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*Lauren K. Swan*[1] *and Carl N. Stephan,*[1] *Ph.D.*

# Estimating Eyeball Protrusion from Body Height, Interpupillary Distance, and Inter-Orbital Distance in Adults

**ABSTRACT:** Eyeball protrusion is one characteristic that must be assessed/predicted in craniofacial identification methods of skull-face superimposition and facial approximation. Previously it has been suggested that average exophthalmometry values, as measured on living individuals, should be used. However, it is unknown if proptosis prediction can be improved beyond the accuracy obtained when using mean values. Some authors have suggested that relationships between exophthalmos, height, interpupillary distance, and interorbital distance exist and it has been reported that these latter variables can be used to estimate eyeball projection. However, crucial tests are yet to be conducted. This study measures these variables and tests the accuracy of exophthalmometry means, a previously proposed prediction equation, and newly derived regression equations to determine which methods provide the best results. Data indicate that variation in exophthalmos is fairly small and as such prediction from other variables, like body height, are weak; thus, exophthalmometry means currently offer the best practical method of prediction. It should be noted that up to 2 mm error from either side of the mean is expected for 68% of cases.

**KEYWORDS:** forensic science, proptosis, exophthalmos, globe, projection, exophthalmometry, ophthalmology, craniofacial identification, facial approximation, facial reconstruction

The value of quantitative assessment of the anterior projection of the eyeball from the eye socket is widely recognized in clinical ophthalmology (1). However, these measures are also indispensable for forensic craniofacial identification techniques, such as facial approximation and superimposition, where faces must be assessed and/or predicted with respect to skulls (2,3). While it is known that normal proptosis values average about 16–18 mm from the lateral orbital rim as measured using a Luedde's or Hertel's exophthalmometer (1), it has been reported that other variables, such as interpupillary distance, are significantly related to globe projection (4). Despite these suggestions, exact relationships remain unknown, although in theory they may be useful for limiting error in estimation of eyeball protrusion.

Some authors indicate that exophthalmometry values increase with increasing age and growth in childhood and then become stable in adulthood (5). However, other authors report that proptosis values increase until the second decade and then decrease slowly thereafter (6). It has also been reported that larger proptosis values are found in taller individuals (4); although, this study included individuals who were younger than 25 years and, who therefore, had probably not completed their biological growth (7,8). In contrast to claims by Bertelsen (4), other studies report that body height is only weakly associated with height (6, 9–12), as it is for body weight (9–12).

In addition to body height, larger proptosis values have been reported with larger interpupillary distances and it has been stated that this relationship is stronger than that between eye projection and body height (4). Bertelsen (4) reasoned that a relationship exists between interpupillary distance and proptosis because of the lateral angling of the orbital axis (which generally differ by about 20° from the ocular axes (13)); so if all other conditions are assumed to remain constant a more lateral position of the eyes also leads to more anterior positioning. This seems to be supported by findings that the ratio between eye projection and inter-orbital width remains the same (approximately 0.15), while globe projection values increase with age (14). Bertelsen suggested using the formula: $y = 15 + ([\times - 61]^{*}\ 0.25)$ to estimate eyeball projection, where $y =$ distance of the cornea from the lateral orbital rim (mm), and $\times =$ interpupillary distance (mm) (4), however, tests of this method have not been reported in the literature. While interpupillary distance may be a useful variable to refine proptosis assessment in living individuals this measurement is not useful for craniofacial identification methods where methods are based on skull morphology. As a result, hard tissue variables must be used and as such the distance between the lateral orbital rims has potential value. Many exophthalmometry studies have measured orbital breadth (5,14–17); however, exact relationships with eyeball proptosis, especially regarding its estimation, have not been studied.

The goals of this study are to further evaluate the relationship between eye proptosis from the lateral orbital rim to body height, interpupillary distance, and interorbital width, and to determine if these variables have value as predictors of globe projection. Furthermore, this study aims to determine the validity of the method proposed by Bertelsen (4) to estimate eyeball protrusion and the accuracy of using average values as previously proposed by Stephan (2).

## Materials and Methods

Body height, eyeball proptosis, interpupillary distance, and interorbital distance were measured in 54 adult individuals (≥18 years) of socially perceived European extraction (29 females: mean age = 24 years, $s =$ 8 years; 25 males: mean age = 33 years,

[1] Department of Anatomical Sciences, The University of Adelaide, Australia, 5005.

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$s = 14$ years). All participants gave informed consent, and all self-reported an absence of: corneal pathology and cataract; thyroid disorder; deformity of the lateral orbital wall, including fracture; Myopia $< -6.0$ diopters; Hyperopia $> +2.0$ diopters; eye disorders/diseases impacting on eye size, e.g., buphthalmos, phthisis; orbital tumour; orbital inflammation; and high blood pressure. Body height was measured using an anthropometer (GPM, Switzerland) and standard anthropometric methods (18). All participants were orientated in the Frankfurt horizontal plane with height measured from base to vertex. Eyeball proptosis was measured on standing participants using a Bausch & Lomb, Hertel-Type, Mirror Exophthalmometer (Western Ophthalmics, USA) and left and right sides were measured on each participant. Interpupillary distance and orbital width were measured using standard anthropometric methods (19) and sliding callipers (GPM, Switzerland). Interpupillary distance was taken from the pupil centres with subjects in supine, but looking directly ahead and focusing on the ceiling approximately 1.6 m away. Interorbital width was measured between the deepest points on the lateral orbital rim at the most anterior aspect of the rim margin (determined by palpation). All measurements were rounded to the nearest millimeter—measurement accuracy for exophthalmometry using equivalent methods is well known to be about 1 mm (4,20,21). Exophthalmometry values were compared between the sides and all variables were compared between the sexes using two-tailed two sample t-tests. Pearson's product moment correlation coefficients were also used to compare exophthalmometry measurements with other variables. Pooled weighted average exophthalmometry values, using data reported in six studies of Caucasoids (5,10,15,22–24) as recommended by Stephan (2), were compared to actual values of individuals and residuals calculated. Bertelsen's equation (4) was also used to predict exophthalmometry values and these were again compared to actual values by the calculation of residuals. Regression analysis was conducted using correlated variables measured in this study and all data were analysed in the Microsoft® Excel® 2000 statistical package.

## Results

Average exophthalmometry values did not differ at statistically significant levels between the right and left sides of males and females ($p > 0.05$), nor did they differ between the sexes ($p > 0.05$), although male measurements were slightly higher (Table 1). Thus, only the left-side values were further evaluated here. Height was found to be statistically significantly larger in males compared to females ($p < 0.05$), as was interpupillary distance and interorbital width (Table 1). In both males and females, height was correlated with exophthalmometry values; however, only in females did interpupillary and interorbital distance correlate with exophthalmometry measurements (Table 2). When using pooled weighted exophthalmometry means as previously reported (i.e., mean = 16.2, $n = 1174$ (2)), the average error was close to zero (<0.5 mm) but had a standard deviation of about 2 mm in males and females (Table 3). Bertelsen's recommendations estimated exophthalmometry values fairly closely giving an error of 1.4 mm, $s = 2.0$ mm in females, and an error of 0.9 mm, $s = 2$ mm in males (Table 3). Linear regression was used to generate regression equations for predicting exophthalmometry from height in both males and females and interorbital distance in females. Multivariate regression was also used to produce prediction equations using all variables in females (Fig. 1). Standard errors of these equations (univariate ~1.8 mm, multivariate 1.6 mm) were narrowly smaller than those resulting from the use of the pooled weighted mean described by Stephan (2) (see Table 3).

TABLE 2—*Pearson's product moment correlation coefficients between exophthalmos and other variables measured in this study.*

| | Males | Females |
|---|---|---|
| Height | 0.31 | 0.54 |
| Inter-pupil. | 0.01 | 0.31 |
| Inter-orbit | −0.07 | 0.46 |

TABLE 3—*Average errors and standard deviations for exophthalmos prediction methods.*

| | Males | | Females | |
|---|---|---|---|---|
| | Mean | *s* | Mean | *s* |
| Pooled mean (16.2 mm) | −0.4 | 1.9 | 0.1 | 2.1 |
| Bertelsen equation | 0.9 | 2.0 | 1.4 | 2.0 |
| Height regress. | 0.0 | 1.8 | 0.0 | 1.8 |
| Inter-orb. regress. | ... | ... | 0.0 | 1.9 |
| Multi. regress. | ... | ... | 0.0 | 1.6 |

| Males | $r^2$ | SE |
|---|---|---|
| $y = 0.007(a) + 4.6$ | 0.10 | 1.9 |
| *Females* | | |
| $y = 0.012(a) - 3.4$ | 0.30 | 1.8 |
| $y = 0.20(b) - 2.5$ | 0.21 | 1.9 |
| $y = 0.01(a) - 0.06(b) + 0.19(c) - 14.5$ | 0.42 | 1.7 |

where: y = exophthalmos
(a) = height
(b) = interorbital distance
(c) = interpupillary distance

FIG. 1—*Regression equations.*

TABLE 1—*Data summary. While measurements were rounded to the nearest millimetre, one decimal place is arbitrarily provided below for means and all other variables.*

| | Females ($n = 29$) | | | | Males ($n = 25$) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | *s* | Min. | Max. | Mean | *s* | Min. | Max. | *t*-test |
| Height | 1645.5 | 96.6 | 1390.0 | 1830.0 | 1787.2 | 90.1 | 1580.0 | 1979.0 | 0.001 |
| L exop. | 16.1 | 2.1 | 13.0 | 21.0 | 16.6 | 1.9 | 12.0 | 20.0 | 0.374 |
| R exop. | 16.3 | 2.2 | 12.0 | 21.0 | 16.7 | 2.1 | 11.0 | 20.0 | 0.568 |
| Inter-pupil. | 59.6 | 3.4 | 53.0 | 67.0 | 63.6 | 2.9 | 57.0 | 70.0 | 0.001 |
| Inter-orbit | 92.1 | 4.8 | 84.0 | 102.0 | 96.8 | 4.5 | 83.0 | 106.0 | 0.001 |

## Discussion

This study is consistent with others (10,25), which indicate that on average there is no large difference in exophthalmos between the left and right sides. Data presented here also suggest that the relationship of proptosis with height is larger than that previously indicated by many authors (6,9–12) although correlation coefficients are not reported in these studies. Whilst Bertelsen claims a positive relationship between exophthalmos and height (providing a scatter plot but no correlation coefficients), this study suggests relationships are not so strong ($r \approx 0.4$). The relationship between interpupillary distance and eyeball proptosis was comparable to that found by Quant and Woo (11) in Chinese samples ($r = 0.4$), but was slightly less and was only observed for females ($r = 0.3$). Inter-orbital distance showed similar trends ($r = 0.5$ (11), $r = 0.4$ (this study)). In contrast to Bertelsen's findings (4), correlations of body height with exophthalmometry values were found to be higher than interpupillary distance (Table 2).

Results of this study demonstrate that while height, interpupillary distance, and interorbital distance are related with exophthalmos, particularly in females, proptosis values are consistent enough between individuals, and measurement errors large enough, that these values offer little benefit to proptosis prediction in comparison to using simple averages. Bertelsen's prediction equation using interpupillary distance performed poorly in comparison to the mean value previously proposed (2). These findings indicate that the mean exophthalmometry measurement previously proposed by Stephan (2) is sufficient for eyeball projection prediction given current measurement errors. Despite the relationship of exophthalmos to other variables such as height, correlations were not high enough to be useful in assisting with the prediction of eyeball projection. It should be noted that prediction error using a mean value of 16.2 mm in Caucasoid samples maybe as large as 2 mm in 68% of cases (see (2) and Table 3).

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Additional information and reprint requests:
Carl N. Stephan
Department of Anatomical Sciences
The University of Adelaide
Australia, 5005
Ph: +61 8 8303 3127
Fax: +61 8 8303 4398
E-mail: carl.stephan@adelaide.edu.au

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# Erratum

**Erratum/Correction** of Swan and Stephan. Estimating eyeball protrusion from body height, interpupillary distance, and inter-orbital distance in adults. J Forensic Sci 2005 July;50(4):777–784.

It has come to the attention of the Journal that the academic degree of the first author Lauren K. Swan is left out inadvertently. The following is the correct degree with author's name: Lauren K. Swan, B.Sc.

The Journal regrets this error. Note: Any and all future citations of the above-referenced paper should read: Swan and Stephan. Estimating eyeball protrusion from body height, interpupillary distance, and inter-orbital distance in adults. [Published erratum appears in J Forensic Sci 2005 Nov.;50(6)] J Forensic Sci 2005 July;50(4):777–784.