fied primarily for other purposes to see if the data support Levy and Levy’s conclusion.

Our sample consisted of 146 undergraduate, 56 percent of whom were male. Handedness was categorized into two classes, right and left, on the basis of writing hand. The classification of handedness is controversial, but McManus (2) has shown that a person’s handedness is best assessed by means of the hand used for writing, provided that no forced change of writing hand had occurred. We therefore excluded five persons who experienced such a history from the analysis. The distribution of handedness by sex did not differ between our study and that of Levy and Levy.

Foot length was measured by standard anthropometric technique (3). All measurements were taken by one of us (A.M.M.) without prior knowledge of the subjects’ handedness.

For the total sample, length of the left foot (L) exceeded that of the right foot (R) measured by both absolute length [L = 257.76 mm ± 1.48, R = 256.99 mm ± 1.42; paired t (280) = 2.62, P < .01] and standardized length of 100(L - R)/(L + R) (4) (mean, 0.140 ± 0.057; t = 2.46, P < .02). This finding shows that L > R is in agreement with previously published results of either paired comparisons of foot length of adults and fetuses (5–8) or measures of osteological asymmetries (9–11), but is in the opposite direction to Levy and Levy’s findings for males (12).

Analysis of variance of 100(L - R)/(L + R) by handedness and sex showed no evidence of a main effect due to handedness [F(1, 137) = 0.112, P = .738]. In agreement with the work of Garn et al. (13), there was no sex-handedness interaction [F(1, 137) = 1.174, P = .280]. The main effect of sex was significant [F(1, 137) = 3.934, P = .049]; previous studies have found a similar trend (6, 7).

The mean foot-length differences for each study by sex and handedness are shown in Table 1. Because of measurement differences between studies, it is difficult to compare our results with Levy and Levy’s directly. However, sign differences indicate that our results are in the opposite direction.

Our failure to replicate Levy and Levy’s findings of a sex-handedness interaction could be due to many factors, but at least sample sizes and distributions of right- and non-right-handed were similar in the two studies. The major difference was one of methodology. Our results were obtained from a

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Table 1. Mean foot-length asymmetry (L - R) by sex and handedness. The number of subjects in each cell is shown in parentheses.

<table>
<thead>
<tr>
<th>Sex</th>
<th>Right-handed</th>
<th>Non-right-handed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cambridge</td>
<td>Levy</td>
<td>Cambridge</td>
</tr>
<tr>
<td>Male</td>
<td>+0.26</td>
<td>+0.20</td>
</tr>
<tr>
<td>(62)</td>
<td>(17)</td>
<td>(12)</td>
</tr>
<tr>
<td>Female</td>
<td>-0.02</td>
<td>+0.29</td>
</tr>
<tr>
<td>(56)</td>
<td>(87)</td>
<td>(11)</td>
</tr>
</tbody>
</table>

recognized anthropometric and quantitative approach, whereas Levy and Levy used a rating method and a less quantitative analysis.

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References and Notes
4. The values of 100(L - R)/(L + R) and L + R were uncorrelated, males, r = .12, P = .28; females, r = .066, P = .61.
5. J. R. Manning, SATRA Research Report 143 (1953). [SATRA is the Shoe and Allied Trades Research Association.]
12. Reconstructing the data of Levy and Levy: males’ mean L - R = -0.67 units; females = +0.64 units. Cambridge study: males = +0.24 mm; females = +0.01 mm.
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Levy and Levy (1) reported foot-length asymmetries that related significantly to sex and handedness. We have collected contradictory data.

We measured the lengths of the right and left feet of 365 undergraduate university students; all were volunteers. Handedness was assessed by recording which hand was preferred for writing, throwing, hammering a nail, drawing, and brushing the teeth. [These are items categorized by Bryden (2) under factor 1, common activities.] Subjects who performed all these activities with the right hand were classified as right-handers, while subjects who did not were classified as non-right-handers. Foot preferences were assessed by recording which foot was preferred for kicking a ball.

Levy and Levy used foot sizes to measure foot length; we recorded the exact length. For measurement, each subject was required to sit and plant each foot firmly on a sheet of paper. A mark was made where a vertical stop, against which the heel rested, touched the paper. Another mark was made where a vertical stop, against which the most protruding part of the anterior end of the foot rested, touched the paper.

Lines were drawn through these marks at right angles to the length of the foot, and the distance between these lines was measured to the nearest millimeter (Table 1). The differences between the feet were often close to or within the error of measurement (+1.5 mm). There were no significant differences between the left and the right foot for any sex or handedness group.

There remains the possibility that the measure used in this study was inadequate. However, anthropometric data support our results (compare values with those in Table 1). A study of right-foot length of 565 adult Canadian males (3) gives an average length of 26.46 cm. Another study of the left-foot length of 2000 English adult males (4) gives an average of 26.49 cm. Finally, a study of right-foot length in 137 adult Canadian females (5) gives an average of 23.77 cm.

Unfortunately, none of these studies provide values for both the right and left

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Table 1. Average length of left (L) and right (R) feet and direction of asymmetry.

<table>
<thead>
<tr>
<th>Handedness</th>
<th>N</th>
<th>Foot length (cm)</th>
<th>Direction of asymmetry</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L</td>
<td>R</td>
<td>L &gt; R</td>
</tr>
<tr>
<td>Females</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right-handed</td>
<td>208</td>
<td>24.08</td>
<td>24.06</td>
</tr>
<tr>
<td>Non-right-handed</td>
<td>27</td>
<td>23.82</td>
<td>23.89</td>
</tr>
<tr>
<td>Males</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right-handed</td>
<td>114</td>
<td>26.47</td>
<td>26.51</td>
</tr>
<tr>
<td>Non-right-handed</td>
<td>16</td>
<td>26.39</td>
<td>26.36</td>
</tr>
</tbody>
</table>

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feet. Nevertheless, it is clear that the values reported in these anthropometric studies correspond closely to our values. This leads us to question a systematic relation between left- and right-foot differences, sex, and handedness.

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References

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Levy and Levy (1) reported that sex and handedness are related to pedal asymmetry, "right-handed males having larger right feet and right-handed females having larger left feet. . . ." The reverse was seen in those who were not right-handed. This finding, if true, would confound traditional neurological tests of trophic limb changes, especially in the contralateral lower extremities, which are known to be altered after infantile brain insult (2).

There are, however, some methodological concerns regarding the rating scale, selection of statistical tests, sample composition, and measurement procedures (3) which cause us to question the validity of their findings. A replication study was performed to correct for these errors.

A sample of 105 individuals, 58 males (24 right-handed and 34 left-handed) and 47 females (25 right-handed and 22 left-handed) were selected. The age range was 17 to 47 (mean age, 19.56 years). A second sample of 20 subjects (9 male, 11 female) was selected to assess day-to-day variability of the measures. The measurements of the subjects' feet were obtained by tracing the outline of each foot onto a large data-coding sheet. Information regarding age, sex, hand preference, and family history of sinistrality was collected. The raw data were analyzed with the chi-square statistic. The data were then transformed to replicate the Levy and Levy seven-point scale and were analyzed with the Kruskal-Wallis statistic. No differences were found in the direction of foot-size differences (asymmetry) of either males or females, dextrals or sinistrals, with or without a family history of sinistrality, for either foot length or width. In fact, the directional frequency of pedal asymmetry across subjects was notably absent (that is, no laterality effect). Contrary to the Levy and Levy findings, when a pedal asymmetry did occur, the number of individuals with longer left feet was virtually equivalent to the number with longer right feet, regardless of sex or hand preference. Moreover, the measurement of foot width revealed an equal distribution of pedal asymmetries (4).

Before discounting the Levy and Levy findings, the issue of measurement error was addressed. To explore between-subject variability, the observed means and standard deviations of foot length and width were compared with, and found to closely parallel, those previously reported when the Brannock Foot Measuring Device was used (5). Thus, there was little reason to suspect that tracing was any less accurate a method of assessing foot size. Statistical checks were made for within-subject variability of the measures, through the use of a pooled variance of repeated measures; day-to-day variability was also assessed with a repeated-measures analysis of variance design. No differences were observed with respect to foot length. A slight day-to-day variability was noted in the repeated-measures analysis of right-foot width (6). Widths increased over days. This result may merely reflect a statistical artifact or may suggest that foot width is more susceptible to environmental factors (temperature, type of shoe worn, and so forth). The average difference in foot length (7) closely paralleled that found in the Levy and Levy study (8). These findings reduce the likelihood that the lack of significant findings was a result of measurement error. Tracing thus seems to be a reliable and valid method of assessing foot size. Using it, we were unable to replicate any of the Levy and Levy results regarding the direction of pedal asymmetries within an adult sample.

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References and Notes
3. Levy and Levy devised a rating scale based largely on subjective measurements. They then used a t-test to analyze half their data, selecting this test over chi-square because of an insufficient number of non-right-handed subjects. Herein they violated two major statistical assumptions. Parametric tests require adequate sample size and interval data, both of which were absent in their data for sinistrals. Their sample was composed of both children and adults, without separate tests for age by sex effects. This procedure left ambiguous whether the sex differences in pedal asymmetries were an artifact of age, especially in view of their incidental report of larger asymmetries in children.
4. For males, 28 had wider left feet, 23 had wider right feet, and 12 showed no difference. For females, 19 had wider right feet, 18 had wider left feet, and 10 showed no difference.
6. F(3) = 3.16, P < .05.
7. The average difference was 3.5 mm ± 0.35 for males and ± 0.24 for females.
8. Levy and Levy reported that the average difference in foot size was typically less than half a shoe size. This is equivalent to approximately 5 mm.

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In contrast to our findings (1) that right-handed females had larger left feet and right-handed males, larger right feet, with the reverse obtaining for non-right-handed individuals, Mascie-Taylor et al., using standard anthropometric techniques, found that all groups except right-handed females had larger left feet. As they note, their data went in the opposite direction from ours and conform with a number of reports that the left foot is larger than the right. Peters et al., measuring foot length from heel to the end of the longest toe with subjects seated and the foot placed flat, found no asymmetries of foot length for any group, disconfirming our observations as well as those of Mascie-Taylor et al. Although the distributions were nonsignificant, they found a preponderance of right-handed males with larger right feet and more non-right-handed males with larger left feet, the data for right-handers tending in the same direction as ours and in the opposite direction from that of Mascie-Taylor et al. Finally, Yanowitz et al. assessed foot size by tracing around the foot and compared asymmetries between groups for both length and width. No asymmetries appeared for any group, confirming Peters et al.

The different measurement techniques may have yielded assessments of different aspects of foot size. We measured the distance from the heel to the end of the big toe, rather than to the end of the longest toe. Of possibly more significance, in the Mascie-Taylor et al. measurements, no pressure was put on the foot, and it can be assumed that static
Foot-Length Asymmetry, Sex, and Handedness
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