important source of energy for pigeons when in continuous flight). It has the greatest volume and surface area of the birds' muscles and is vital as a source of energy and for stamina during flight. The *m. supracoracoideus* is paler in colour, contains more white muscle fibres and is rich in glycogen which is useful for sudden manoeuvres such as take-off and landing. Since the upstroke needs approximately one sixth of the exertion force of the down stroke, the fact that there are less red muscle fibres and less lipids is of no real concern. The longer a race will be, the more vital an appropriate supply of fat in the diet is. Protein is of less importance than lipids and carbohydrates from an energetic point of view. The importance of the *m. pectoralis profundus* in uplift was investigated by Degernes and Feducia [9]. They performed unilateral or bilateral tenectomy of the tendon of this muscle to see if deflighting would occur. Although none of the birds undergoing either of these procedures had normal dorsal extension of the affected wing, they were all still able to

escape and produce some uplift (though obviously not enough to fly appropriately). The pectoralis muscle force is seen to peak at an early stage of the wing cycle during the downstroke [10]. The volume, tension and colour of the muscles are qualities looked at in racing birds.

Wing quality is an important factor of evaluation when racing pigeons are concerned. Feathers are one of nature's most prominent adaptations that enable birds to fly. Many requirements must be fulfilled for successful flight such as skeletal, muscular and aerodynamic ones. However the mechanical constraints imposed by the forces of flight on the feathers were not well explored. The peak strain on the flight feathers occurs in the 'foreward swing' of the flight cycle, at a point when the wings are supinated, adducted and protracted at the same time. In this way, the ventral feather surfaces are opposing each other in front and below the body [10]. The wing and tail of a bird have feathers with a special form and arrangement according to species [8]. The primary flight feathers/remiges are the 10 feathers originating from the region of the fingers and metacarpus (Figure 3). The secondary feathers/remiges are those that originate from the lower arm. Both groups of feathers are long and powerful with an asymmetrical vane. The covering feathers are called coverts/tectrices and these cover the fore- and hindwing. The alula/spurious wing is the group of 3 feathers (small remiges and their coverts) located on the thumb region of the wing and they are controlled via their own small muscles. They are pressed downwards when the bird is in fast horizontal flight but when the angle of attack is increased, they help prevent the airflow from becoming turbulent by acting as a forewing and are also important as a braking mechanism. The tail of pigeons is comprised of a number of stout steering feathers called

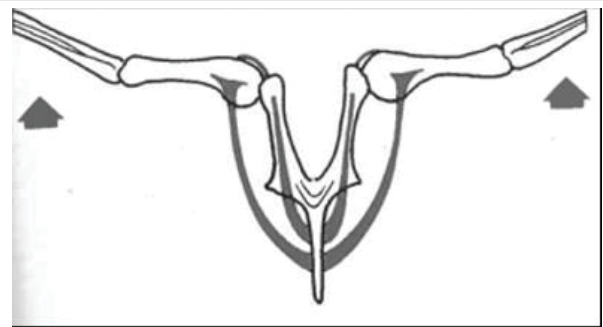


Figure 1: Contraction of the *m. pectoralis profundus* causes the wing to rise (after Vansalen, 36).



Figure 2: Contraction of the *m. pectoralis superficialis* causes the wing to move downwards (after Vansalen, 36).

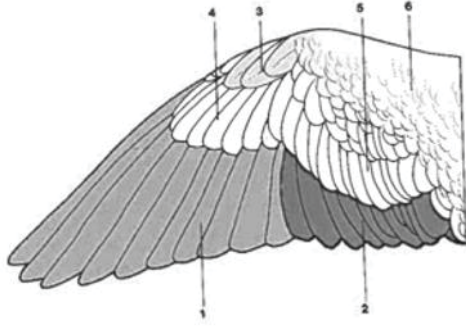


Figure 3: left wing of a pigeon showing the primary flight feathers (1), secondary flight feathers (2), alula (3), coverts of the forewing (4), coverts of the hind wing (5) and the shoulder coverts (6) (after Vansalen, 36).

rectrices, with symmetrical vanes and their covering feathers and is used as a steering organ in pigeons. The hind wing serves mainly as airfoil with parameters like width and linearity of the hind wing being checked when evaluating a bird. The forewing functions mainly in propulsion. These feathers are deeply imbedded in the wing bones, as they have to deal with a heavy load during flight. They are subject to aerodynamic forces during flight and the shafts will bend according to loads, with the outer cortex being the most significant structural feature with respect to this bending [11]. The area and depth of the outer vane of the flight feathers were notably smaller than the inner vane and these were also stiffer in the pigeon than in the barn owl, possibly showing that an increased load and strain may be placed on these feathers in pigeons [12].

The body weight of pigeons was investigated by Kangas and Branch [13]. They concluded that the body weight of male birds could become stable after only 7 days of ad libitum feeding whereas the female pigeons did not show this stability. The hens showed consistently greater daily variation in weight than the males even before egg laying, although less in this period. The ideal shape of a bird destined to race is one that offers least resistance and is aerodynamic. The deep keel of some pigeons may mislead one to think that it will not be an ideal flier however this deep keel is related to longer and more precisely attached breast muscles. So heavy, deep-keeled birds may actually be prized racing birds contrary to popular belief.

When compared to the human brain, the brain of pigeons is relatively smaller compared to body size, mainly due to the smaller cerebrum (with positive, conscious actions being involved in this portion of the brain) as stated by Whitney [14]. The cerebrum is the part that responds most to training. It is believed that once a pigeon learns what is wanted, and is positively rewarded, each successive habitual act taught will be easier to teach than the previous ones.

The sense of vision is undoubtedly vital for racing pigeons and is believed to be far superior to that of mammals including humans. The pigeon eye is flatter than that of mammals, limiting movement of the eyeball so they rely on head movements to follow objects and other differences may be implicated for movement perception. Pigeons have two visual

systems, frontal and lateral, which function differently and objects moving between the two systems usually pose problems in vision for the birds [15].

The pupillary size is linked to the nervous system and birds with larger pupils have been noted to not be able to finish long distance and/or difficult races. In short distance races the size of the pupil is less important. The iris of a racing bird is flat, with few/no breeding lines and of uniform colour [16]. The outer iris is covered by blood vessels, below which are the radial muscles, which dilate the pupil upon contraction and is dark and richly coloured. The inner iris is paler and contains circular muscles and is indicated by the distance lines found in this circle of correlation. Contraction causes constriction of the pupil. The degree of pupillary constriction was found to influence the racing speed, with birds having a greater degree constriction flying faster than those with wider pupils [17].

The ability to return home from unfamiliar locations utilizes various sensory cues both to determine the direction towards home and to uphold their flight in that determined direction having to fly under a variety of conditions including opposing winds, night time and in less than ideal weather conditions [2]. The initial orientation of the birds and leadership by older, experienced birds and other group effects were also noted when mass releases of birds were done, with younger birds following the older and more experienced ones [18].

Sun position and atmospheric odour and olfactory signals are also believed to aid in homing with the birds shown to integrate local odours at release site with various olfactory cues picked up on transport [19,20]. The accepted hypothesis is that if olfactory cues are lacking, the visualizing of the landscape will determine the homing capacity and it is thus proposed that the birds use a large aerial view of the landscape rather than using multiple, small landmarks [21,22].

According to Schmidt-Koenig [23] the three subdivided forms of homing are the following: *piloting* (use of familiar landmarks in familiar territory), *directional orientation* (flight along a fixed compass bearing, with no use of landmarks and may be wind error compensated or not), and *navigation* (flying to a goal without use of landmarks). In a study by Wu et al. [24], the results shown that relayed visual information may be responsible for early warning of approaching objects whereas other cells may signal an approaching object before impact allowing appropriate avoidance responses. The presence of magnetite-based receptors in the ethmoid region of the upper beak proved to be significant in the fixed-direction responses as opposed to the compass orientation [25].

Most birds flew almost at constant speed throughout the flight and also consistently among the different days. When the effect of crosswinds on homing direction were investigated and tested, it was found that pigeons sometimes compensated fully, occasionally even more than needed, for wind drift. Thus, they could compensate quite precisely for crosswind error, but usually maintain a preferred airspeed and do not increase or decrease their speed for adjustment [26].

Pigeons perform very poorly when they were unable to see the sun and also in overcast/foggy conditions, especially if released from novel sites. With proper training, birds may also learn to home under the cover of nightfall [2]. Rainfall may also affect the racing ability of pigeons. Conditions with low, medium or heavy rainfall are commonly encountered in races and birds are often seen to land and refuse to fly in heavy rain [27].

The temperature-humidity index (THI) was first described by Thom [28] and developed for humans and adapted to cattle by e.g. Berry, et al. [29]. It is calculated according to the temperature and humidity values recorded, using a specific formula [30]. Results of this study showed that a THI of 68 was enough to adversely affect cattle by causing discomfort, and as the values increased, production was affected. This index was utilized in this study to see if a significant effect on performance was present.

Many other factors exist that affect racing performance. Poor health in a flock may decrease speed and stamina when racing, leading to poor performance. Protocols include vaccination against Poxvirus, Paramyxovirus-1 and Salmonellosis and anti-parasitic treatment such as annual deworming, year round pyrethrin dusting and treating for Trichomoniasis before racing and breeding periods. Many viral (*Adenovirus*, *Avian Poxvirus*, *Circovirus*, *Herpes virus*, *Paramyxovirus-1*) diseases may affect pigeons [31]. The most important *Bacterial diseases* in a racing flock being: *Salmonella typhimurium var copenhagen*, *Escherichia coli* and a group of bacteria causing chronic respiratory disease and resulting in poor performance, made up of *Chlamydia psittaci*, *Pasteurella* species and *Mycoplasma* species. Additionally *Fungal diseases*, *Parasitic diseases* (e.g. *Coccidiosis*, *Haemoproteus*, *Trichomonas gallinae*) and *Ectoparasites* (e.g. *Mallophaga*, *Hippoboscid pigeon flies*) disturb birds and cause stress them [32].

According to Frank [16], the eye of a healthy pigeon should be clear, shining, observant and fully open. If illness strikes, the eyes usually become dull, with possible drooping eyelids.

The aim of this study was to investigate various outer and inner environmental impacts on the flying performances of a racing pigeon flock of Jilly (in years 2011–2013). The fieldwork of this study consisted of taking down of various body measurements of 49 birds, which was improved by collection of racing-, meteorological-, geographical-, and pedigree data as well as by comparison to the conformational data from the doctoral work of Horn [5] written in 1935. The various anatomical characteristics of the birds were measured and their impact on speed and racing performance was investigated.

Materials and Methods

Forty nine birds were selected for the investigation and various data was recorded on site at the breeder's loft in Gödöllő, Hungary. The pigeon breeder was Dr. Bertalan Jilly (membership code B-01), one of the authors, who invited to carry out this investigation. He is breeding a closed strain of racing postal pigeon since 45 years which is based on two

initial pairs imported from Georges Fabry, Belgium, 1970. For its continuous refreshment he gets newer individuals from the following breeders: Delbar, Janssen, van Wanroy, de Weerd, Marcelis, and Fulgoni. The age of the birds investigated ranged from 1 to 7 years and the population consisted of 23 cocks and 26 hens. The birds were all vaccinated on the 10th January 2013 against *Paramyxovirus*. The weather on the day of visit (Friday 5th April, 2013) for data recording and collection was overcast, with low rainfall (<10 mm) and an average daytime temperature of 8°C.

The taking of various body measurements was used to assess the birds. A measuring tape was used for wing length measurement, from base of wing to tip of outermost primary feather (Figure 4), as well as for wing width (from the dorsal tip at the bend of the wing, above which one will find the alula or 'spurious wing', to the tip of the first secondary feather). The primary feather length was also measured using the outermost/last primary feather (Figure 5), together with the secondary feather length using the length of the first secondary feather (inner most, before transition to primaries). The body length was also measured from point of the shoulder to the tip of the tail. Callipers were used to measure the chest width (widest point of the chest from the inside of the wings, Figure 6) and the chest depth (from the middle of the dorsum of the bird to the deepest point of the sternum ventrally, Figure 7). The live weight of each bird was measured using a tared (zeroed out) digital balance, by placing them in a box. The birds were fed last in the previous afternoon and not fed in the morning of the investigation.



Figure 4: Measurement of wing length; photo Mercieca, 2013.



Figure 5: Measurement of outermost primary feather length; photo Gáspárdy, 2013.



Figure 6: Measurement of chest width; photo Mercieca, 2013.



Figure 7: Measurement of chest depth; photo Gáspárdy, 2013.

Some of the body measurements taken down in this study were corrected for 2 years of age (adjustment) in order to obtain a parameter for this age as well as to make it comparable to Horn's results. The raw body measurements data (body length, chest width, wing width, wing length and live weight) from the doctoral work of Artúr Horn [5] were also taken over, and involved as a control into the investigation. The populations of birds used in Horn's work consisted of 60 individuals.

The breeding value for flying speed (BV speed) was also a parameter to be estimated. Since the speed was expressed with its breeding value, its estimation is considered as a genetic measure. The racing performances of all the investigated birds were recorded for the racing period 2013 (May-July). For birds older than 1 year, the racing performances from the racing periods of the years 2011 and 2012 were also added to the estimation. A total of 466 competitions were considered. The racing data included: place of start, date of race, starting time, time of arrival, duration of race, distance in meters, speed (meters/min), body condition at start and body condition at finish. Speed was calculated (dividing the distance flown in meters by the duration of the race in minutes) for the first 60% of the birds, which arrived from every race. The distances flown for each race were also noted down and ranged between 160 km with the starting point being in Rajka, Hungary, and 760 km, for races starting from Magdeburg, Germany.

According to the opinion of Jilly, the *body condition* status and change of the birds were integrated into the investigation. The breeder gave the body condition on a scale from 1-5, with

5 being the best condition and 1 being very thin. The change in body condition was calculated by subtracting the condition at start from that at the arrival. To characterize the individual birds, an average value for condition loss was used.

The impact of the *breeding stage* of the birds on the racing performance was also proven. The incubation or rearing status at the time of each race was therefore integrated. The reproductive status was coded as follows: code 1 for birds before nesting; code 2 for birds being in incubation; code 3 for birds rearing squabs.

A code for *sex* was given, with male birds having code 1 and female birds having code 2. Meteorological data were also collected for each race. These included: temperature at start of race, temperature at end of race, wind speed, wind direction, relative air humidity at start and at finish, and rainfall (if any).

A *rainfall* code was used: code 1 denoting no rainfall (0 mm), code 2 denoting low or medium rainfall (0-25 mm) and code 3 denoting heavy rainfall (>25 mm).

A *wind* code was also used according to the prevailing wind direction and its effect on the birds' flight according to the anticipated direction of flight. Code 1 - supporting winds or no wind; code 2 - hindering or crosswinds.

The *temperature-humidity index*, THI was then calculated using the temperature and humidity values collected. It was done for the start and finish of each race and an average value was also calculated, using the formula (30):

$$THI = DBT - [0.55 - 0.55 * RHum \%] * (DBT - 58),$$

where: DBT = Dry Bulb Temperature (Fahrenheit), RHum% = Relative Humidity.

Using an altitude map, the impact of *elevations* on the races was investigated, as was advised by the breeder. The elevations came in the form of hills and mountains. The most prominent elevations were recorded and the sum of the elevations calculated. A coding system was used for this too: code 1 - total elevation of up to 500 m, code 2 - total elevation 500 m or more.

All data was recorded on Microsoft Excel [33]. The impact of the above effects was controlled by Statistica program package [34].

The BV speed (breeding value for speed) for each flight of each bird was calculated by using an individual animal model, which is a by pedigree information improved BLUP-method [35]. The model used only the statistically proven environmental effects (fixed: bird itself, year of race, wind direction, rain fall, reproductive status; co-variates: distance, temperature-humidity index at the end of the race) and bird genetic relatedness to allow prediction of the animal's individual merit. Other impacts (sex, age at race, elevation of landscape, loss in body condition, temperature at start and wind speed) were checked for significance but were excluded from the final model due to their insignificant impact on speed.

The mean values and corresponding standard error for chest width, chest depth and body weight which were adjusted to 2 years of age, and wing length and wing width were calculated. The means for each parameter in actual (Jilly's 2011–2013) and in Horn's (1935) population were compared using Student's T-test [36].

Then correlation coefficients were calculated to measure the strength and direction of the association between the BV speed and the age corrected body measurements.

Factor analysis was used to further analyse the association of the age-adjusted traits using Statistica 12 [34] to determine which parameters are statistically belonging together. The main reasons for use of factor analytic techniques were to reduce the number of variables and to detect structure in the relationships between the variables. Therefore, factor analysis is applied as a data reduction or exploratory structure detection method.

Results and Discussion

The total least squares mean value for speed was 1012.9 m/min. According to the BV speed, the best bird was the female with ID HU 12-01-47930 (BV speed = +397.26) and the weakest racing individual was the male with ID HU 12-01-47936 (BV speed = -677.07). Jilly stated that a good bird was a blue male with ID HU-07-01-98450 that had one good performance each year and was culled out at 6 years of age. Its bloodline is present in some individuals in the flock presently. The BV speed values for these birds were in the upper range of the list (+112.72 and +143.60, respectively) but also birds better than these existed in the flock. The racing birds in the Jilly's population are the progenies only who serve with information for the breeding parents. The selection practiced by him is called as recurrent selection.

The reproductive stage has been thought to affect the animals' racing performance and speed for some time [5]. Horn investigated the reproductive stage for each animal and each race as was done in this study. The incubation or the rearing day were recorded and believed to be important in racing performance. It was postulated that birds in the incubation or rearing phase of the reproductive cycle would be motivated to return to the loft quicker, thus increasing their speed and improving their performance as compared to birds out of these reproductive phases. This was further investigated in this study and statistically proven to have a significant positive impact on the investigated trait (speed) and was therefore used in the final individual model for calculation of BV speed along with the other mentioned parameters.

The temperature-humidity index (THI) values were generally higher at the end of a race. The reason for this is that the index gives a larger impact of temperature than humidity. At the start, there is hypothetically a lower temperature and a higher humidity value but since the temperature is more influential, the index is lower which is beneficial. At the end of the race, the higher temperature allows for a higher index, which may prove to be a stressor. An index value of 83–84 or higher is predicted to be a severe stressor for animals (the

primary study proved this on cattle at a much lower value of 67) so a negative effect on performance when such conditions arose, would be noted. The index values ranged from 55.4–96.8 with the majority being below 84. Only the THI for the end of the race was used as a covariate in the final model for BV speed calculation.

The mean values (and equivalent standard errors) from the body measurements of Jilly's flock compared to Horn's flock (Table 1) showed that the mean body weight of birds was significantly lower in the present data (475.8 g) than in Horn's flock (488.2) with a p-value of 0.03. The mean values for chest width and wing width proved to be significantly lower in the present data ($p < 0.01$) whereas chest depth showed no significant difference between the two samples having a value of 7.16 cm in both ($p = 0.96$). The mean values of primary feather length, secondary feather length and body length were tabulated for the present study only having mean values of 17.02 cm, 9.25 cm and 24.68 cm, respectively.

Horn [5] performed a similar experiment to the one presented here. His birds ranged from 1–5 years of age and he believed that age and sex both influence racing performance. The anatomical measurements recorded by Horn varied slightly from the ones done here. The body length was measured from the tip of the shoulder to end of the rump thus he took the real anatomical bony trunk into account. In this study the body length was measured till the tip of the tail. For this reason comparing measurement results from the two studies would give erroneous p values, hence it was excluded. The chest width was measured by taking the whole width of the animal, from the lateral surface of the left wing to that of the right wing (of a bird in hand, with closed wings) in Horn's study as compared to this work where the anatomical chest measurement excluding the lateral wing surfaces was done. The wing width, wing length and live body weight before feeding were done in the same way as Horn's technique, although the weight measurement was done to 5-gram accuracy in Horn's work compared to the 1 g accuracy in this study.

The comparison of mean values obtained from the measured body parameters for wing width, wing length and body weight, had significant p-values and showed that the sample of the present day study were on average 12.4 g lighter, had a wing

Table 1: Base statistics and comparison of body measurements.

Body measurements	Horn, 1935 (n= 60)		2013 (n= 49)		p-value
	Mean	SEM	Mean	SEM	
2-year body weight	488.2	3.75	475.8	4.15	0.03
2-year chest depth	7.16	0.04	7.16	0.05	0.96
2-year chest width	9.66	0.08	6.73	0.09	<0.01
Wing length	27.96	0.13	30.44	0.15	<0.01
Wing width	12.31	0.13	11.11	0.15	<0.01
Last primary feather length	-	-	17.02	0.18	
2- year 1 st secondary feather length	-	-	9.25	0.06	
2-year body length	-	-	24.68	0.12	

length that was on average 2.48 cm longer and a wing width that was on average 1.2 cm narrower than the birds measured in Horn's study. This is possibly explained as an evolutionary change (obtained by selective breeding) to make the birds lighter, and longer in the forewing and narrower in the hind wing that may allow better performance by moving towards creating a 'speedy' type of bird. Due to financial rewards offered to the owner of the fastest pigeon, selection for those pigeons that home the fastest may be a determining reason for this [2].

The chest depth showed no significant difference between the two samples allowing the present day birds to still have a deep chest (body capacity) needed to for flight. Thus, the birds of Horn's study appeared to be stockier, heavier, shorter and wider in the wing with a comparably smaller chest depth. The chest widths were compared and had a larger value in Horn's data (2.93 cm wider) predictably so due to the various measuring techniques in the two studies. The mean values for last primary and 1st secondary feather length were measured for the present study only. The outermost primary feather length mean value was 17.02 cm, lower than the mean length of 19.3 cm as described by Bachmann et al. [12]. The body length of the birds was also measured differently in the two studies, so a comparison was not done. The body length in the present data had a mean value of 24.68 cm. Although body type was mentioned, the breeder of the sample of birds used in this present study does not use an evaluation system for body type, and birds of all types (deep keeled, longer or shorter in the wing, heavier or lighter etc.) are raced altogether and in the various race distances. More attention is paid to the health, eye evaluation and general condition of the animal to determine the racing capacity.

In many cases the correlation coefficients (Table 2) among the variables were low and non-significant ($r < 0.31$ and $p > 0.05$). In fewer cases statistically proven associations were found. The majority of them were positive and showed medium strong association such as the connection between the body

weight adjusted to 2 years of age and the wing length ($r = 0.32$ and $p < 0.05$). Strong association was found between the BV speed and the real flying speed ($r = 0.71$) and between the body weight and chest depth ($r = 0.67$). The only significant proven association of BV speed was to the real flying speed, without any significant relation to the body parameters. The body length showed positive association with the 2-year body weight ($r = 0.46$), chest depth ($r = 0.48$), 1st secondary feather length ($r = 0.44$), and wing width ($r = 0.41$). Strong negative correlation ($r = -0.58$) was found between the last primary feather length and wing width. Out of this, the last primary feather length had positive relationship ($r = 0.36$) to the wing length only. The second strongest negative association ($r = -0.40$) was between the wing length and the body condition loss. It was also noted that wing width did not have a significant association ($r = 0.13$) with wing length.

The BV speed showed a strong significant positive association with the real flying speed only with no statistically proven correlation with the body measurements and the body condition loss.

The majority of body condition loss associations were not significant except for the negative correlation to wing length ($r = -0.40$). As the wing length value increases, a decrease in body condition loss is expected. Perhaps a longer wing allows the bird to maintain flight and better utilize stored energy, allowing a better overall condition upon returning from a race. In fact, condition losses ranged from mild to strong and are dependent on many other racing factors. The breeder objectively assessed the body condition before and after each race for each bird using visual examination and tactile palpation. Another proven negative association, albeit stronger, ($r = -0.58$) was found between the primary feather length and wing width. As the primary feather length increases, the width of the wing is seen to decrease. Perhaps this is an evolutionary trait allowing birds to have longer and narrower wings. The body length showed positive associations with r -values ranging from 0.41 (wing width) to 0.48 (chest depth). An increased body length

Table 2: Correlation coefficients (r) between variables (n = 38; marked correlations are significant at $p < 0.05$).

Variable	Means	Std. Dev.	Body condition loss	Breeding value for flying speed	Flying speed	2-year Body length	2-year Body weight	2-year Chest depth	2-year Chest width	2-year 1 st secondary feather length	Last primary feather length	Wing width	Wing length
			(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(1)	-1.29	0.45	1.00	0.28	0.26	-0.02	-0.03	-0.04	0.02	-0.16	0.06	-0.22	-0.40*
(2)	-0.81	172.8	0.28	1.00	0.71*	0.00	0.10	0.23	-0.05	0.04	0.19	-0.03	0.19
(3)	1270.21	324.0	0.26	0.71*	1.00	0.16	0.04	0.09	0.20	0.12	0.09	0.15	-0.07
(4)	24.74	0.85	-0.02	0.00	0.16	1.00	0.46*	0.48*	0.22	0.44*	0.13	0.41*	0.31
(5)	473.97	35.02	-0.03	0.10	0.04	0.46*	1.00	0.67*	0.30	0.20	0.27	-0.05	0.32*
(6)	7.18	0.30	-0.04	0.23	0.09	0.48*	0.67*	1.00	0.33*	0.39*	0.23	0.11	0.51*
(7)	6.70	0.74	0.02	-0.05	0.20	0.22	0.30	0.33*	1.00	0.13	-0.12	0.04	-0.30
(8)	9.28	0.42	-0.16	0.04	0.12	0.44*	0.20	0.39*	0.13	1.00	0.25	0.37*	0.39*
(9)	17.09	1.30	0.06	0.19	0.09	0.13	0.27	0.23	-0.12	0.25	1.00	-0.58*	0.36*
(10)	11.16	1.22	-0.22	-0.03	0.15	0.41*	-0.05	0.11	0.04	0.37*	-0.58*	1.00	0.13
(11)	30.58	1.02	-0.40*	0.19	-0.07	0.31	0.32*	0.51*	-0.30	0.39*	0.36*	0.13	1.00

meant a larger bird, which predictably showed an increase in body weight ($r=0.46$), however, it also correlated to increases in wing width, chest depth and secondary feather length ($r=0.44$). Increase in body weight was strongly correlated to an increase in chest depth ($r=0.67$) but showed a medium strong correlation to wing length ($r=0.32$). Perhaps a heavier bird needs a deeper chest and longer wing to compensate for the increased weight allowing flying performance to be maintained. It was interesting to note that there was no strong positive association between the wing width and wing length ($r=0.13$). The chest depth showed the strongest positive associations with other traits including wing length ($r=0.51$) and 1st secondary feather length ($r=0.39$). Perhaps the presence of a deeper chest required the wing and flight feathers to be longer in order to maintain proper uplift during flight. With this, chest depth and width were also in positive correlation ($r=0.33$) though not as strongly as would be expected. The secondary feather length showed a medium strong positive association to the wing width ($r=0.37$) and wing length ($r=0.39$). An increase in wing length and wing width requires an increase in the secondary feather length though this relationship is not as strong as expected. Besides the negative association mentioned previously, the primary feather length shows a medium strong association to wing length ($r=0.36$). This is expected, as the forewing of a pigeon is largely comprised of the primary flight feathers so a parallel increase in both can be seen. Wing width and body length are positively associated ($r=0.41$) meaning most birds with longer bodies also had wider wings allowing a larger wing surface area (hind wing) to aid in uplift of an expectedly larger bird. In respect of body weight Bhowmik et al. [37] calculated stronger correlation coefficients between body weight and body length, and wing length (wing span) ($r=0.74$ and 0.71 , respectively) in Jalali Pigeon, a lighter bodied local breed of Bangladesh; the reason for difference might be our adjustment.

Using factor analysis, the factor loading (varimax normalised) of the traits into different determining groups was done, with factor weights >0.70 taken as significant ($p<0.05$) as shown in Table 3. It was found that the eight traits investigated were put into four factors including those measurements responsible for 'body capacity' (body weight, body length and chest depth), the measurements contributing to the 'wing surface area' (wing width and last primary feather length, but merged together with the factor containing wing length) and the 'speed of bird'. These traits are therefore belonging to different determining groups (factors) with a majority of positive factor weights being noted, together with a single proven negative association. The proportion total of these factors gives an explained variance of 73% for the parameters with a decreasing order (factor 1 = 25%, factor 2 = 17%, factor 3 = 16%, factor 4 = 15%). The remaining 27% is unexplained variance.

Determining which parameters are statistically proven to belong together according to the results obtained would help to reduce the higher number of known correlated variables to fewer unobserved factors. The main reasons for use of factor analytic techniques were to reduce the number of variables and to detect structure in the relationships between the variables,

Table 3: Factor weights of traits by different determining groups ($n = 38$; marked correlations are significant at $p<0.05$).

Traits	Factor 1	Factor 2	Factor 3	Factor 4
Body condition loss	-0.11	0.48	-0.25	-0.48
Breeding value for flying speed	0.06	0.90*	-0.11	0.41
Flying speed	0.11	0.89*	0.14	-0.10
2-year body length	0.73*	0.07	0.27	0.09
2-year body weight	0.80*	-0.03	-0.27	-0.06
2-year chest depth	0.85	0.10	-0.10	0.11
2-year chest width	0.52	-0.02	0.12	-0.68
2-year 1 st secondary feather length	0.55	0.08	0.25	-0.38
Last primary feather length	0.27	0.16	-0.76*	0.33
Wing width	0.19	0.06	0.93*	0.17
Wing length	0.42	0.00	-0.09	0.82*

actively classifying them. Therefore, factor analysis is applied as a data reduction or exploratory structure detection method.

The significant variables belonging to factor 1 were body length, body weight and chest depth with values of 0.73, 0.80 and 0.85 respectively. The positive, proven statistical association of these traits into factor 1 shows that these related traits could be responsible for the 'body capacity' of the bird. Since these traits belong to one factor, this encompasses the anatomical trunk (depth) and weight of the bird together with the length, and their relatedness, which means that if one of them increases, a parallel increase should be noted in the others.

The significant variables belonging to factor 2 included the BV speed and the flying speed, resulting in the factor being called the 'speed' factor. The positive and significant factor values were 0.90 and 0.89 respectively. This shows that the BV speed calculated using the individual animal model is positively associated to the calculated flying speed of the birds. Thus as the merit of the animal increases, as calculated by the breeding value, a parallel increase in speed is seen. All other variables taken into consideration for this factor showed either insignificant positive or negative factor values meaning that the real speed and breeding value for speed are independent from the body characteristics of the birds.

The significant variables belonging to factor 3 allowed it to be termed the factor for 'wing surface area'. These included primary feather length and wing width (placed in close association with the wing length in factor 4). The factor values were -0.72, 0.93 and 0.82 respectively. The proven positive associations (0.93 and 0.82) show that an increase in the factor value resulted in an increase in the wing width and wing length. A single, proven negative association (-0.72) was seen with primary feather length in factor 2. Strengthening this, the correlation between the primary feather length and the wing width (Table 2) was also negative. This showed that with an increase in the factor value there was a decrease in the primary feather length.

In a study comparing the wings of pigeons and barn owls by Bachmann, et al. [12], the wing area of the barn owl was

found to be much larger than that of the pigeon. Having similar weight, the wing area loading of the pigeon is higher, meaning that they are not able to fly slowly as a barn owl can. Barn owl feathers were larger than pigeon feathers indicating a lower wing load that would allow this slow flight. The loading of the wing in pigeons was thus higher showing that their energy expenditure would be greater in these birds. From the analysis of feather morphology modelling made by Sullivan et al. [38], it has been confirmed that the interlocking adherence of barbs to one another in pigeon will lead to a diminished barb rotation during deflation and an even stronger structure.

Conclusions and Recommendations

The breeding value estimation calculated using an individual animal model, is a relatively new and unexplored field for pigeons and has only received acceptance and practice on farm animals. For pigeons, local breeders have only calculated the actual speeds. Thus, further investigation into the breeding value estimation is recommended.

When comparing the results of this study to the data of Horn's work (1935), the wing lengths in the population of the present study were greater than those of Horn's population and no association between the wing length and wing width was found. It was also noted that the greater the wing length, the lower the body condition loss. This automatically proves the selection for longer distance for the present population. Although no bird body type evaluation was done in this work, it could be concluded that present day birds are more specialised, performance oriented, more appropriately fed, healthier and have greater outer and inner environmental support leading to their improved performance. The proven changes in the conformation of the birds shows that they have become more athletic than the heavier, shorter winged birds from the early 20th century according to the population comparison.

Overall, by the lack of significant associations, it can be concluded that the flying speed of a racing pigeon cannot be accurately determined according to the body measurements, wing parameters, live weights and average body condition losses. Thus it can be said that flying speed is largely independent from the shape and size of the pigeons. However, with regards to wing length, live weight and chest depth (as breast muscle volume), we can imagine a special importance in the flying and racing success.

Jilly's 40 years of experience [39,40] strengthens our findings: longer wings result in higher speeds and lower body condition losses. He explains this observation by discussing that the body weight disperses better over a larger wing allowing the bird to access greater forces for better flight. With this proven idea, more significant advice can be given to other pigeon breeders. A recommendation would be for further studies regarding creating an estimation model were various, simultaneous traits can be integrated into a body index that will possibly allow better correlation to the flying speed as compared to the relations of individual traits to the BV speed done here. This will potentially allow better estimation of flying speed.

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