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Cross-Sectional Anthropometric Study of the External Ear

ABSTRACT: This cross-sectional anthropometric study was aimed at estimating expansion of the external ear during adult life, in order to evaluate the extent to which anatomical features appearing in earprints may vary with time. A review of the literature was provided. Data extracted from photographed ears of 1353 subjects were analyzed. The effect of age on auricle length, earlobe length, and auricle width was explored using univariate analyses of variance. The regression coefficients of age on these dimensions were, respectively, 0.178, 0.115, and 0.073 mm/yr for males, and 0.162, 0.100, and 0.073 mm/year for females ($p = 0.000$). Regression coefficients of age corrected for stature were assumed to be less accurate. Anthelix prominence and helix width were analyzed using data of 175 subjects, and appeared unaffected by age. As lobe expansion appeared to exceed the estimated cartilage expansion, it was assumed that particularly the imprint of the lobe would be less stable with time.

KEYWORDS: forensic science, auricle growth, cross-sectional study, ear length, ear width, earlobe, earprint

Earprints have shown potential as a means of person identification in forensic investigations (1–7). A latent earprint located at or near a scene of crime may be secured and compared with the earprint of a suspect, or with a collection of prints secured from other crime scenes. When using earprints by searching for matching prints in a database, the print—hence the morphology of the external ear or auricle—must be relatively stable over an acceptable period of time. While considering factors affecting the stability of the anatomical features of the ear, expansion of the auricle during adult life caught our attention.

In the past, several studies have been conducted into age-related changes of the auricle (8–15). Although focus and applied methods—and therefore to some extent results—varied among the various studies, it did appear from published research that, unlike most other parts of the body, the auricle continues to increase in size during adult life. The explanations for this phenomenon were diverse. Iannarrelli (16) believed that an increase in auricle length with age was largely due to sagging of the cartilage-free earlobe. Ito et al. (15), however, presented evidence for histological changes of the elastic cartilage with age. Their research showed a reduction with age in the number of cartilage cells per unit area, and it was hypothesized that auricle expansion could perhaps be at least partly explained by expansion of the extracellular matrix of the cartilage.

The study further showed a degradation of the network of elastic fibers that would reduce the flexibility of the cartilage. A loss of cartilage elasticity with age, which had already been assumed by Pellnitz (9) and Schwalbe (17), could perhaps result in leveling of the external ear. Geyer (18,19) referred to instability of anthelix prominence with age. Hajniš (10) proposed that the helix unrolled with age. Both processes could further contribute to the increase in auricle dimensions. Hardisty (20) mentioned yet another explanation for the increase in average auricle length with age, as found

in cross-sectional studies. He postulated that there could also be a secular trend toward smaller ears. Finally, referring to a Chinese belief, Khaw (21) suggested that long ears could also be a biological marker for longevity.

Knowledge on the pace of expansion of various parts of the auricle at different ages may provide an insight into potential changes in the position of their representations in earprints. It would contribute to our understanding of intraindividual variation in earprints within a certain time span. With this study, we aimed to first provide an overview of what is known from the literature on auricle expansion. It was noted that the older studies did not include statistical analyses to support conclusions. The more recent studies, however, did not address potential differences in the rate of expansion between the cartilaginous and cartilage-free parts of the auricle, and frequently also not between the sexes and/or between various stages of adult life. We therefore aspired to also explore the effect of age on various auricle dimensions ourselves. We were particularly interested in determining the contribution of earlobe lengthening to the increase in auricle length. We also wanted to explore potential variation in the pace of expansion during the various stages of life, and possible differences between the sexes.

Available Data on Auricle Growth

Various studies have suggested an early maturation of the external ear (13,15,22). Expansion, however, appeared to continue during adulthood, albeit at a slower pace. Heathcote (11) performed a linear regression analysis of auricle length on age, combining data on auricle length of 206 subjects of various descents, aged 30–93 years. His results implicated an annual increase in auricle length of *c.* 0.22 mm within the age interval studied. Asai et al. (12) performed a similar study. Their analysis included data on auricle length of 400 Japanese subjects aged 21–94 years. The results suggested an annual increase in auricle length of *c.* 0.13 mm. In both studies, potential differences between the sexes were not explored

Ito et al. (15) performed separate studies for the sexes. They classified 966 males and 992 females (aged 0–99 years) at 5-year intervals, and compared auricle length and width among the age

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groups by multiple comparison tests. Their results implied a steady increase in auricle length up to the latter half of the seventies in males, whereas in females increments were also significant after this age. Ito et al. did not focus on the pace of expansion, but the provided graph could suggest a higher rate of expansion for female ears after the age of *c.* 60 years as compared with male ears.

Ferrario et al. (14) also found dissimilarities between the sexes. They gathered data on auricle length of 310 Italian subjects, classified by sex into three age groups (12–15, 19–30, and 31–56 years old). A two-way factorial analysis of variance showed a significant increase in auricle length between each age group, and a significant difference in auricle length between the sexes. The significance of an interaction effect indicated a difference between the sexes in the effect of age on auricle length. The average auricle length of male subjects increased by 4.1 mm from the first to the second age group, and by another 1.9 mm from the second to the third group. For females, these values were 0.9 and 2.8 mm, respectively. Expansion therefore appeared to be off to a slower start in females as compared with males.

Hajniš (10), Pellnitz (9), and Schwalbe (17) also investigated potential differences in auricle expansion during various stages of life, and between the sexes. Their studies, however, did not include a statistical analysis. Hajniš (10) measured auricle length in 626 Czech subjects, aged 18–80 years. All but those aged 18–20 years were classified by sex into age groups at 10-year intervals. His data showed a more or less steady increase in average auricle length of male subjects up to the age group of 60–70 years, with a notably higher increase from this group to the age group of 70–80 years. For female subjects, a steep increase appeared to occur at an earlier age: between age groups of 50–60 and 60–70 years. The difference between the age groups of 18–20 and 20–30 years was further negligible in females, while in males it was not. This could support the “slower start” for female auricle growth found by Ferrario et al. (14). The total increase in auricle length during adulthood was estimated at 8–9 mm for both sexes.

Pellnitz (9) carried out a similar study in Germany. He classified 1000 subjects of ages ranging from 1 to 89 years by sex into age groups at 10-year intervals. The difference in average auricle length between subjects in their twenties and subjects in their eighties amounted to 11 mm in males and 13 mm in females. For male subjects aged 20 years and over, the average auricle length increased more or less steadily with each consecutive age group, although not between the age groups of 30–40 and 40–50. This lack of increments was also observed between females of the same age groups. The increase in average auricle length per decade for females over 50 appeared to exceed that for males. Schwalbe (17), finally, believed that differences in auricle length between the ages of 20 and 50 were not significant. He assumed that auricle expansion took place after the age of 50, and continued until the age of 70–80.

The above-mentioned authors carried out cross-sectional studies, but longitudinal studies have also been performed. Susanne (23) found that the average auricle length of 44 male Belgian subjects (average age 32 years at the start of the experiment) had increased by 4.86 mm over a period of 22 years. Gualdi-Russo (24) first classified his subjects (104 males and 58 females from Italy) into four age groups. He measured auricle dimensions twice with a 10-year interval. For males, the average growth increments varied from 1.4 mm in the youngest group (subjects in their twenties at the time of the first measurement) to 2.7 mm in the two subsequent age groups (subjects in their 30s and 40s). Increments reduced to 2.2 mm in the final age group (subjects aged 50 years

and older at the time of the first measurement). For females, these values were 1.7, 1.9, 2.6, and 1.9 mm, respectively. The rate of expansion was relatively low for the first age group, particularly in males. A difference in the rate of lengthening between the sexes appeared to be particularly high for the second age group. Gualdi-Russo compared these results with those of a cross-sectional study. As the number of subjects in the latter study was very small, individual variation would, however, have had too strong an influence on the outcome.

A study by Pellnitz (9) was one of the few that incorporated potential differences between the rate of expansion of cartilage and earlobe. Pellnitz measured both total auricle length and length of the cartilaginous part of the ear. The average length of the latter increased by 6.3 mm from male subjects in their twenties to those aged 80 years and older. For female subjects, this was 8.0 mm. Considering that the average auricle length increased by 11 and 13 mm, respectively, for both sexes *c.* 5 mm of the increase in total auricle length could have been due to lengthening of the earlobe.

To verify whether variation in the pace of earlobe lengthening could potentially underlie reported variation in auricle lengthening during various stages of life, a study by Quelprud (8) was further helpful. He provided graphs on the development of the earlobe. Judging by his graphs, earlobe length would increase steadily throughout adult life in both sexes, possibly accelerating after the age of 40. Quelprud also included a graph that allowed us to compare the extent to which the earlobe is attached to the head among the various age groups. This value decreased in subjects over the age of 50, particularly in males, which would indicate a more rapid increase of the free-hanging part of the earlobe after this age.

Auricle width was addressed in several of the above-mentioned publications. Ito et al. (15) suggested a relatively great difference in ear widening between the sexes, as their results would imply a significant increase in auricle width up to the first half of the fifties in males, but up to the first half of the eighties in females. With respect to potential differences in the pace of widening at various stage of life, the (cross-sectional) study by Quelprud (8) was further informative, as he classified his subjects into relatively small age groups at 1–5-year intervals depending on age. For males, Quelprud’s data showed a continuous increase in average ear width, albeit at a varying pace. The increase in average width was only slight between the age groups of 16–19 and 45–50 years, while it appeared to be greater between the subsequent age groups. Females showed only a minute increase in average auricle width for the age groups 16–19 to 27–30 years. After this age, the average auricle width increased at a higher rate for females than for males.

The total increase in width between the age groups 16–19 and 61 and older amounted to 2.8 mm in males and 3.2 mm in females. These results are relatively similar to those of Pellnitz (9), who concluded that during adulthood auricle width increased by 2.2 mm in males, and by 3.3 mm in females. Hajniš (10) found a greater difference between the sexes. According to his data, the total increase in auricle width during adulthood would amount to 1–1.5 mm in males and *c.* 4 mm in females. The average width increased more or less continuously between each age group in females. This was not the case in males, as width increments appeared to occur until the age of 50. This would support the results of Ito et al. (15).

When comparing male adolescents, young adults, and mid-aged adults, Ferrario et al. (14) observed a difference in the average auricle width of 1.8 mm between the first two groups, and a further 1.6 mm between the second and the third groups. For females

these values were, respectively, 0.8 and 2.5 mm. This would, again, point to a relatively slow start of expansion in females. The significance of a difference between the sexes was, however, not supported by the performed two-way factorial analysis of variance. Finally, Gualdi-Russo (24)—our only example of a longitudinal study of ear width—found no increase in width over a 10-year period in males, and only a slight increase in females, which was considered to be insignificant after applying a paired *t*-test.

In conclusion, if there were a difference between the sexes in the pace of auricle expansion, it might be that in females expansion is off to a slower start in the early adult years, but continues to an older age. Several studies further suggested that length expansion might be accelerated during a certain period in the later half of life. In both sexes, the increase in length exceeded that in width. In males, the latter may even be minimal during the second half of life.

Materials and Methods

Both ears of 919 male and 434 female Dutch (Caucasian) subjects were photographed in a standardized manner. Data were anonymized and subjects consented to use of the photos for this study. We used a digital photo camera (Nikon Coolpix 995 [Nikon, Melville, NY]; AF, imager: 3.1 mega pixel effective; lens: 38–152 mm [as 35 mm equiv.]) that was provided with an extension holding a frame in front of the lens at a fixed distance. This frame contained a measuring scale, and was placed at approximately a 90° angle to the side of the head, surrounding the auricle. Resulting tiff files (2048 × 1360 px) were imported into Adobe Photoshop software and then printed at a resolution of 600 dpi. A number of photographs were omitted from our study due to a lack of quality due to, for instance, incorrect lighting or previously unnoticed hairs concealing exact auricle dimensions. In total, 908 male left ears, 915 male right ears, 429 female right ears, and 434 female left ears remained in the study.

Making use of the depicted measuring scale in every photograph, auricle length, auricle width, and earlobe length were determined for each photographed ear. In a number of photographs, we also determined helix width at two positions. Figure 1 provides an overview of all recorded dimensions. Auricle length and width were determined using a method proposed by Mollison (25) (described in Lange (26)). The distance between the most superior point of the helix and the most inferior point of the earlobe on lines parallel to the ear base (the auricular attachment to the head) determined the length of the auricle. The width of the auricle was determined by the greatest distance between the ear base and the posterior part of the helix, on a line perpendicular to the ear base. The distance between the most inferior point of the earlobe and the deepest point of the intertragic notch determined the length of the earlobe (27). All measurements were performed by the second author.

As the loss of elasticity of cartilage with age might possibly coincide with leveling of the anthelix and/or unrolling of the helix, we also set out to explore age-related variation of these two features in a limited number of subjects aged 20 years and older. One male and one female subject from each available birth year were selected at random. These numbers were then, again randomly and when available, supplemented to up to 12 males and 12 females per 10-year interval, resulting in a selection of 175 subjects (86 males and 89 females). In photographs of their right ear, the anthelix was classified into one of three categories on the basis of estimated prominence: prominent, shallow, or neither prominent

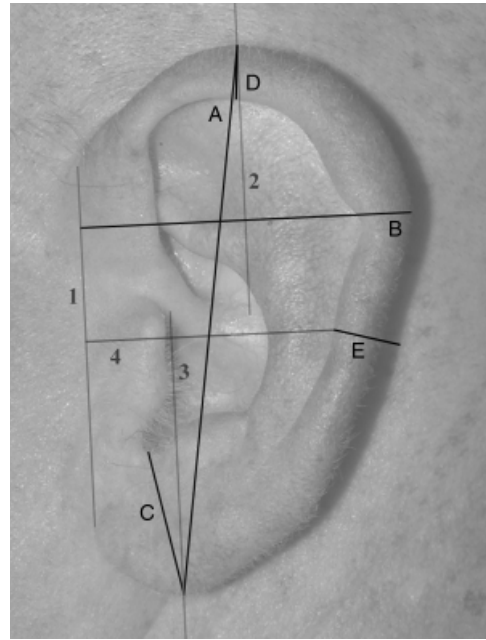


FIG. 1—Overview of auricle dimensions and auxiliary lines. A, auricle length; B, auricle width; C, earlobe length; D, superior helix width; E, posterior helix width; 1, ear base; 2 and 3, auxiliary lines parallel to ear base; 4, auxiliary line perpendicular to ear base.

nor shallow. Helix width was further measured at two positions: at the intersection of a line perpendicular to the center of the ear base, and at the most superior point of the helix.

We anticipated a possible correlation between some auricle dimensions and body height. We therefore strived to record the stature of the subjects. The majority of subjects up to the age of 50 were measured (height without shoes); older subjects were asked to provide stature during young adulthood. To explore the effect of age on auricle length and width, and on earlobe length, we applied separate univariate analyses of variance (GLM procedure) for the sexes, using SPSS software (version 11.5). Age was analyzed as a covariate, both with and without correcting for stature by adding this variable as a second covariate to the model.

In addition, subjects were classified into age groups at 10-year intervals. As there were only a few subjects under the age of 20 years or over the age of 90 years, at both extremes two age groups were combined to form groups of, respectively, 18–29 years of age, and 80 years and over. In order to detect possible differences in the pace of expansion of the various auricle dimensions during various stages in life—as suggested by, among others, Hajniš (10) and Ferrario et al. (14)—separate univariate analyses of variance (GLM procedure) were again performed for both sexes, this time including the variable “age group” as a fixed factor. To explore the significance of observed differences between the sexes, all data were further combined and the analyses repeated, exploring the effect of age group and sex, as well as interaction between these two variables.

Data on helix dimensions were also analyzed using univariate analyses of variance (GLM procedure). Age was analyzed as a covariate. To explore the association between prominence of the anthelix and age, the Spearman rank correlation coefficient was calculated, which is a measure for the association between ordinal variables. In all mentioned analyses, *p*-values smaller than 0.05 were considered to be significant.

TABLE 1—Descriptive statistics for auricle length, earlobe length, and auricle width.

Sex	Dimension	Mean (mm)	Standard Deviation (mm)	Range (mm)
Male (n = 1823)	Auricle length	71	5.5	50–89
	Earlobe length	20	3.3	10–34
	Auricle width	35	3.3	25–47
Female (n = 863)	Auricle length	64	5.4	47–82
	Earlobe length	19	3.3	11–30
	Auricle width	33	2.9	24–44

Results

Table 1 provides, for males and females separately, the mean, standard deviation, and range of overall auricle length, auricle width, and earlobe length. All three dimensions appear to be generally smaller in females. Figures 2a–f provide, for both sexes, scatter-plots of the data on each of the three dimensions in relation to age. Table 2 provides the results of the analyses exploring the effect of age on the three auricle dimensions for both sexes. The effect of age was tested both with and without correcting for stature. Age and stature showed a positive correlation to auricle size. For males, the effect of both variables on each of the tested dimensions was significant; for females, the effect of stature on earlobe length was not. As the regression coefficient of stature on

each auricle dimension was irrelevant to the research question, it was not included in Table 2. The regression coefficient of age on auricle width appeared to be similar for the two sexes; for auricle and earlobe length, it was greater for males than for females. Because the dimensions of a person’s left and right ear are correlated, the significance of the regression was also tested for the left and right ears separately. For all combinations of auricle dimension and measured ear (i.e., left or right), the *p*-values for the effect of age remained 0.000.

To explore possible variation in the pace of expansion during adult life, the data were also classified by age group. Table 3 provides the estimated effect and *p*-value of fixed variable “age group” on each of the three analyzed dimensions. Differences between the estimated effect of each dummy variable (representing an age group) on an auricle dimension reflect potential differences in the pace of expansion during the various stages of life. The increase in auricle length between two subsequent age groups appeared to be the greatest between the first and second age group, which would imply a faster pace of lengthening during young adulthood than at old age. This was particularly obvious for males. The difference in the effect of the last two dummy variables (i.e., between age groups 70–79 and 80+) was further relatively low for males, while the difference between those representing age groups 60–69 and 70–79 was relatively high.

The estimated effect of age group on earlobe length appeared to be relatively similar for the two sexes. For males, increments seemed to be decreasing with age, and there was no indication of

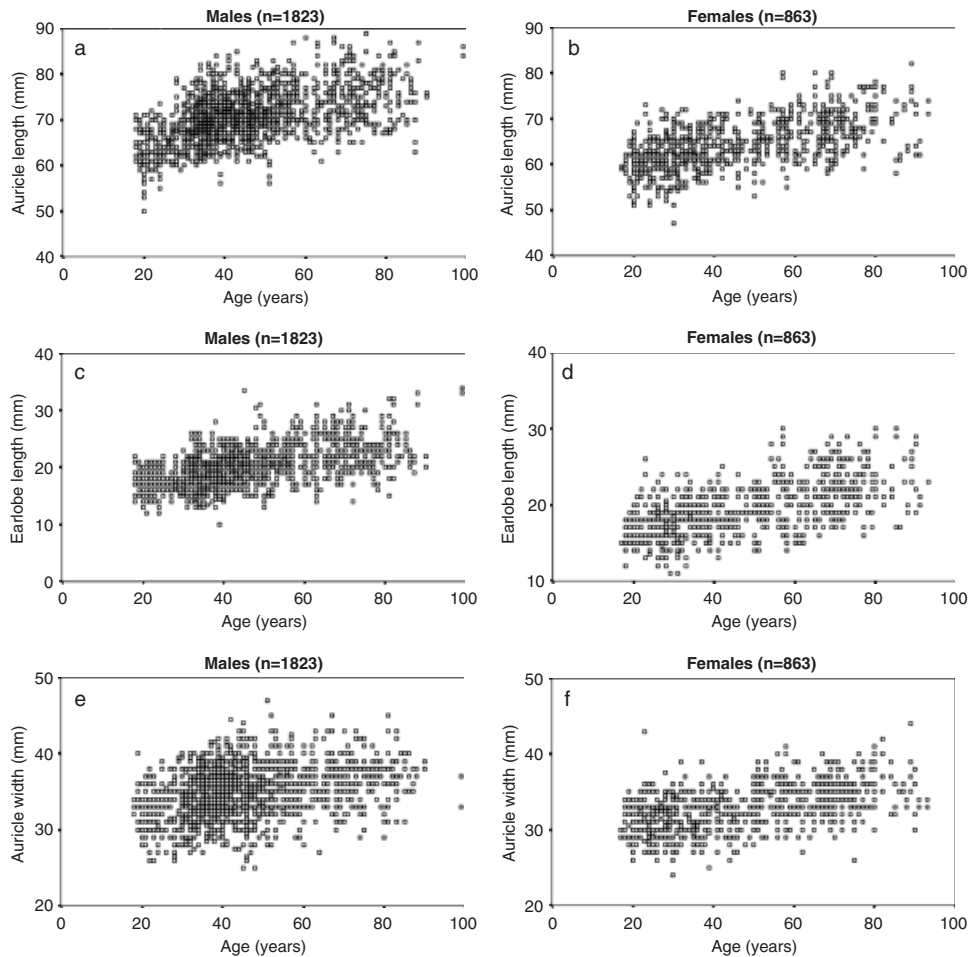


FIG. 2—(a–f)—Data on auricle length (a, males; b, females), earlobe length (c, males; d, females), and auricle width (e, males; f, females) scattered against age.

TABLE 2—Regression coefficient β_{age} (estimated increase in mm/year), *p*-value, and 95% confidence interval for the effect of covariate “age” on the various auricle dimensions.

Covariate “Age”		Without Correcting for “Stature”			Corrected for “Stature”		
Tested Model		Dimension = Intercept + β_{age} age + Error			Dimension = Intercept + β_{age} age + $\beta_{stature}$ stature* + Error		
Sex	Dimension	β_{age}	<i>p</i> -Value	95% Confidence Interval	β_{age}	<i>p</i> -Value	95% Confidence Interval
Male	Auricle length	0.178	0.000	0.164–0.191	0.201	0.000	0.184–0.218
	Earlobe length	0.115	0.000	0.107–0.123	0.120	0.000	0.110–0.130
	Auricle width	0.073	0.000	0.064–0.082	0.081	0.000	0.070–0.093
Female	Auricle length	0.162	0.000	0.147–0.176	0.175	0.000	0.154–0.196
	Earlobe length	0.100	0.000	0.091–0.109	†	†	†
	Auricle width	0.073	0.000	0.065–0.082	0.077	0.000	0.066–0.089

*Values for $\beta_{stature}$ are omitted from this table as they are irrelevant to the research question.

†The effect of “age” on female earlobe length corrected for “stature” was omitted from this table as the effect of “stature” on female earlobe length appeared not to be significant when the right and left ears were analyzed separately.

TABLE 3—*p*-value and estimated effect of dummy variables representing age groups on three auricle dimensions.

Fixed Variable “Age Group”		Estimated Effect in mm							
Sex	Dimension	<i>p</i> -Value	18–29	30–39	40–49	50–59	60–69	70–79	80–99
Male	Auricle length	0.000	0*	5.1	6.6	8.1	8.7	10.7	11.4
	Earlobe length	0.000	0*	1.5	2.8	4.0	5.1	5.9	6.7
	Auricle width	0.000	0*	1.6	2.2	2.9	3.6	4.0	4.1
Female	Auricle length	0.000	0*	2.4	3.8	5.6	6.9	8.3	9.8
	Earlobe length	0.000	0*	0.7	1.6	3.4	3.8	5.0	5.8
	Auricle width	0.000	0*	0.1	0.5	2.5	2.8	3.3	4.5

*This parameter is set to zero because it is redundant.

an acceleration in the rate of lengthening after a certain age. For females, development appeared more irregular. The estimates for earlobe length often represented a large part of the estimate for overall length. This would imply a larger role of lobe stretching than of cartilage expansion in auricle development. The effect of age group on auricle width, finally, appeared to differ between males and females. Increments between the first three age groups were much higher in males than in females; between the last two age groups, they were relatively small. To determine the significance of observed differences between the sexes, interaction effects of sex and age group on the various auricle dimensions were explored and appeared to be significant for auricle length and auricle width (*p*-values < 0.05), but not for earlobe length. This was also the case when analyses were performed for data on the left and right ears separately.

As a next step, we explored the association between anthelix prominence and age in a smaller group of 175 subjects. The association between the two variables was expressed by the Spearman rank correlation coefficient. For males, this coefficient was 0.034 (*p*-value 0.758) and for females, it was 0.393 (*p*-value 0.000). In addition, the regression coefficient of age on both helix

dimensions was compared with that on auricle length and width for this limited group of subjects. Table 4 provides the results of these analyses. It appeared that the effect of age on auricle length and width was still very significant for this smaller group of subjects. The effect of age on both helix width dimensions was, however, not.

Discussion

Figures 2a and b show that the number of subjects with relatively long ears increases with age. The average auricle length did not simply increase with age due to a decrease in the number of individuals with relatively short ears. The idea of auricle length being a biological marker for longevity was thereby rejected. Of course, longitudinal studies such as those by Susanne (23) and Gualdi-Russo (24) had already shown that we could not attribute the increase in average auricle length with age found in cross-sectional studies to a statistical misinterpretation of other biological processes, such as a higher survival rate for subjects with longer ears, or a secular trend toward smaller ears.

We investigated whether auricle expansion could be due to leveling of the anthelix and/or unrolling of the helix, but we noticed no significant association between anthelix prominence and age for males. For females, a Spearman rank correlation coefficient of 0.393 indicated a weak positive correlation between the two variables. The anthelix being more prominent in older females would, however, contradict the assumption of leveling of the anthelix with age. The effect of age on both helix width dimensions was not significant, and auricle expansion could, therefore, not be attributed to unrolling of the helix either.

We provided estimates for the annual increase of auricle length, auricle width, and earlobe length, both with and without correcting for stature. This was done as stature and auricle size were positively correlated, and stature could act as a confounder in our

TABLE 4—Regression coefficient β_{age} and *p*-value for the effect of covariate “age” on auricle length, auricle width, superior helix width, and posterior helix width for 86 male and 89 female subjects.

Covariate “Age”	Males		Females	
	β_{age}	<i>p</i> -Value	β_{age}	<i>p</i> -Value
Auricle length	0.184	0.000	0.138	0.000
Auricle width	0.071	0.000	0.076	0.000
Superior helix width	0.003	0.748	0.003	0.663
Posterior helix width	0.013	0.146	0.007	0.198

Values greater than 0.05 are considered insignificant.

analysis as younger subjects were generally taller than older subjects. We, however, do not believe that incorporating the variable stature into the model would provide a better estimate of the effect of age. From Maat (28), we knew that the average stature of the Dutch population had significantly increased over the last 130 years. From Meadows and Jantz (29), we further learned that this positive secular trend was mostly due to an increase in the length of the legs. According to Dr. J. P. Vandenbroucke (Leiden University Medical Center, personal communication), the overall tendency appeared to be that changes toward greater adult height have been accompanied by proportionally longer legs, shorter trunks, and slightly shorter arms. We therefore hesitate to assume a similar positive secular trend for auricle size. Although the manner of determining auricle length was not uniform in all published studies, a comparison between the average auricle length as provided in various older studies and our recent data did not indicate that we should assume a positive (nor negative) secular trend for auricle length. Consequently, we think that omitting the variable stature from the model would provide us with a better estimate of actual annual auricle growth, as we assume that the effect of age will be overestimated when corrected for stature.

We estimated an annual increase in auricle length of *c.* 0.18 mm for males and 0.16 mm for females. Similar analyses by Heathcote (11) and Asai et al. (12) resulted in estimates of 0.22 and 0.13 mm, respectively. As in the studies mentioned, males and females were mixed and analyzed without correcting for sex; it may, in theory, be possible that the regression coefficient was affected by potential skewness of sex distribution. A sample containing a relatively great number of older males, and/or a relatively great number of younger females could, for instance, yield a higher regression coefficient for age. The difference between Heathcote's estimate of annual increase and ours was particularly great when realizing that his study did not include subjects under the age of 30, while our data showed relatively high increments between (particularly male) subjects younger than 30 and those aged 30–39. When comparing his results with those of longitudinal studies (23,24), there was, however, no indication of the estimate being unrealistic.

We could be tempted to explain the relatively low estimate of 0.13 mm in the Japanese study (12) by theorizing that expansion is relative to overall auricle size. We found a significant association between auricle length and stature. As the average stature of the Japanese population is lower than that of the Dutch population, auricle dimensions could generally be smaller in the first population as well. The ranges in auricle length of 50–87 mm in the Japanese sample, and 50–89 mm in our sample, however, did not indicate a great difference in auricle length between the two populations. Asai et al. provided a 95% confidence interval for the regression coefficient of 0.07–0.18; in our study, these were 0.164–0.191 (males) and 0.147–0.176 (females). As the values show an overlap, we do not assume a difference in growth rate between populations on the basis of the data provided.

From Table 3, it can be seen that we estimated a difference in ear length of 11.4 mm between males aged 18–29 and those aged 80–99. When comparing this value with results in the older literature, it appeared that it was very similar to the difference of 11 mm between age groups 20–30 and 80–90 as recorded by Pellnitz (9). Hajniš' (10) estimate of lengthening during adult life was a few millimeters less. This difference could not be attributed to the lack of subjects over the age of 80 in the latter study, as our study recorded only small increments between males aged 70–79 and those aged 80–99.

Increments in length appeared to be particularly great between age groups 18–29 and 30–39. Although smaller in females than in males, they were higher than between any other consecutive age groups in both sexes. We could not corroborate this finding with results of studies in the literature. Hajniš (10) suggested a pronounced acceleration in the pace of auricle lengthening at a later age, the differences in average auricle length of subjects in their sixties and those in their seventies being 4 mm. Our data would only support a potential, yet less pronounced, acceleration at this age in males. It was often suggested that acceleration in particularly male auricle lengthening at old age was mostly due to lengthening of the earlobe (16,30). We, however, found no evidence for acceleration in the pace of male earlobe lengthening after a certain age.

We did notice differences in the pace of auricle lengthening and widening between the sexes. We had initially assumed that such differences could have been due to a correlation between auricle length and lengthening. Females generally having smaller ears and earlobes than males could then explain the lower regression coefficients. The analysis of data by age group, however, indicated differences in the relative pace of expansion at various ages (Table 3). We found significant differences in the pace of both auricle lengthening and widening between the sexes, but not in the pace of earlobe lengthening. Auricle lengthening and widening appeared to be off to a slower start in females as compared with males. This was also suggested by Hajniš (10) and Ferrario et al. (14). There was no indication of female auricle lengthening slowing down after 70, while in males increments between age groups 70–79 and 80–99 appeared only minute. We would quickly dismiss the latter difference as a statistical artifact, particularly because increments between age groups 60–69 and 70–79 were relatively high. However, our results did appear to support those of Ito et al. (15).

A difference between the sexes in the relative pace of expansion during the various stages of life was more apparent for auricle widening than for auricle lengthening. We had anticipated that, as a result of our method of photographing the external ear, absolute auricle width would be somewhat underestimated, as this measurement was taken from a two-dimensional photograph, while the auricle is situated at an angle to the head. As we know from several authors (8,14,19) that this angle decreases during adulthood, we further anticipated that the increase in auricle width with age could be overestimated. Geyer (19) reckoned that in both sexes, the auricle starts to move to a position more closely set to the head already during puberty. According to Quelprud (8), however, this is only the case in females. He believed that in males this process takes place after the age of 40. If Quelprud were right, we would have more likely overestimated width expansion during early adulthood in females than in males. From our results, however, widening appeared to be occurring relatively early in life for males as compared with females. The noted difference between the sexes could, therefore, not be attributed to a presumed variation in auricle position.

We chose to measure the length of the earlobe using a method proposed by Martin (27), which provided two landmarks that could be easily marked in a photographed ear. Using the inferior point of the intertragic notch as one of those landmarks meant that a small part of measured length contained cartilage. The role of earlobe stretching in overall lengthening could therefore in theory be slightly overrated in our study. However, although overall auricle length and earlobe length were not measured on parallel lines and consequently increase in overall length minus increase in earlobe length would not exactly equal an increase in the

cartilaginous part, it did appear that the effect of stretching of the lobe on overall auricle length was greater than that of expansion of the cartilaginous part. Particularly for females, this effect could have been accelerated by heavy jewellery.

Conclusions

Estimated length and width increments of the auricle during the various stages of life differed significantly between the sexes. The difference appeared particularly obvious for width expansion. Earlobe expansion did not differ significantly between the sexes, nor did we find evidence for acceleration of lengthening at old age. Lengthening of the earlobe appeared to make up the greater portion of total lengthening. The estimated cartilage expansion (i.e., auricle expansion minus lobe expansion) appeared to be the greatest during early adulthood.

As lobe stretching appeared to exceed expansion of the cartilaginous part, we assume that—in the context of our earprint research—particularly the imprint of the lobe will be less stable with time. This region in the earprint, however, already appeared to be less preferable for metrical classification. Neubert (31) (cited from Hammer and Neubert (32)) compared auricle dimensions with dimensions of imprinted features in earprints that were created with weak and strong pressure. He found dimensions of the imprinted earlobe to deviate the most from actual auricle dimensions. Dr. S. Sholl (University of Glasgow, personal communication) also compared intraindividual variation of different regions of earprints subjected to pressure distortion. She also noted that the lobe region was one of the least stable regions of the earprint.

Predicted increments of cartilaginous parts appeared to be relatively small, particularly when considering that the time span we are dealing with in forensic practice is not “a lifetime.” During early adulthood, increments appeared to be relatively high, particularly in males. This was not in concordance with the literature, which would make further research interesting. If the results from our cross-sectional study provide an accurate reflection of auricle expansion, updating prints when possible may be particularly recommended for relatively young offenders. This would optimize the chance of matching recent prints to older prints of the same ear in a database. Of course, all would depend on how exact data on certain dimensions of the print need to be processed in order to find an acceptable number of possible matches, i.e., a relatively low number of false negatives and false positives (or, in practice, nonmatches in a high position on a ranking list). A system for automated matching is a tool for the investigator to locate matching prints in a database. Potential individualization will require examination by an experienced investigator, who will need to consider the variability particularly of the earlobe when comparing prints that were deposited many years apart.

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