Factors Affecting Hand Tremor and Postural Sway in Children

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Abstract

Objectives: It is crucial to consider covariates relevant for outcome variables in developing dose-effect relations of environmental hazardous toxins. The aim of this study was to clarify the covariates affecting hand tremor and postural sway in children.

Methods: Hand tremor and postural sway, as well as hair mercury concentrations, were measured in 155 boys and 148 girls at age 7 years.

Results: Current mercury concentrations in child hair ranged from 0.35 to 6.32 µg/g (geometric mean, 1.71 µg/g for boys and 1.58 µg/g for girls), and were not significantly correlated with the neuromotor parameters. All hand tremor and postural sway parameters, except for tremor intensity at 1–6 Hz with non-dominant hand, were significantly larger in the boys than in the girls. Using multiple regression analysis, some postural sway parameters were related negatively to age in the boys and girls ($p < 0.05$), and positively to height ($p < 0.05$). Similarly, hand tremor parameters were positively related to age, height and heart rate either in the boys or in the girls ($p < 0.05$). Also, there were positive relationships between tremor intensity at 1–6 Hz and transversal and sagittal sways at 1–2 Hz and 2–4 Hz ($p < 0.05$).

Conclusions: Heart rate and postural sway, together with age, sex, and height, should be considered in interpreting hand tremor in children. Hand tremor or postural sway may not be so sensitive or specific to methylmercury exposures at levels of less than 7 µg/g in hair.

Key words: hand tremor, postural sway, covariates, methylmercury, child

Introduction

The assessment of neuromotor functions, e.g., postural sway and hand tremor, in children at the developmental stage seems to be troublesome, because various anthropometric factors such as height and body weight interfere with interpretation of the data (1), and children and infants are not little adults and are uniquely vulnerable to environmental factors (2). In addition, few neuromotor tests have been designed to be sensitive enough for the early detection of subtle deficits in involuntary movements (3). For this reason, significant findings have been reported only on the effects of postnatal exposures to hazardous substances such as lead (4, 5), but not on the effects

of prenatal exposures to methylmercury (6), which may have been attributable to the difference between neurotoxic substances. As covariates/confounders involved in neuromotor measures for children, age, height, body weight, head circumference, use of alcohol and marijuana during pregnancy, duration of breastfeeding, socioeconomic status, mother's education, and etc. were considered in previous studies (4, 5, 7–9). Most of them have not been associated with neuromotor functions, or the significance of associations with neuromotor functions has not been described. On the other hand, recent research applying the above neuromotor tests to adults reported that postural sway and heart rate affected hand tremor to some degree (10, 11). For the establishment of neuromotor measures in children, therefore, it is crucial to explore such factors affecting postural sway and hand tremor.

In 7-year-old Japanese children, a cross-sectional study on the neurodevelopmental effects of mercury exposure was conducted (12). In the study, the methylmercury exposure level at parturition was estimated to be between 0.11 and 6.86 (median 1.63) µg/g in hair, but any parameters of postural sway

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or hand tremor were not associated with the exposure; at the same time, we could not explain sex difference in the neuromotor parameters. In this case, what sex difference in such parameters resulted from remains unclear. To answer these questions, we tried to scrutinize covariates or confounders affecting the neuromotor function.

Materials and Methods

Subjects

The nature of the procedures used in this study was explained to the parents of the first graders of 28 elementary schools in Akita and Tottori Prefectures, Japan, 14 of which are located near a fishing harbor (12). Children who were born from April 2nd, 1995 to April 1st, 1997 were invited to participate in this study in July–September, 2002 and 2003. In Japan, there were many mines and smelters 30 years ago, and it is probable that soil or water was contaminated by lead, copper or cadmium; therefore, the study population did not include those who came from such areas. Of 327 participating subjects, 24 children were excluded because two children obviously suffered from some neurological disorder (spinal progressive muscular atrophy and epilepsy), one child had a congenital malformation (cleft palate), 20 children had low birth weights (less than 2500 g), and one boy could not perform only the neuromotor test. Thus, 155 boys and 148 girls were enrolled in this study. The study protocol was approved by the ethical review committee at the Akita University School of Medicine.

Methods

Hair samples were collected from the occipital area in all children, by cutting strands of hair close to the scalp. The hair lengths ranged from 1 to 30 (mean 10) cm. Total mercury in aliquots of dried hair samples (15 to 20 mg), rinsed with acetone, was determined by cold vapor atomic absorption spectrophotometry at the National Institute for Minamata Disease (13, 14). A detailed survey of medical records during pregnancy and delivery, including smoking and drinking habits, gestation period, birth weight, and past and present history of illness in the child was conducted, by one medical doctor, at the elementary schools or civic centers where neurodevelopmental examinations were carried out. Also, the medical data were checked by referring to the maternal and child health handbook that mothers had kept for their children.

One trained examiner examined postural sway and hand tremor (11, 12, 15) using the Neurobehavioral Test System (CATSYS 2000, Danish Product Development Ltd., Denmark). Postural sway was measured on a flat floor. The subject was instructed to stand quietly on a platform for 66 s under eyes-open and eyes-closed conditions; Main parameters measured under both conditions were: sway area (mm²: area traveled by the center of force), transversal sway (mm: mean deviation in the medio-lateral direction, Dx) and sagittal sway (mm: mean deviation in the anterior-posterior direction, Dy). The spectral analysis of Dx and Dy was conducted with the fast Fourier transform (FFT) analysis (16) to identify the specific sway; and, square roots (mm) of the power calculated from the power spectrum within the frequency bands of 0–1 Hz, 1–2 Hz, and 2–

4 Hz served as measures of the amount of postural sway for each frequency range. Hand tremor was measured successively for each hand for 16.4 s: the subject was instructed to hold a light stylus as he/she would hold an ordinary pen, with their elbows bent at a right angle and free of body contact or any obstacles. The stylus was held horizontally, parallel to the abdomen at about 10 cm in front of the navel, and the index finger was positioned about 1 cm from the tip of the stylus. The frequency analysis of tremor intensity was conducted with the FFT analysis, and the power spectrum (m/s²) within the frequency bands of 1–6 Hz, 6–10 Hz, and 10–14 Hz, were calculated. Heart rate was measured using the ECG-Amplifier 1271SP (NEC-Sanei Co., Japan) connected to an analog-to-digital converter (sampling time, 1 ms) and a computer, after the subject lay quietly supine for five min (12).

Statistical analysis

The significance of differences in characteristics between boys and girls was analyzed by the Student (or Welch) *t* test, Mann-Whitney *U* test or Fisher exact probability. Also, sex differences in neuromotor parameters were tested by the analysis of covariance to adjust for age, height, body weight, heart rate, gestation period, birth weight, mother's smoking and drinking habits during pregnancy, past history of otitis media, and mercury concentration in child's hair. Mother's smoking and drinking habits during pregnancy and past history of otitis media were scored as "absence"=0 and "presence"=1. Multiple regression analysis was employed to evaluate the relations of age, height, body weight, heart rate, and possible covariates to neuromotor parameters in boys and girls, separately. The partial correlation coefficient, as well as the Pearson product-moment correlation coefficient (*r*), was calculated to determine the relationships between the sway and tremor parameters after controlling for age, height, and heart rate. All analyses, with two-sided *p* values, were performed using the Statistical Package for the Biosciences (17).

Results

Characteristics of the 155 boys and 148 girls are shown in Table 1. Age, height or body weight did not differ significantly between both sexes. There were significant relationships

Table 1 Characteristics (mean±SD) of Japanese children and their mothers

	155 boys	148 girls	<i>p</i> values
Age (years)	6.9±0.3	6.9±0.3	0.3068
Height (cm)	119.6±5.2	119.8±4.7	0.6777
Body weight (kg)	23.7±4.3	23.6±3.3	0.8488
Heart rate (beats/min)	81.2±9.6	83.6±10.8	0.0409
Body weight at birth (g)	3326±385	3160±344	0.0410
Gestation period (weeks)	39.1±1.3	39.3±1.2	0.4103
Past history of illness in child			
Otitis media	38.7%	38.5%	1.0000 [†]
Smoking during pregnancy*	9.7%	4.7%	0.1219 [†]
Drinking during pregnancy*	16.1%	9.5%	0.0890 [†]

* Mother's habits during pregnancy.

[†] Fisher exact probability.

between age and height in the boys ($r=0.389$, $p<0.0001$) and in the girls ($r=0.346$, $p<0.0001$), and significant relationships between height and body weight in the boys ($r=0.677$, $p<0.0001$) and in the girls ($r=0.624$, $p<0.0001$). The mercury in hair ranged from 0.35 to 5.83 (geometric mean 1.71) $\mu\text{g/g}$ in the boys and from 0.55 to 6.32 (geometric mean 1.58) $\mu\text{g/g}$ in the girls, and the hair mercury did not differ between both sexes ($p>0.05$). The log-transformed mercury in hair was not significantly correlated with any neuromotor parameters (i.e., postural sway and hand tremor) either in the boys or in the girls ($p>0.05$ by the Pearson product-moment correlation coefficient).

All neuromotor parameters except for tremor intensity at 1–6 Hz with non-dominant hand were significantly larger in the boys than in the girls (Table 2). In the analysis of covariance, the significant covariates (the correlation and parameter number in parentheses) were age (negative, 15), height (positive, 16), and mother's smoking (positive, 3) and drinking (positive, 8) habits during pregnancy for some postural sway parameters; and, age (positive, 2), height (positive, 2), heart rate (positive, 5), and body weight at birth (positive, 8) for some tremor parameters.

As shown in Table 3, postural sway parameters, in general,

Table 2 Differences in postural sway parameters (mean $\pm$ SD) between Japanese 155 boys and 148 girls after adjusting for ten possible covariates such as age, height, and body weight: results of analysis of covariance

	155 boys	148 girls	p value
Postural sway:			
Eyes open			
Sway area, mm^2	865 $\pm$ 550	563 $\pm$ 293	<0.0001
Transversal sway (Dx), mm	5.46 $\pm$ 1.84	4.45 $\pm$ 1.22	<0.0001
Dx at 0–1 Hz, mm	6.82 $\pm$ 2.32	5.55 $\pm$ 1.49	<0.0001
Dx at 1–2 Hz, mm	0.90 $\pm$ 0.33	0.75 $\pm$ 0.24	<0.0001
Dx at 2–4 Hz, mm	0.39 $\pm$ 0.15	0.32 $\pm$ 0.10	<0.0001
Sagittal sway (Dy), mm	5.63 $\pm$ 1.84	4.80 $\pm$ 1.54	<0.0001
Dy at 0–1 Hz, mm	7.04 $\pm$ 2.38	5.98 $\pm$ 1.88	<0.0001
Dy at 1–2 Hz, mm	1.11 $\pm$ 0.47	0.90 $\pm$ 0.32	<0.0001
Dy at 2–4 Hz, mm	0.50 $\pm$ 0.19	0.41 $\pm$ 0.15	<0.0001
Eyes closed			
Sway area (mm^2)	1263 $\pm$ 876	808 $\pm$ 488	<0.0001
Transversal sway (Dx), mm	6.09 $\pm$ 1.90	4.92 $\pm$ 1.39	<0.0001
Dx at 0–1 Hz, mm	7.60 $\pm$ 2.33	6.15 $\pm$ 1.70	<0.0001
Dx at 1–2 Hz, mm	1.26 $\pm$ 0.64	0.99 $\pm$ 0.34	<0.0001
Dx at 2–4 Hz, mm	0.55 $\pm$ 0.26	0.44 $\pm$ 0.17	<0.0001
Sagittal sway (Dy), mm	6.23 $\pm$ 1.76	5.20 $\pm$ 1.43	<0.0001
Dy at 0–1 Hz, mm	7.71 $\pm$ 2.20	6.46 $\pm$ 1.84	<0.0001
Dy at 1–2 Hz, mm	1.62 $\pm$ 0.62	1.32 $\pm$ 0.46	<0.0001
Dy at 2–4 Hz, mm	0.71 $\pm$ 0.31	0.57 $\pm$ 0.22	<0.0001
Tremor intensity, m/s^2 :			
Dominant hand			
Total	0.192 $\pm$ 0.071	0.169 $\pm$ 0.053	0.0034
1–6 Hz	0.144 $\pm$ 0.060	0.127 $\pm$ 0.044	0.0078
6–10 Hz	0.108 $\pm$ 0.036	0.098 $\pm$ 0.032	0.0126
10–14 Hz	0.050 $\pm$ 0.019	0.044 $\pm$ 0.016	0.0054
Non-dominant hand			
Total	0.219 $\pm$ 0.079	0.201 $\pm$ 0.069	0.0387
1–6 Hz	0.168 $\pm$ 0.064	0.158 $\pm$ 0.058	0.1705
6–10 Hz	0.119 $\pm$ 0.046	0.107 $\pm$ 0.038	0.0182
10–14 Hz	0.057 $\pm$ 0.026	0.051 $\pm$ 0.021	0.0215

were related negatively to age and positively to height. Body weight was positively related to the total Dy and the Dy at 0–1 Hz with eyes open in the boys, but negatively to the Dx at 1–2 Hz and Dx at 2–4 Hz with eyes open in the girls. In including mother's smoking and drinking habits during pregnancy in independent variables of the multiple regression analysis, drinking habit, in addition to age and height, was positively related to twelve sway parameters only in the boys ($p<0.05$, data not shown).

The total tremor intensity and component tremor intensities at 6–10 Hz and 10–14 Hz for the dominant hand were positively related to age in the girls, and most of tremor parameters were positively related to height in the boys (Table 4); also, heart rate was positively related to most of tremor parameters in the boys. In adding birth weight and mother's smoking and drinking habits to the independent variables, birth weight, together with age, height and heart rate, was positively related to eight tremor parameters only in the boys ($p<0.05$, data not shown).

With respect to the association between the tremor and sway parameters (Table 5), tremor intensity at 1–6 Hz was significantly correlated with the Dx at 1–2 Hz and 2–4 Hz and Dy at 2–4 Hz with eyes open among the boys and girls. Among the girls, tremor intensity at 1–6 Hz was also significantly correlated with some sway parameters with eyes closed.

Discussion

In this study, the children with hair mercury levels of 0.35–6.32 $\mu\text{g/g}$ showed no significant relations of current mercury exposure to either postural sway or hand tremor parameters. When maternal hair mercury concentration was used as a proxy for mercury exposure at parturition, we failed to find any significant relationships between prenatal methylmercury exposures and neuromotor variables in the same children (12). Similarly, a dose-effect association of methylmercury with postural sway parameters has not been observed in the Faroese birth cohort (6). Methylmercury exposures in both populations resulted mainly from seafood diet (18, 19). On the other hand, postural instability and increased hand tremor have been reported in adults exposed to lead, manganese, arsenic, and organic solvents (11, 20–23). Therefore, it is suggested that postural sway or hand tremor may not be so sensitive or specific to prenatal low-level exposures to methylmercury, at least less than 7 $\mu\text{g/g}$ in hair.

The present study of 7-year-old children showed that postural sway and hand tremor differed between both sexes. In the Faroese birth cohort, difference in postural balance observed between both sexes at age 7 years (24). Also, boys under 10 years swayed more than girls (7, 9). Thus, this difference at the developmental stage may have originated not from anthropometric factors, but from certain biological factors such as sex chromosome or from exposures to a certain neurotoxin other than methylmercury. In addition, Darlington et al. (25) reported that although the menstrual cycle phase had no significant effect on sagittal sway, it did significantly affect transversal sway. In healthy elderly people, however, gender-based balance differences were not shown during quiet standing

Table 3 Relations of age, height, body weight, and heart rate to postural sway parameters in Japanese children: Results of multiple regression analysis

	Standard regression coefficient				Multiple correlation coefficient
	Age	Height	Body weight	Heart rate	
155 boys:					
Eyes open					
Sway area	−0.200*	0.310**	0.024	−0.041	0.318**
Transversal sway (Dx)	−0.176*	0.343**	−0.068	−0.084	0.301**
Dx at 0–1 Hz	−0.191*	0.349**	−0.066	−0.085	0.309**
Dx at 1–2 Hz	−0.094	0.293*	−0.064	−0.091	0.261*
Dx at 2–4 Hz	−0.154	0.288*	−0.065	0.003	0.234
Sagittal sway (Dy)	−0.071	0.074	0.258*	−0.022	0.306**
Dy at 0–1 Hz	−0.089	0.077	0.248*	−0.016	0.298**
Dy at 1–2 Hz	−0.131	0.246*	−0.048	0.048	0.205
Dy at 2–4 Hz	−0.172*	0.319**	−0.095	0.083	0.259*
Eyes closed					
Sway area	−0.194*	0.279*	0.016	−0.088	0.299**
Transversal sway (Dx)	−0.166	0.362**	−0.081	−0.046	0.298**
Dx at 0–1 Hz	−0.169	0.363**	−0.070	−0.046	0.304**
Dx at 1–2 Hz	−0.156	0.212	−0.046	−0.038	0.192
Dx at 2–4 Hz	−0.139	0.280*	−0.122	−0.018	0.208
Sagittal sway (Dy)	−0.063	0.090	0.154	−0.101	0.249*
Dy at 0–1 Hz	−0.073	0.077	0.163	−0.106	0.249*
Dy at 1–2 Hz	−0.169	0.204	−0.042	0.000	0.190
Dy at 2–4 Hz	−0.137	0.228	−0.113	0.046	0.179
148 girls:					
Eyes open					
Sway area	−0.180*	0.234*	−0.069	−0.039	0.219
Transversal sway (Dx)	−0.189*	0.248*	−0.145	−0.082	0.233
Dx at 0–1 Hz	−0.195*	0.248*	−0.145	−0.096	0.241
Dx at 1–2 Hz	−0.159	0.378***	−0.221*	0.033	0.281*
Dx at 2–4 Hz	−0.146	0.322**	−0.219*	−0.005	0.243
Sagittal sway (Dy)	−0.099	0.149	0.097	0.013	0.216
Dy at 0–1 Hz	−0.087	0.157	0.086	0.021	0.211
Dy at 1–2 Hz	−0.174	0.070	0.023	−0.033	0.173
Dy at 2–4 Hz	−0.181*	0.076	−0.036	−0.033	0.170
Eyes closed					
Sway area	−0.263**	0.214	−0.098	−0.057	0.262*
Transversal sway (Dx)	−0.295***	0.271*	−0.102	−0.098	0.314**
Dx at 0–1 Hz	−0.294***	0.263*	−0.088	−0.104	0.314**
Dx at 1–2 Hz	−0.286**	0.283*	−0.172	0.062	0.298**
Dx at 2–4 Hz	−0.218*	0.201	−0.144	0.037	0.224
Sagittal sway (Dy)	−0.221*	0.228*	−0.014	−0.041	0.257*
Dy at 0–1 Hz	−0.219*	0.246*	−0.034	−0.040	0.258*
Dy at 1–2 Hz	−0.285**	0.139	−0.017	0.000	0.267*
Dy at 2–4 Hz	−0.211*	0.184	−0.105	0.050	0.214

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

(26). In either case, it is important to consider gender-specific neuromotor dysfunctions due to environmental or occupational hazardous substances.

In this study, age was negatively associated with postural sway parameters in both boys and girls. Postural sway decreased linearly with age from 2 to 14 years (8); also, sway amplitude in 64 healthy children aged between 3.5 and 17 years decreased with age for boys, but not for girls (7). In another research, Usui et al. (9) reported that upright postural sway decreased markedly between the ages of 3 to 5 years and then slowly after six years of age. By contrast, postural sway in adults is known to increase with advancing age (27, 28). Thus,

postural sway appears to decrease with increasing age in children at ages of less than 15 years, although postural stability in adults is worse in elderly people. Nevertheless, it may be difficult to identify the turning-point of aging effects on postural sway, because there seems to be no single anthropometric factor that explains the variations in body-balancing movements during standing (1).

Concerning the hand tremor, age was positively related to two tremor parameters only for the dominant hand of girls (Table 4); while, the age-range interval of our study was within 12 months. On the other hand, the amplitude of finger tremor has been reported to be significantly higher in 22 children at

Table 4 Relations of age, height, body weight, and heart rate to tremor intensity in Japanese children: Results of multiple regression analysis

	Standard regression coefficient				Multiple correlation coefficient
	Age	Height	Body weight	Heart rate	
155 boys:					
Dominant hand					
Total	−0.011	0.249*	−0.091	0.179*	0.240
1–6 Hz	−0.063	0.288*	−0.052	0.165*	0.267*
6–10 Hz	0.079	0.167	−0.146	0.232**	0.262*
10–14 Hz	0.018	0.192	−0.154	0.157	0.201
Non-dominant hand					
Total	−0.151	0.350**	−0.067	0.188*	0.323**
1–6 Hz	−0.124	0.360**	−0.049	0.183*	0.331**
6–10 Hz	−0.154	0.298*	−0.130	0.198*	0.289*
10–14 Hz	−0.168	0.263*	−0.099	0.153	0.255*
148 girls:					
Dominant hand					
Total	0.213*	−0.078	−0.010	−0.003	0.202
1–6 Hz	0.141	−0.029	0.027	−0.055	0.148
6–10 Hz	0.290**	−0.106	−0.052	0.042	0.288*
10–14 Hz	0.267**	−0.134	−0.080	0.041	0.288*
Non-dominant hand					
Total	0.064	0.080	−0.137	0.076	0.156
1–6 Hz	0.065	0.075	−0.129	0.052	0.139
6–10 Hz	0.067	0.037	−0.101	0.142	0.184
10–14 Hz	0.028	0.080	−0.131	0.103	0.156

* p<0.05, ** p<0.01.

Table 5 Partial correlation coefficients^a between tremor intensity and postural sway parameters among Japanese children

	Tremor intensity (1–6 Hz)			
	155 boys		148 girls	
	Dominant hand	Non-dominant hand	Dominant hand	Non-dominant hand
Eyes open				
Sway area	0.027	0.008	0.197*	0.129
Transversal sway (Dx)	0.036	0.024	0.091	−0.021
Dx at 0–1 Hz	0.028	0.007	0.102	−0.014
Dx at 1–2 Hz	0.217**	0.166*	0.234**	0.249**
Dx at 2–4 Hz	0.226**	0.174*	0.314***	0.295***
Sagittal sway (Dy)	0.005	−0.070	0.114	0.076
Dy at 0–1 Hz	−0.014	−0.082	0.109	0.083
Dy at 1–2 Hz	0.121	0.107	0.197*	0.234**
Dy at 2–4 Hz	0.220**	0.177*	0.270**	0.278***
Eyes closed				
Sway area	0.026	0.018	0.274***	0.220**
Transversal sway (Dx)	0.039	0.031	0.123	0.067
Dx at 0–1 Hz	0.044	0.029	0.144	0.081
Dx at 1–2 Hz	0.068	0.075	0.154	0.170*
Dx at 2–4 Hz	0.156	0.115	0.224**	0.212*
Sagittal sway (Dy)	0.100	0.086	0.156	0.204*
Dy at 0–1 Hz	0.068	0.053	0.177*	0.219**
Dy at 1–2 Hz	0.107	0.091	0.219**	0.220**
Dy at 2–4 Hz	0.179*	0.153	0.224**	0.238**

^a Age, height and heart rate were used as confounders in all analyses.

* p<0.05, ** p<0.01, *** p<0.001.

ages 7–9 years than in 22 children at ages 13–15 years (29), which included boys and girls. Also, tremor acceleration in subjects at ages 10–90 years has been reported to increase with advancing age, although the author did not seem to consider sex

difference (30). From these reports, hand tremor parameters appear to depend on age, but the relation remains uncertain in children aged between 7 and 15 years.

In the present study, height was positively associated with

postural sway and hand tremor parameters. Usui et al. (9) described that the sway of the center of gravity was larger in tall than in short people, and correction for height was made. On the contrary, some research showed that height and age were negatively associated with sway variables (4, 7). In children at the developmental stage (i.e., aged between 4 and 10 years), the relationship between age and height seems to be considerably strong; for example, the correlation coefficient was 0.96 for 76 children aged between 2 and 14 years (8). For this reason, the relation of height to neuromotor parameters may have been affected by the strong collinearity between age and height in the multivariate analysis. Nevertheless, postural sway would not be independent of height of the center of gravity.

Body weight was related positively to the sagittal sway in the boys of this study, and negatively to the transversal sway in the girls. Also, body weight had a very close relation to height in the boys and girls. Likewise, Riach and Hayes (8) reported that the correlation coefficient between body weight and either age or height was 0.90 or 0.93, respectively. In the latter case, the effect of body weight may be changeable due to the collinearity between height and body weight. Hence, Bhattacharya et al. (4), attempting to clarify the effect of early lead exposure on children's postural balance, used body weight and other possible confounders, together with age, sex, and height, as independent variables of multiple regression analysis. On the basis of these findings, it is speculated that if the study population did not include children with excessive obesity or emaciation, body weight would hardly affect postural sway by controlling for age and height. Rather, too many covariates should not be used to avoid overmatching in an intermediate between exposure and disease (31), and the estimation accompanying such overmatching may be biased toward the null hypothesis (32).

In the present study, heart rate was positively related to tremor intensity at 1–6 Hz and 6–10 Hz in the boys. A similar finding has been observed in female adults (10). Originally, inapparent minor tremors on the human body surface were described in 1930s (33, 34), and Ozaki et al. (35) reported that heart beat, in addition to muscle tonus, might play an important role in minor tremors under various physiological conditions.

Likewise, Gallasch and Kenner (36) proved that the R peak on the electrocardiogram triggered microvibrations in the supported arm. In our study, since the subjects were instructed to hold a light stylus, free of body contact or any obstacles, the effect of heart rate on hand tremor may have readily been detectable. In this sense, heart rate should be checked for subjects with palpitation.

Postural sway parameters in the boys and girls of our study were significantly linked with tremor intensity at 1–6 Hz (Table 5). This finding is concordant with two previous reports (3, 11). It is likely that involuntary postural sway at 1–4 Hz intervened directly in finger tremor via the humerus and forearm, because the frequency of tremor was almost similar to that of postural sway.

In conclusion, age, sex, and height are suggested to be the major developmental variables contributing to neuromotor measures for children. Heart rate and postural sway can also affect hand tremor not only in adults but also in children. In addition, body weight at birth and mother's drinking habit during pregnancy were suggested to be associated with the neuromotor function in Japanese boys, but the implication of these two factors awaits further research. The most important thing is that these neuromotor tests in a series of study should be carried out carefully by one trained examiner, although such tests seem to be apparently simple and feasible for examiners. Letz (37) stresses the importance of motivational influences that can affect the reliability and the validity of the tests, and two or more examiners may produce a measurement bias (38). In fact, there are only a few studies that have provided statistically significant findings obtained using the CATSYS system (5, 11, 22, 23, 39, 40, 41).

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