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BOŽENA ŠKVAŘILOVÁ

ASYMMETRY OF THE UPPER EXTREMITY IN CONTEMPORARY CZECH CHILDREN

ABSTRACT: Asymmetries in the body shape are, within a certain range, a physiological phenomenon that reflects genetic and exogenous influences during the development of the individual. The purpose of the present study was to investigate the development of asymmetries in the upper extremity in relation to age and sex, to differentiate fluctuating and directional asymmetry and to define the borderlines of physiological and non-physiological asymmetries in different traits.

Asymmetries of the upper extremities were analyzed in 1,002 children from Prague, Czech Republic, aged 6–18 years. The length of the upper extremity, upper arm, forearm and hand, circumference of the arm, forearm and wrist and width of the epiphysis of the humerus, wrist and hand were assessed. Left-handed subjects were excluded from the study.

The results revealed that the degree of asymmetries of the upper extremity is equal in both sexes and does not change substantially with age (absolute asymmetry increases in direct relation to the growth of the trait). With regard to the size of the traits, the asymmetries of the upper extremity are markedly smaller than previously evaluated facial asymmetries (Škvařilová 1993); this applies in particular to length parameters. This may be the result of phylogenetic selection directed against asymmetry of the locomotor system.

Asymmetries of the upper extremity are of the directional rather than fluctuating type, in particular in adult men, in whom there is an obvious developmental trend from fluctuating to directional asymmetries. These findings concerning the dominance of the right hand are associated with the effect of function and functional laterality. There is also an indication of a certain lateral compensation between the length of the upper arm and the lower segments of the extremity. The doubled value of standard deviations of signed asymmetry was used to define the range of physiological asymmetry as 4 mm for length and circumferential (except the wrist) parameters of the upper extremity, 3 mm for the circumference of the wrist and 2 mm for the width variables of the extremity. The suggested range does not depend on age and sex, but in directional asymmetries it is important to make a correction in favour of the dominating side (as a rule by 0.5–1 mm). The definition of the range of physiological and non-physiological asymmetry may be of practical importance in a number of medical disciplines.

KEY WORDS: Upper extremity – Fluctuating and directional asymmetry – Absolute and relative asymmetry – Range of physiological asymmetry

INTRODUCTION

Morphological asymmetry can be defined as a deviation from complete symmetry of the organism and its different parts in relation to the median plane of the body. These asymmetries are to a certain extent regular phenomena (Peck *et al.* 1991). They are the outcome of genetic and exogenous factors and can change with age. When the differences are more marked, they are a so-called pathological asymmetry (Burian 1939).

Asymmetries reflect developmental processes of the organism and the extent of its homogeneity; they are linked with the degree of heterozygosity and also with the manifestation of inborn defects. A number of investigations have shown that subjects with different inborn defects and deviations who are also to a greater extent homozygous, display a greater morphological variability, including asymmetries (Woolf, Gianas 1977, Barden 1980, Malina, Buschang 1984). Considering these findings, it was shown that the increasing heterozygosity of the organism is associated with a smaller phenotypic variability (Livshits, Kobyliansky 1991). More heterozygous subjects are therefore, in different characteristics (anthropometric, biochemical, dermatoglyphic etc.), closer to the average, while more homozygous subjects differ from the average. This relationship pertains also to asymmetries (Livshits, Kobyliansky 1987). In a general way it holds that heterozygous subjects have a more favourable developmental homeostasis that ensures them protection against external influences. This can be explained by the capacity of the more polymorphous HLA system of heterozygotes to react with a greater number of foreign antigens (Hughes, Nei 1988). More homozygous subjects who have increased variability and asymmetries, are therefore more sensitive to various developmental factors. Increased asymmetries of morphological traits are thus a clear measure of the organism's developmental instability and can also serve as an early predictor of the organism's likelihood of developing disorders during subsequent ontogeny (Livshits, Kobyliansky 1987, 1991).

Increased asymmetries can be an indicator of not only developmental disorders but also of adverse influences of the external environment or the poorer health status of the individual. They were found in quantitative dermatoglyphic characteristics and the size of teeth in children with facial clefts and their healthy relatives in the case of a positive family history (Woolf, Gianas 1977, Sofaer 1979), in the size of teeth in subjects suffering from Down's syndrome (Barden 1980, Shapiro 1983), in anthropometric signs of mentally retarded subjects (Malina, Buschang 1984), in dermatoglyphic signs of schizophrenic and psychotic subjects (Markow, Wandler 1986), in dental parameters in subjects with fragile X chromosome (Peretz *et al.* 1988) and also in morphometric signs in premature born children (Livshits *et al.* 1988) and older subjects (Kobyliansky, Livshits 1989). The effect of environmental stress such as excessive noise, cold, heat and malnutrition on increased asymmetries was demonstrated experimentally in laboratory animals (Sciulli *et al.* 1979), but such an effect can also be manifested in man (Doyle, Johnston 1977, Kieser *et al.* 1986). Also, inbreeding in small populations enhances asymmetry (Kieser *et al.* 1986), markedly more so than stress (Comuzzi, Crawford 1990). Similar findings were reported in inbred animals (Leamy 1986).

An increased asymmetry in the shaping of the organism is not necessarily manifested in the mean of a group, as differences in favour of one or the other side are more or less mutually compensated. In this type of evaluation, during which we determine whether the right or left side is larger (by the sign plus or minus), the scatter of asymmetric values increases and thus also the appropriate standard deviation. Asymmetry can also be evaluated regardless of the sign as absolute values of right-left differences where the increased asymmetry is always apparent in the mean values. This type of asymmetry is called absolute asymmetry, in contrast to the previous type of evaluation which is described as signed asymmetry in which we differentiate between fluctuating and directional asymmetry. In fluctuating asymmetry the predominance of the right or left side in the individual subject is incidental and in the group as a whole it is negligible. The mean values of both sides correspond with each other (they do not differ significantly). Conversely, in directional asymmetry one side predominates significantly over the other in the group.

It is also useful to express the size of asymmetry as the percentage of the size of the given parameter, and such an asymmetry is described as relative asymmetry. It allows to compare the magnitude of absolute or directional asymmetry in parameters of different size. In fluctuating asymmetries the percentage expression loses its value as the asymmetry in the group does not differ significantly from zero and its value can therefore be considered random.

A problem also remains as to how asymmetries commonly found in the population (physiological asymmetries) develop. Livshits and Kobyliansky (1989, 1991) provided evidence for a considerable influence of genetic factors in the development of fluctuating asymmetries of anthropometric signs. The additive and dominant genetic components contributed almost one third (0.3) each, and the remaining 0.4 was accounted for by external environmental factors. The mechanisms of action of the genetic component are, however, obscure, and explanations are at the level of hypotheses and speculations. The accumulation of adverse alleles may be involved or a slower development of homozygotes that make the organism more sensitive to adverse factors during ontogenesis (Livshits, Kobyliansky 1989). A correlation of the size of asymmetries with the degree of heterozygosity and inbreeding suggest that this is so. The competition of both sides for material produced by proliferation in the early period of embryonic development is also assumed to play a role, as well as the different sensitivity of these gene products to external influences (Livshits, Kobyliansky 1989). No doubt some part is also played by morphogenetic processes that take a different course at different sites, cell differentiation, tissue interactions and induction and other developmental processes that diversify to an increasing extent under the influence of surrounding impulses.

The etiogenesis in directional asymmetries is different. In their genesis a greater role is played by non-genetic influences, in particular functions under the influence of laterality. Such asymmetries become apparent only gradually during the postnatal period as a rule, and they increase the original fluctuating asymmetry (the absolute asymmetry increases). Genetic fixation of this state during

phylogenesis (as a result of function) can explain congenital differences in the size of paired organs in some animals (e.g. some crabs). Directional asymmetries can also change into fluctuating ones under the influence of the already mentioned stresses and other factors which are not focused on one side only. Usually the absolute asymmetry of the organism increases. It is thus obvious that both types of asymmetry may change into one another under the influence of certain external factors. They are part of one continuum and have a certain developmental plasticity. Absolute asymmetry is only another mode of their expression and is therefore determined by the same causal factors.

Investigations of the asymmetries of an organism are important not only to recognize evolutionary principles of ontogenesis and disorders stemming from internal and external causes, but also on purely practical grounds. This sphere comprises e.g. the possibility to define the limits of physiological and non-physiological asymmetry for the needs of some medical disciplines. The identification of directional asymmetries is also important. While in Europe the body measurements are usually taken on the left side, in the USA they are taken on the right side. Therefore, only parameters can be compared where lateral differences have the character of fluctuating asymmetries. Certain interpretations are also possible from the aspect of phylogenetic development. The objective of the present study was therefore to evaluate in relation to age and sex the magnitude of asymmetries in the dimensions of the upper extremity, to try to differentiate fluctuating and directional asymmetries and to define the borderlines of physiological and non-physiological asymmetry in different traits. The study is based on the analysis of data assembled during our previous research (Škvařilová 1975a,b).

MATERIAL AND METHODS

For the investigation of asymmetries of the upper extremity, a group of 1,072 healthy children from Prague schools aged 6–18 years were used. A more detailed description of the group is given in papers dealing with the growth of the extremity (Škvařilová 1975a,b). For evaluation of asymmetries 70 left-handed children were eliminated (6.5% of the group, assessed by questions addressed to the pupil or teacher); the remaining 1,002 children were divided into five age groups comprising 81–120 subjects (see *Table 4*). There are three-year groups (6–9, 9–12 and 15–18); two at the age of puberty comprise one and a half years (12–13.5 and 13.5–15 years). This unequal classification into age groups is due to the original composition of the series in which the growth during puberty was not investigated in one-year but half-year intervals. The creation of one age group from 12–15 years would double the number of probands as compared with the other groups and increase substantially the probability of statistically significant results. The classification used ensures comparable numbers in all groups; their age range is not important as the right and left side are compared individually, using the paired t-test. According to anthropometric principles (Martin, Saller 1957), the length of the upper extremity (a-da), the upper arm (a-r), forearm (r-sty) and hand (insty-da) was measured, as well as the circumference of the arm, forearm and wrist, and the width of the epiphysis of the humerus, wrist and hand.

From the data collected from every subject, the differences between the right and left side were calculated and, with regard to the dominant side (signed asymmetry), their mean values ($\bar{d}$) and standard deviations ($s\bar{d}$). To test whether these differences (asymmetries) differed significantly from zero, the paired t-test was used. With regard to the large number of t-tests the author chose as the critical level for differentiating fluctuating and directional asymmetry the level $p<0.01$. The results are summarized in *Tables 1* and *2*. From standard deviations in different age groups the means were calculated ($Xs\bar{d}$, *Table 3*) and used to define the borderline of physiological and non-physiological asymmetry (as double the value from the mean of asymmetry i.e. $\bar{d} + 2Xs\bar{d}$). In addition to these procedures, also the values of absolute asymmetry were calculated and, with regard to the numbers of subjects in each age category, the means for the whole series (*Table 4*). These characteristics are not supplemented by calculations of standard deviations as the values of absolute lateral differences do not have a normal distribution. For the comparison of asymmetry in parameters of different size, the values of absolute asymmetry were expressed as the percentage of the size of the trait (mean of both sides), and from the simple sum of data in different age groups means for the whole series were calculated (*Table 5*).

RESULTS

Asymmetries in the dimensions of the upper extremity undergo a certain development with age, which differs in different groups of traits (*Table 1*). Asymmetry in the length of the upper extremity (a-da) has, in the majority of age groups, a directional character with dominance of the right side. With advancing age this dominance becomes more pronounced but does not exceed much 1 mm. The same helds also true for the length of the upper arm (a-r). On the other hand, the length of the forearm (r-sty) and hand (insty-da) are characterized, with the exception of the oldest age group of boys, by a fluctuating type of asymmetry. In the oldest age group of boys the left side dominates significantly in both traits, and also in the majority of non-significant asymmetries in the other groups the left side is larger. A similar phenomenon is not found in any of the other investigated traits and may indicate a certain compensation for the greater length of the right upper arm.

Intersexual differences of asymmetry in the length parameters of the extremity are not expressed. As regards

TABLE 1. Mean values ($\bar{d}$) and standard deviations ($s\bar{d}$) of signed asymmetry in dimensions of the upper extremity.

Variable	age	$\bar{d}$	$s\bar{d}$ boys	t	$\bar{d}$	$s\bar{d}$ girls	t
a – da	6–9	0.25	1.98	1.34	0.70	1.96	3.44***
	9–12	–0.05	2.10	0.21	0.61	2.12	3.14**
	12–13.5	1.02	1.93	4.93***	1.03	1.79	5.64***
	13.5–15	0.82	2.00	3.58***	1.04	1.92	5.42***
	15–18	1.36	2.27	6.45***	1.18	2.12	5.43***
a – r	6–9	0.33	1.68	2.09*	0.74	1.62	4.40***
	9–12	0.21	1.83	1.03	0.47	1.74	2.95 **
	12–13.5	0.49	1.94	2.36*	0.48	1.92	2.45*
	13.5–15	0.64	1.85	3.02**	1.00	1.87	5.35***
	15–18	1.56	1.91	8.80***	1.24	2.16	5.60 ***
r – sty	6–9	–0.05	1.88	0.28	–0.09	1.94	0.45
	9–12	–0.09	1.57	0.51	–0.25	1.75	1.56
	12–13.5	0.20	1.75	1.07	0.35	1.87	1.83
	13.5–15	0.17	1.90	0.78	0.09	1.85	0.49
	15–18	–0.85	2.18	4.20***	–0.21	2.09	0.98
insty – da	6–9	0.44	1.77	2.64*	0.40	1.68	2.30*
	9–12	–0.21	1.45	1.29	0.01	1.53	0.07
	12–13.5	–0.30	1.63	1.72	–0.15	1.60	0.92
	13.5–15	–0.23	1.77	1.13	–0.06	1.59	0.38
	15–18	–0.63	2.04	3.33**	–0.46	1.97	2.28*
arm circumference	6–9	0.54	1.88	3.05**	0.41	1.98	2.00*
	9–12	0.44	1.52	2.59*	0.50	1.53	3.57***
	12–13.5	0.27	1.72	1.46	0.11	1.61	0.67
	13.5–15	0.67	2.11	2.77**	0.23	1.81	1.27
	15–18	0.75	2.21	3.65***	0.21	2.00	1.02
forearm circumference	6–9	0.23	2.06	1.19	0.15	1.84	0.79
	9–12	0.20	1.67	1.07	0.12	1.54	0.85
	12–13.5	0.50	1.62	2.88**	0.28	1.60	1.72
	13.5–15	0.81	1.81	3.90***	0.34	1.86	1.83
	15–18	1.06	2.24	5.10***	0.55	1.88	2.85**
wrist circumference	6–9	–0.04	1.43	0.30	0.28	1.66	1.63
	9–12	0.17	1.32	1.15	0.30	1.26	2.60*
	12–13.5	0.70	1.54	4.24***	0.20	1.41	1.39
	13.5–15	0.49	1.50	3.15**	–0.14	1.56	0.90
	15–18	0.67	1.69	4.27***	0.33	1.78	2.06*
humerus epiphysis width	6–9	–0.01	0.89	0.12	0.04	0.90	0.43
	9–12	0.06	0.84	0.64	0.22	0.85	2.82**
	12–13.5	0.40	1.03	3.62***	0.37	1.06	3.42***
	13.5–15	0.12	1.13	1.02	0.07	0.95	0.74
	15–18	0.26	1.14	2.46*	0.06	1.11	0.60
wrist width	6–9	0.03	0.83	0.38	0.03	0.77	0.38
	9–12	–0.02	0.81	0.22	0.00	0.83	0.00
	12–13.5	0.25	0.98	2.38*	0.00	0.87	0.00
	13.5–15	0.45	0.95	4.57***	0.11	0.91	1.21
	15–18	0.60	1.09	5.93***	0.50	1.04	5.35***
hand width	6–9	0.31	0.96	3.43***	0.44	0.96	4.42***
	9–12	0.40	0.94	3.80***	0.58	0.96	6.59***
	12–13.5	0.45	1.16	3.62***	0.56	1.11	4.94***
	13.5–15	0.87	0.85	9.87***	0.45	1.02	4.41***
	15–18	0.98	1.08	9.77***	0.67	1.07	6.97***

* significant asymmetry at $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

TABLE 2. Occurrence of directional asymmetry in dimensions of the upper extremity in individual groups.

Variable	age	6–9	9–12	12–13.5	13.5–15	15–18
a–da	M			x	x	x
	F	x	x	x	x	x
a–r	M				x	x
	F	x	x		x	x
r–sty	M					–x
	F					
insty–da	M					–x
	F					
arm circumference	M	x			x	x
	F		x			
forearm circumference	M			x	x	x
	F					x
wrist circumference	M			x	x	x
	F					
humerus epiphysis width	M			x		
	F		x	x		
wrist width	M				x	x
	F					x
hand width	M	x	x	x	x	x
	F	x	x	x	x	x
total of sign. values		5	6	8	10	14
out of them	M	2	1	5	7	9
	F	3	5	3	3	5

x = significantly larger right side (at $p < 0.01$)
–x = significantly larger left side (at $p < 0.01$)

TABLE 3. Standard deviation of signed asymmetry in individual age groups and their mean values (Xsd).

Variable	age	6–9	9–12	12–13.5	13.5–15	15–18	$X s\bar{d}$
a–da	M	1.98	2.10	1.93	2.00	2.27	2.06
	F	1.96	2.12	1.79	1.92	2.12	1.98
a–r	M	1.68	1.83	1.94	1.85	1.91	1.84
	F	1.62	1.74	1.92	1.87	2.16	1.86
r–sty	M	1.88	1.57	1.75	1.90	2.18	1.86
	F	1.94	1.75	1.87	1.85	2.09	1.90
insty–da	M	1.77	1.45	1.63	1.77	2.04	1.73
	F	1.68	1.53	1.60	1.59	1.97	1.67
arm circumference	M	1.88	1.52	1.72	2.11	2.21	1.89
	F	1.98	1.53	1.61	1.81	2.00	1.79
forearm circumference	M	2.06	1.67	1.62	1.81	2.24	1.88
	F	1.84	1.54	1.60	1.86	1.88	1.74
wrist circumference	M	1.43	1.32	1.54	1.50	1.69	1.50
	F	1.66	1.26	1.41	1.56	1.78	1.53
humerus epiphysis width	M	0.89	0.84	1.03	1.13	1.14	1.01
	F	0.90	0.85	1.06	0.95	1.11	0.97
wrist width	M	0.83	0.81	0.98	0.95	1.09	0.93
	F	0.77	0.83	0.87	0.91	1.04	0.88
hand width	M	0.96	0.94	1.16	0.85	1.08	1.00
	F	0.96	0.96	1.11	1.02	1.07	1.02

TABLE 4. Mean values of absolute asymmetry (absolute right–left differences) in individual age groups and the mean value for the whole series (X).

Variable	age	6–9	9–12	12–13.5	13.5–15	15–18	X
a–da	M	1.64*	1.93	1.95	1.90	2.44**	1.98
	F	1.74*	1.96	1.84	1.99	2.18**	1.94
a–r	M	1.39*	1.64	1.76	1.64	2.17**	1.73
	F	1.40*	1.52	1.64	1.85	2.22**	1.72
r–sty	M	1.49	1.27*	1.50	1.68	2.10**	1.64
	F	1.55	1.50*	1.63	1.59	1.85**	1.62
insty–da	M	1.40	1.25*	1.43	1.47	1.86**	1.50
	F	1.30*	1.31	1.41	1.33	1.71**	1.41
arm	M	1.43	1.28*	1.43	1.80	2.00**	1.61
circumference	F	1.54	1.28*	1.33	1.48	1.69**	1.45
forearm	M	1.49	1.28*	1.34	1.51	2.12**	1.58
circumference	F	1.40	1.23*	1.31	1.43	1.55**	1.38
wrist	M	1.11	1.04*	1.36	1.13	1.49**	1.24
circumference	F	1.17	0.95*	1.14	1.17	1.46**	1.17
humerus	M	0.66*	0.68	0.81	0.88	0.91**	0.79
epiphysis width	F	0.70	0.68*	0.85	0.80	0.90**	0.78
wrist	M	0.61*	0.62	0.77	0.79	0.97**	0.76
width	F	0.52*	0.67	0.68	0.76	0.82**	0.69
hand	M	0.73*	0.77	0.95	1.00	1.26**	0.95
width	F	0.69*	0.90	0.99	0.84	1.02**	0.89
n	M	114	81	88	94	117	494
	F	94	120	97	101	96	508

* the lowest values, ** the highest values in individual age groups

TABLE 5. Mean values of absolute asymmetry in terms of percent of the size of characteristics of the upper extremity and their mean values for the whole series (X).

Variable	age	6–9	9–12	12–13.5	13.5–15	15–18	X
a–da	M	0.30	0.31	0.29	0.26*	0.32**	0.30
	F	0.26*	0.33**	0.27	0.28	0.30	0.29
a–r	M	0.61	0.64	0.63	0.54*	0.67**	0.62
	F	0.62	0.60	0.57*	0.63	0.74**	0.63
r–sty	M	0.86**	0.64*	0.68	0.69	0.86**	0.75
	F	0.92**	0.79	0.73	0.69*	0.80	0.73
insty–da	M	0.95**	0.77	0.81	0.75*	0.93	0.84
	F	0.91	0.82	0.79	0.72*	0.93**	0.83
arm	M	0.75**	0.61*	0.63	0.73	0.75**	0.69
circumference	F	0.80**	0.59	0.56*	0.59	0.67	0.64
forearm	M	0.79	0.62	0.61*	0.62	0.83**	0.69
circumference	F	0.75**	0.60	0.59*	0.62	0.67	0.65
wrist	M	0.83	0.71	0.88**	0.68*	0.88**	0.80
circumference	F	0.89	0.66*	0.75	0.75	0.94**	0.80
humerus	M	1.25	1.15*	1.24	1.26**	1.24	1.23
epiphysis width	F	1.35	1.21*	1.37	1.27	1.42**	1.32
wrist	M	1.40	1.29*	1.49	1.41	1.69**	1.46
width	F	1.23*	1.45	1.36	1.48	1.59**	1.42
hand	M	1.15	1.11*	1.26	1.22	1.50**	1.25
width	F	1.11*	1.34	1.32	1.12	1.35**	1.25

* the lowest values, ** the highest values in individual age groups

the circumference of the arm, forearm and wrist in girls during the entire period and in boys up to puberty, the fluctuating type of asymmetry predominates – however, in older boys directional asymmetry with dominance of the right side is present. The width variables of the extremity differ from each other with the character of the asymmetry. Throughout the follow up period in both sexes, the width of the hand has a directional type of asymmetry with dominance of the right side. As to the width of the wrist, there is an indication of development from fluctuating asymmetry to directional asymmetry with predominance of the right side. This predominance appears in boys sooner than in girls. As regards the width of the epiphysis of the humerus, the findings are not consistent and suggest

fluctuating asymmetry. The values of signed asymmetry are small; in individual dimensions differences of 0.3–0.6 mm are already significant.

The table of the occurrence of directional asymmetry in relation to age and sex (*Table 2*) confirms the increasing ratio of this type of asymmetry with advancing age. It is evident, however, only in boys, where the number of significant findings in different age groups increases gradually. In the oldest age group in boys, all dimensions, with the exception of the width of the epiphysis of the humerus, display directional asymmetry. A similar trend is not found in girls, and in the last group, besides the above mentioned width of the epiphysis of the humerus, directional asymmetry is also missing in the circumference of the arm and wrist or the length of the hand and forearm. The width of the hand in both sexes and the length of the upper extremity and upper arm in girls are characterized by directional asymmetry throughout the investigation period.

The standard deviations of signed asymmetry in different age groups and their means resp. (*Table 3*) are about 2 mm for the length of the whole extremity, upper arm and forearm, about 1.75 mm for the length of the hand and the circumference of the arm and forearm, about 1.5 mm for circumference of the wrist and about 1 mm for width of the hand, wrist and epiphysis of the humerus. With a certain rounding off we can thus define the range of physiological asymmetry as 4 mm for the length of the upper extremity, the length of its three segments and the circumference of the arm and forearm, 3 mm for the circumference of the wrist, and 2 mm for the width measurements of the extremity. Small differences in the size of standard deviations between age groups and between the two sexes confirm the feasibility of this range regardless of sex and age.

The values of absolute asymmetry (*Table 4*) are on average only slightly smaller than the standard deviations of signed asymmetry; in the last age group, in some traits they are already greater. This is associated with the directional type of asymmetry. Absolute asymmetries increase with age; the highest values were always recorded in the oldest age group, the lowest ones in the youngest two groups. Relative asymmetry, however, does not change with age (*Table 5*); only in the width of the hand and wrist a small increase was recorded. Absolute asymmetry thus increases in relation to the growth of the feature. Intersexual differences of absolute and relative asymmetry are minimal.

Absolute asymmetries diminish as the size of the feature diminishes, from 2 mm in the length of the upper extremity to 0.7 mm in the width of the wrist. Relative asymmetries have a reverse trend; they are greatest in small features. The smallest relative asymmetry was recorded in the length of the whole upper extremity where it is only 0.3%. The length of the upper arm, forearm and hand as well as the circumference of the arm, forearm and wrist have twice as great an asymmetry (0.6–0.8%). The greatest relative asymmetry was recorded in the width of the hand, wrist and epiphysis of the humerus (1.2–1.4%).

DISCUSSION

Our findings are consistent with the presumed effect of function on the parameters of the upper extremity. Asymmetries are more likely to be of the directional type with a predominance of the right side. In boys the dominance of the right side becomes more marked with advancing age, in particular as far as the circumference of the extremities and the width of the wrist are concerned, i.e. in traits which are most readily influenced by function. In girls where the functional load is smaller this trend is not apparent, but directional asymmetry is observed throughout the investigation period in the width of the hand and the length of the upper extremity and its upper part. Boys also have in all age categories a significantly broader right hand, and the asymmetry as regards the length of the upper extremity and upper arm increases gradually. In both sexes the lengths of the forearm and hand display a fluctuating type of asymmetry with a certain compensating relationship to the length of the upper arm. Consistent with expectations, a predominantly fluctuating type of asymmetry in the width of the epiphysis of the humerus was found. The effect of the functional workload is confirmed by increased asymmetries recorded in students of physical education and sports (Siniarska, Sarna 1980).

The results are consistent with some previous, though not numerous, studies on asymmetries of the extremities that provide evidence of a significant lateral difference in the upper extremity but not the lower extremity (Laubach, McConville 1967, Malina, Buschang 1984, Schell *et al.* 1985). All of the above authors recorded a larger arm circumference on the right side and the latter authors also found a greater width of the epiphysis of the humerus. The latter finding is, however, unique. None of the authors found difference between the right and left side of the calf circumference or width of the femoral condyle. Similarly Siniarska and Sarna (1980) recorded in 71% of the subjects a greater arm and forearm circumference and in 63% of the probands a longer upper extremity on the right side. They mention also a greater width, length and circumference of the right arm and a greater width of the right wrist. Sovák (1962) mentions a longer upper right extremity in 75% of the subjects and conversely a longer left lower extremity in 52%. Jurowska (1972) found greater absolute asymmetries in the lengths of different segments of the upper and lower extremity than in the total length of the extremity and speculates on the mutual compensation of lengths of individual segments, which is consistent with our own findings. The author mentions also that there are greater asymmetries in females, which is at variance with the conclusions of Schell *et al.* (1985), who report greater asymmetries in males. In our group of children the magnitude of absolute asymmetries did not differ between the sexes.

The question arises whether in left-handed subjects a dominance in size in favour of the left side can be found. Previous research does not suggest this, although the main problem, and probably also the cause of the negative findings still remains the small numbers in the groups (Garn *et al.* 1976, Schell *et al.* 1985). A larger group was, however, investigated by Plato *et al.* (1980), who did not find any significant asymmetries in six dimensions of the second metacarpal bone in 36 left-handed subjects; but in 19 ambidextrous ones they recorded in three traits a dominance in size in favour of the right side, and in right-handed subjects all traits were larger on the right side (four significantly). Kimura and Konishi (1981) also mention that asymmetries in left-handed subjects are small. This fact indicates that function is not the only source of directional asymmetry. It is also quite evident that e.g. directional asymmetry cannot be explained by function in dermatoglyphic traits, which are again more expressed in right-handed subjects than in left-handed ones (Kobyliansky, Micle 1986). Apparently genetic factors may also play a part as well as developmental factors and others, which are difficult to identify. A problem under discussion remains the origin of crossed asymmetry of the extremities in which the dimensions of the left lower etremity are larger in right-handed subjects (Siniarska, Sarna 1980). This phenomenon is explained by a greater workload on the contralateral lower extremity (Náhoda 1972). Earlier findings confirm unequivocally that the laterality in the anthropometry of the extremities must be respected not only in comparative studies but also when defining the borderlines of physiological and non-physiological asymmetry.

Our previous studies on facial asymmetries (Škvařilová 1993) revealed that the absolute asymmetries of facial dimensions were identical with the asymmetries of much greater length dimensions of the upper extremity and were definitely larger than those of the comparable characteristics of widths of the extremity. The relative asymmetries varied around 2% of the size of the trait in lateral facial dimensions and between 0.3 and 1.4% in dimensions of the upper extremity. In view of the size of the measurements the asymmetries of the upper extremity are thus obviously smaller than facial asymmetries. This fact is particularly striking in the length parameters of the extremity. We assume that this is the result of selection which puts at a disadvantage every individual with a marked asymmetry of the locomotor apparatus. This selective pressure acted during the long period of phylogenesis in animals and man and led finally, under the influence of function, to a considerable symmetry in the extremities as regards shape and size. Despite the directional type, the asymmetries of the upper extremity are small, while larger facial asymmetries have a fluctuating character.

The range of physiological asymmetry calculated as the double value of the standard deviation of signed asymmetry is about 4 mm for the main length and circumferential measurements (except the wrist) of the upper extremity. For the circumference of the wrist it is 3 mm, and for the width parameters of the extremity it is 2 mm. The suggested range does not depend on age or sex as confirmed by minimal intersexual and age differences. In directional asymmetries it is necessary to make a correction in favour of the dominating side by the mean value of the signed asymmetry. If the right side is larger, a greater difference in favour of this side is acceptable and vice versa. In dimensions of the upper extremity the correction is of 0.5–1 mm, in exceptional instances as much as 1.5 mm.

We are aware that the suggested range of physiological asymmetry is conventional, and it may be a matter for discussion what multiple of the standard deviation should be used. The suggested range puts 5% of the population into the abnormal range. It can be deduced that when there are 100 independent traits, only some 6 subjects out of 1,000 would be within the defined range of normality for each trait (Vácha 1980). With regard to the large number of examined characteristics, every subject will thus be abnormal in some trait. This is why Vácha (1980) suggests that a wider interval should be used and the range of normality should be three standard deviations. Such a range, in which the values we suggested would be increased by one half, is in our mind generally a pathological range. In our concept, we define by the double value of the standard deviation the area of physiological asymmetry; if the deviations are greater, we speak of non-physiological asymmetries. We do not venture, however, to define the term pathological in asymmetries, and in our mind the term pathological asymmetry is vague and inadequate in biology.

Despite the mentioned problems, the calculation of the range of physiological asymmetry is not a useless variable and may be of practical importance in some medical disciplines. Some inborn defects are associated with asymmetries, sometimes specific ones. Their precise definition helps in the diagnosis of and differentiation from acquired asymmetries (hemifacial microsomia vs. Romberg's syndrome vs. post-traumatic asymmetry). Sometimes they may be the only manifestation of anomaly (e.g. in branchiogenic defects), and identification of typical asymmetries among relatives of the affected subjects implies detection of the microform of the defect and can influence the genetic prognosis in a fundamental way (Šmahel 1974). Preoperative and postoperative evaluation of asymmetries is important in plastic and maxillofacial surgery since it allows the comparison with the norm of physiological asymmetries to evaluate the results of treatment or plan the extent or method of surgical operations. For example Figalová and Farkaš (1968) tried to elaborate an anthropometric method of localizing the auricle in the case of aplasia associated with facial asymmetry. Asymmetries of the jaws and their evaluation are also a matter of interest in orthodontic and jaw-orthopaedic therapy (Malypetrová 1965, Malypetrová, Živný 1968). The findings can also be used in prosthetics in the construction of prostheses and epitheses, which should not differ in size from the contralateral side more than the range of physiological asymmetry. Strádalová (1979) was concerned with this problem and elaborated standards. In orthopaedics the objective definition of the range of physiological asymmetry is of particular importance in dimensions of the upper and lower extremities for diagnostic work and indication of treatment. Asymmetries of the lower extremities can influence locomotion in an adverse way as well as the shape of the spine and posture. A difference of 2 cm leads to limping (Janovec 1984) and is already an indication for surgical correction (Náhoda 1972). Asymmetries restrict the function of the organism and are therefore a matter of interest also for other medical disciplines (sports medicine, occupational medicine, rehabilitation etc.).

Despite the practical and general importance of the problem of asymmetries in the shaping and functioning of the human body, so far adequate attention has not been paid to this sphere of research. Some questions remain without answers and new questions arise. Further investigations are therefore desirable.

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Božena Škvařilová
Department of Anthropology
Charles University
Viničná 7
128 44 Prague 2, Czech Republic