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Standardization of Quantitative Tests for Preclinical Detection of Neuromotor Dysfunctions in Pediatric Neurotoxicology

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Abstract

In the neurotoxicology pediatric domain, few neuromotor tests are specifically designed to be sensitive enough for the early detection of subtle deficits in voluntary and involuntary movements. In research and clinical domains, an effort is done to objectify or quantify the qualitative aspects of a movement (pattern of movement) in predicting neurological problems. This study aimed to standardize quantitative motor measures initially developed for adults and adapted to the evaluation of preschoolers. The sample consisted of 110 healthy children aged 4–6. The following quantitative neuromotor tests were selected: alternating movements and pointing movements (DOCO Microsystèmes Inc., Montréal, Canada), postural tremor, postural sway and simple reaction time (Danish Product Development Ltd., Snekkersten, Denmark). Validation measures included global motor tasks and a neurological examination. Results indicate adequate test–retest reliability and complementarities amongst the selected voluntary and involuntary measures. Both the feasibility and relevance of quantitative neuromotor tests in preschool aged children were established. Results also provide a representation of intra-individual and inter-individual variability within this population. Lastly, the results highlight the importance of developmental factors, behavioral factors and testing conditions in the neuromotor evaluation of young children. The proposed tests could help in the early detection of children at risk for motor dysfunctions following neurotoxic exposure. The tests can also be used for the follow up of various conditions relating to motor functions (cerebral palsy, muscular dystrophy, preterm infants) and in the evaluation of the effects of medication.

Keywords: Quantitative motor tests; Pediatric neurotoxicology; Children; Motor functions

INTRODUCTION

The development of techniques to evaluate the effects of contaminants on humans has been a growing concern within the scientific community. Unlike evaluations of adult populations, pediatric research does not carry the same accumulated experience. Pediatric neurotoxicology has truly developed in the past decade, principally through large epidemiological studies on exposure to lead (Baghurst et al., 1995; Dietrich et al., 1993; Stiles and Bellinger, 1993), mercury (Grandjean et al., 1997; Myers et al., 2003) and organochlorine compounds (Gladen and Rogan, 1991; Jacobson and Jacobson, 1996; Vreugdenhil et al., 2002).

In children, several measures have been explored (Davidson et al., 2000), such as electrophysiological measures, somatosensory functions, neurological func-

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tions. Despite the fact that motor function is an essential aspect of child development, it has rarely been studied in depth in neurotoxicology. The most common measure is the assessment of cognitive functions, including intelligence (I.Q.) and more specific functions (memory, attention). In the 1990s, an additional effort was made to computerize test batteries. This is how, for example, the Behavioral Assessment and Research System: BARS (Rohlman et al., 2001, 2003) and the Neurobehavioral Evaluation System: NES (Letz, 2003) were born.

When exposure levels are low, as is often the case in environmental health, subclinical effects are sought. Recent studies highlight the importance of evaluating and objectify the quality of movements in predicting developmental problems (Kroes et al., 2002, 2004; Largo et al., 2001b). The quantitative tests selected here were conceived to detect subtle preclinical motor anomalies and to characterize several aspects of a movement (speed and pattern of movement). The proposed tests include: alternating movements, pointing movements, postural tremor, postural sway and reaction time.

Tremor is a relevant tool for measuring the effect of chronic Hg exposure (Beuter and de Geoffroy, 1996). An increase of physiological tremor amplitude is often observed following exposure to various toxic substances (Anger, 1990; Beuter and Edward, 1998). Rapid alternating movements (i.e., diadochokinesis) (Beuter et al., 1999a) as well as pointing movements (Beuter et al., 1999b) have proved to be sufficiently sensitive to detect low level exposure to Hg in adult Amerindian Cree from Northern Quebec. The same tests were used with workers exposed to manganese (Beuter et al., 1999c) and, to evaluate persons with Parkinson's disease (Lemay et al., 2004). The other tests (reaction time, accelerometer, force platform,) are taken from the Catsys system (Danish Product Development Ltd., Snekkersten, Denmark). These tests have already been standardized in adults (Després et al., 2000) and have been used in several studies on the effects of toxic substances (Beuter et al., 1999c; Nadeau et al., 2003; Netterstrom et al., 1996).

METHODS

Participants

The sample consisted of 110 non-exposed children aged between of 4 and 6 years, in good health and free of any developmental problems. Parents were recruited in school districts and daycare centers (Montreal area, Quebec, Canada). Written consent was obtained from the principal of the institutions, teachers, as well as from the parents of the child. Moreover the parents filled out a brief questionnaire about the child's health in order to exclude non-healthy participants. The exclusion criteria were: an APGAR inferior to 5 after 5 min, evidence of trauma at birth, less than 2500 g at birth, congenital or chromosome abnormalities, epilepsy, a history of major disease, a serious neurological deficit or a developmental delay, the consumption of medication affecting the central nervous system (i.e., Ritalin), an uncorrected auditory or visual deficiency.

Equipment and Procedure

The evaluation was carried out in the child's school or daycare. A closed room was allocated for the experimentation (which lasted about 45 min). Neuromotor evaluations were performed by a physical therapist with the help of a trained assistant. The tests were performed in the same order for all of the children and the same equipment was used for all children during the entire study. Children were first familiarized with the instrumentation, and practice trials demonstrations were always performed before the recording of the test.

Since the selected instruments were originally designed for adult motor assessment, they were adapted for children. Visual and auditory reinforcements were added (in Doco Microsystèmes Inc. Montréal, Canada) and procedures were slightly modified (recording time, position adopted in Catsys system) in order to optimize the participation of children and maintain their attention and motivation during all the recording session. These modifications were tested in a pilot study on 10 preschoolers (data not published).

The following dimensions of neuromotor function were assessed:

1. Rapid alternating movements were measured with the Diadochokinesimeter (Fig. 1) (DOCO Microsystèmes Inc.) which records angular displacement over 7 s during rapid pronation–supination movements of the forearms. This test is the quantitative equivalent of the "puppet test" in neurology. Children were asked to rotate foam balls connected to flexible rods while keeping the elbows close to the trunk and flexed at 90°. The rotation of the balls was recorded by optical encoders (resolution: 0.18°, sampling frequency: 200 Hz). Three conditions were tested twice: (1) rotation of the right hand with the left hand kept immobile in neutral position, (2) rotation of the left hand with the right hand

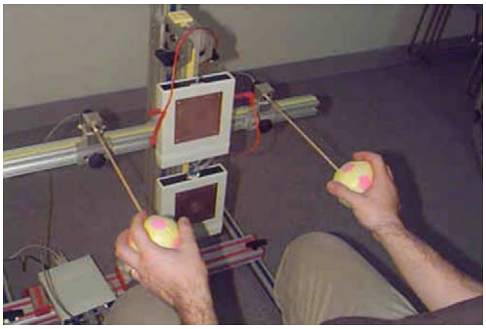

Fig. 1.

immobile, (3) symmetric rotation of both hands. Performance is quantified through twelve parameters that characterize the oscillations (Beuter et al., 1999a; Okada and Okada, 1983).

2. Rapid and precise pointing movements were recorded with the Eurythmokinesimeter (Fig. 2) (DOCO Microsystèmes Inc.). This device is made of two targets (one proximal and one distal separated by 30 cm) containing three electrically isolated concentric rings. This test is the quantitative equivalent of the ''finger-nose test'' in neurology. Children sat in front of the system and were asked to strike as quickly and as precisely as possible the central area of the targets in alternation, with a special stylus held as a pencil. The test was performed for 20 s with each hand. Since the targets are electrically separated, it is possible to detect tremor as well as hesitations (sampling frequency: 500 Hz). The child's performance is quantified through nine characteristics defined in Beuter et al. (1999b).
3. Postural hand tremor was measured twice in each hand during 8 s using a stylus containing a biaxial micro-accelerometer (Denmark Danish Product Development Ltd., Tremor 7.0). The children held the stylus in a horizontal position, the elbow joint bent at 90° in front of their navel. Throughout the recording, the child looked at the visual stimulus fixed to the stylus tip (representing a small monkey face with mobile eyes). The child is asked to remain completely motionless, keeping the eyes of the animal from moving. Five measures are calculated based on Fourier analysis.
4. Static upright balance was measured using a force platform (DPD Ltd., Sway 7.0 Snekkersten, Denmark). Children were asked to stand on the platform with their feet 1 cm apart. Postural sway was measured for 23 s eyes opened and 23 s eyes closed (static conditions), 10 s on one foot and 10 s in tandem-heel to toes position (balance conditions). Postural sway is quantified by six parameters.
5. Simple reaction time to an auditory stimulus was measured using a hand held switch activated with the thumb. Child was asked to press on a button as quickly as possible after a sound signal was heard (DPD Catsys 7.0). The signals are randomly presented during 50 s and the average reaction time is calculated.

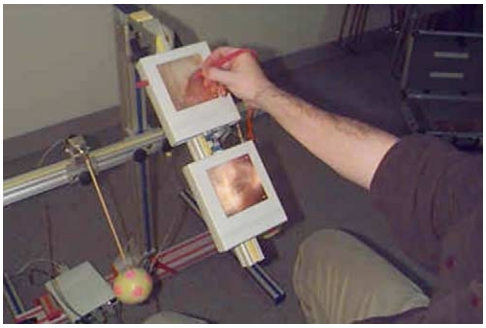

Fig. 2.

Complementary Neurological and Gross Motor Evaluation

Gross motor functions were examined using 10 motor tasks suggested by Huttenlocher et al. (1990) in order to identify children at risk of presenting a developmental delay (walking on toes and on heels, walking on a line forward and backward, ability to remain motionless for 1 min, hand coordination, downward arm drift, hopping on one foot, and tapping reproduction sequences). Neurological function was measured with the Amiel-Tison and Gosselin examination (1998) evaluating parameters such as posture and passive tone at rest, reflexes, postural reactions, and overlapping of cranial sutures.

Hair Sample

Several studies demonstrated the sensitivity of the selected motor measure on Hg exposure in adults (Beuter et al., 1999a,b,c). Thus, we collected a small sample of hair to quantify Hg exposure at the time of testing, in order to confirm that normative data was obtained with non-exposed children. Analyses were performed at the Laboratoire de Toxicologie INSPQ, which is accredited by the Canadian Association for Environmental Analytical Laboratories. The laboratory procedures are described in Rhainds et al. (1999). Analyses were done on 5-mm diameter and

1 cm length of hair using atomic absorption spectrometry (Pharmacia Model 120).

Behavioral Evaluation

The behavior of the child during the testing session was assessed using a modified version of the Infant Behavior Record from Bayley Scales of Infant Development (Bayley, 1969). The behavioral dimensions documented were sociability, cooperation, emotional tone, activity level, attention, impulsivity, anxiety and irritability. A general attention score was created from three scales (activity, attention, and impulsivity).

STATISTICAL ANALYSES

Statistical calculations were performed with SPSS-PC version 11.5. Variables that deviated from normal distribution (determined by Kolmogorov-Smirnov tests) were normalized by logarithmic transformation. Student's *t*-tests, ANOVAs and Pearson correlation coefficients were used where appropriate. Multiple linear regression analyses were carried out with adjustment for covariates. For each motor test, only few characteristics were selected for statistical analyses. They were selected from four criteria: clinical relevance of the characteristic, adequate distribution of the data, stability between first and second trials and absence of redundancy with other parameters. Definitions of the selected parameters are presented in Table 1. Statistical analyses were made only on the performance of the preferred hand. It is nevertheless important in a clinical context to evaluate the performance of the non-dominant hand. In fact, too large differences between both hands may suggest potential unilateral neurological problems.

Table 1

Definitions of the characteristics selected for the analyses

Arm postural tremor[a]	
Tremor intensity	Root mean square of acceleration recorded in the 0.9–15 Hz band. Larger values indicate larger tremor amplitude (m/s^2).
Center frequency	Median frequency of the acceleration in the 0.9–15 Hz band (Hz).
Frequency dispersion	Degree of irregularity of tremor. Frequency band centered around the medium frequency, which contains 68% of the power.
Postural sway (eyes open, closed, one foot and tandem position (heel to toes))[a]	
Mean sway	Simple mean of the distance from the mean force center position to all recorded center position during the test.
Sagittal sway	Simple mean of the recorded *y*-direction values of the force center in a coordinate system (mm).
Transversal sway	Simple mean of the recorded *x*-direction values of the force center in a coordinate system (mm).
Sway velocity	Average travel speed of the force center in the horizontal sway plate plane (mm/s).
Rapid alternating movements of the forearms (DIADO)[b]	
Velocity	Mean velocity for each cycle averaged over all cycles (degrees/second). Larger values indicate faster movement.
Coefficient of variation	Standard deviation of all normalized diado characteristics. The larger the number the more irregular the performance.
Synkinesis	Associated contralateral movements observed when one hand is moving. Larger values are considered worse.
Coherence between hands	Reflects the similarity of the oscillations in the two hands. A high coherence value means that the two hands are synchronized.
Precise and rapid pointing movements (EKM)[c]	
Unsureness	Average number of contacts per event (including side-slipping and multiple contacts in one target). Larger value indicates more tremor.
Fitts' law constant (speed-accuracy trade off)	A measure of ability independent of the compromise between speed and accuracy. Fitts' law asserts that the time required to make a rapid movement is proportional to an index of difficulty involving the precision of the movement.
Irregularity	Standard deviation of intervals between events. Larger values indicate irregularity in the performance.

[a] For more detailed definitions, see: Després et al. (2000).

[b] For more detailed definitions, see: Beuter et al. (1999a).

[c] For more detailed definitions, see: Beuter et al. (1999b).

Table 2
Characteristics of study sample

	Total *N*	Mean	S.D.	Range	*N*	%
Age (months)	108	65.6	6.2	52.0–80.0		
Gender (% male)	108				48	43.6
Height (cm)	108	112.7	5.3	101.3–127.3		
Weight (kg)	104	20.1	3.3	14.2–35.7		
Head circumference (cm)	108	51.6	1.4	49.0–55.4		
Manual preference (right)	108				88	80.7
Mother's age at testing time (years)	52	29.8	2.5	25–36		
Mother's education (years)	52	13.4	1.7	11–18		
Hg hair concentration (μg/g)	106	0.214	0.164	0.10–1.30		

RESULTS

The characteristics of the sample are presented in Table 2. The average Hg concentration in children's hair was clearly below 10 μg/g in hair, the norm fixed by the World Health Organization. Children showed a pronounced interest towards the quantitative tests and did not show any apprehension of the equipment or testing situation. Two children were excluded from the database since they presented an important language delay and/or significant behavioral problems. Other grounds for exclusion were: refusal to participate in a task (postural tremor, $n = 2$; postural sway, $n = 2$), lack of understanding of instructions (reaction time, $n = 1$; pointing movements, $n = 1$), inability to complete the task (pointing movements, $n = 1$; postural

Table 3
Descriptive statistics for reaction time, tremor and sway oscillation characteristics

	N	Mean	S.D.	Minimum	Maximum
Reaction time	107				
Preferred hand		0.453	0.098	0.253	0.720
Non-preferred hand		0.483	0.110	0.272	0.719
Postural hand tremor	106				
Preferred hand					
Tremor intensity		0.242	0.082	0.100	0.490
Center frequency		5.79	1.02	3.25	8.65
Frequency dispersion		2.98	0.582	1.65	4.40
Non-preferred hand					
Tremor intensity		0.256	0.081	0.100	0.510
Center frequency		5.52	0.884	3.60	7.45
Frequency dispersion		2.86	0.565	1.80	4.00
Postural sway oscillations	105				
Eyes opened					
Mean sway		7.91	2.33	3.1	13.1
Transversal sway		5.16	1.78	2.0	9.9
Sagittal sway		4.86	1.81	1.9	10.7
Sway velocity		15.07	4.14	8.0	27.0
Eyes closed					
Mean sway		9.61	2.73	3.9	17.1
Transversal sway		6.31	2.10	2.5	13.0
Sagittal sway		5.91	1.86	2.3	12.1
Sway velocity		22.41	6.82	11.0	44.0
Tandem (heel to toe)	103				
Mean sway		18.08	4.26	8.4	31.2
Transversal sway		10.86	2.36	6.2	17.4
Sagittal sway		12.17	3.88	4.4	22.3
Sway velocity		64.70	16.56	30.0	117.0

sway, $n = 2$), and computer problems (postural sway, $n = 2$, pointing movements, $n = 3$). The postural sway test on one foot was excluded from the normalization because it proved to be too difficult for many children.

Performance

None of the children showed major symptoms in the neurological examination. Tables 3 and 4 display the normative data obtained in each of the quantitative neuromotor tests (average of two trials). No significant difference was observed between the two test trials, except for the intensity of postural tremor, which was higher on the second trial ($t = 2.67$, $p = 0.01$). This suggests the presence of a fatigue effect and implies that it is important to limit the number of trials for this test and that it would be unwise to lengthen the recording time. Fatigue or learning effects have not been observed in other neuromotor tests. Moreover, in the case of alternating movements and pointing movements, the variables linked to speed showed a better stability between the two trials (correlations vary between 0.61 and 0.82, $p = 0.01$) than the variables related to precision of movement (correlations vary between 0.23 and 0.54, $p = 0.01$).

Influence of Covariates

Some differences were noted between the sexes. The postural sway of boys was significantly larger than that of girls in both the static condition (eyes open: $F = 4.01$, $p = 0.04$ and eyes closed: $F = 6.44$, $p = 0.01$) and the balance condition (tandem position: $F = 4.65$, $p = 0.03$). The boys also obtained a weaker performance in global motor score ($F = 15.45$, $p = 0.000$), again linked to the tasks related to equilibrium (walking on their heels: $F = 7.25$, $p = 0.008$; walking backwards on a line: $F = 9.52$, $p = 0.003$). Girls obtained higher results than boys on attention and cooperation scores, ($F = 16.60$, $p = 0.000$ and $F = 11.27$, $p = 0.001$, respectively).

Age, weight, height and cranial circumference were significantly inter-correlated ($r = 0.22$ to 0.61, $p < 0.01$). Among these developmental variables, age was mainly linked to voluntary tasks (reaction time, $r = -0.43$, $p = 0.000$; alternating movements, $r = 0.23$ to 0.48, $p < 0.01$; pointing movements, $r = -0.29$ to -0.45, $p < 0.001$; global motor score ($r = 0.36$, $p = 0.000$)). However, age was not significantly correlated with measures of involuntary movement such as postural tremor and postural sway.

Table 4
Descriptive statistics for the selected characteristics of alternating movements (Diadochokinesimeter) and pointing movements (Eurythmokinesimeter)

	N	Mean	S.D.	Minimum	Maximum
Alternating movements	108				
Velocity					
Preferred hand alone		60.69	12.63	27.63	108.15
Non-preferred hand alone		57.51	10.64	37.39	93.73
Both hands		60.73	12.57	32.53	99.26
Coefficient of variation					
Preferred hand alone		0.127	0.0425	0.061	0.255
Non-preferred hand alone		0.122	0.0329	0.069	0.205
Both hands		0.116	0.0396	0.042	0.236
Synkinesis					
Preferred hand		0.586	0.136	0.296	0.919
Non-preferred hand		0.640	0.125	0.258	0.878
Coherence between hands		0.683	0.089	0.408	0.872
Pointing movements	104				
Fitts' constant					
Preferred hand		0.231	0.058	0.112	0.467
Non-preferred hand		0.246	0.054	0.130	0.395
Unsureness					
Preferred hand		2.83	1.09	1.16	7.25
Non-preferred hand		3.33	1.23	1.30	8.00
Irregularity					
Preferred hand		0.503	0.224	0.150	1.116
Non-preferred hand		0.552	0.237	0.205	1.293

Table 5
Multiple linear regression analyses for attention score and global gross motor score ($N = 95$)

Dependant variable	Predictors	Pearson r	Stand. B	R^2	Overall regression (F)
Attention score	Global motor score	−0.40***	−0.18		
	Reaction time	0.01	0.17		
	Postural tremor	−0.23**	0.01		
	Sway oscillations	−0.34***	−0.24*		
	Alternating movements	−0.22*	−0.09		
	Pointing movements	−0.45***	−0.36***	0.33	7.34***
Global gross motor score	Age	−0.42***	−0.17		
	Attention score	−0.39***	−0.26**		
	Reaction time	0.22*	0.01		
	Postural tremor	0.23*	0.08		
	Sway oscillations	0.35***	0.25**		
	Alternating movements	−0.33***	−0.24*		
	Pointing movements	0.32***	0.19*	0.42	80.93***

Stand. B: standardized Beta. + = 0.1; * = 0.05; ** = 0.01; *** = 0.001.

The other covariates (age and mother's education, Hg concentration, cranial circumference) were not significantly associated with the performance of the children in the quantitative tests. Some motor characteristics were correlated with the child's behavior. As shown in Table 5, the attention score of a child predicted the performance obtained during the pointing movement test and the sway test.

Correlations Between Motor Tests

Significant correlations were observed between global motor tasks and quantitative measures (Table 5). Postural sway, alternating movements and pointing movements were the main factors predicting performance in global tests (while controlling for covariates). Table 6 illustrates more specifically the correlations

Table 6
Correlations between quantitative motor scores and specific gross motor scores

	Walk on heels	Tandem forward	Tandem backward	Hand coordination	Hopping on one foot	Global motor score
Reaction time	−0.05	0.07	0.08	0.00	−0.27**	0.16
Postural tremor	−0.07	0.11	0.13	0.10	−0.13	0.19
Sway oscillations						
Static	0.12	0.21*	0.30**	0.25**	−0.14	0.36***
Tandem	−0.20*	0.12	0.01	0.11	−0.05	0.10
Alternating movements						
Velocity	−0.05	−0.13	−0.23**	−0.17	0.32***	−0.32***
Coefficient of variation	0.07	0.22*	0.11	0.30***	0.05	.21*
Pointing movements						
Unsureness	0.06	0.21*	0.23*	0.09	−0.32***	0.32***
Irregularity	0.09	0.49***	0.32***	0.17	−0.28**	0.44***

+ = 0.1; * = 0.05; ** = 0.01; *** = 0.001.

Table 7
Correlations between fine motor characteristics

	Reaction time	Postural tremor	Sway oscillations	Alternating movements	Pointing movements
Reaction time	1.000				
Postural tremor	−0.02	1.000			
Sway oscillations	0.12	0.41***	1.000		
Alternating movements	−0.33***	−0.05	0.08	1.000	
Pointing movements	−0.38***	−0.12	−0.15	0.17	1.000

+ = 0.1; * = 0.05; ** = 0.01; *** = 0.001.

observed between the various quantitative tests and the five global motor tasks. To sum up, pointing movements were associated with the ability to walk forward and backward on a straight line, and with the ability to hop on one foot. Rapid alternating movements were also correlated with these same three tasks and, predictably, with the qualitative pronation–supination test. Lastly, postural tremor was not associated with any global motor task.

Significant correlations were observed among the different quantitative tests (Table 7). On the one hand, the measures of voluntary movements (pointing movements, rapid alternating movements and reaction time) were strongly inter-correlated. On the other hand, measures of involuntary movements (postural sway on the platform and postural tremor) were also significantly correlated.

DISCUSSION

In this study, several quantitative neuromotor tests were successfully adapted for use in pediatric neurotoxicology. Several factors contributed to the success of this evaluation. The visual and auditory reinforcements added to the devices increased the children's collaboration by keeping them motivated and attentive throughout the recording session. Moreover, the short length of the tests, their playful aspect as well as the simplicity of the instructions made the neuromotor evaluation possible on 4-year-old children.

Effects of Covariates

Age was the major developmental variable contributing to *voluntary/active* movement measures (alternating movements, pointing movements, reaction time and global motor tasks). A significant improvement in fine motor skills is observed in the normal development during childhood, characterized by an increase of speed (Largo et al., 2001a) and a decrease in associated movements (Largo et al., 2001b). Improvement with age can be attributed to a better utilization of the antagonist muscular system or a better ability to plan subsequent movements (Kerr, 1975), to normal central nervous system development and the maturation of inter-hemispheric connectivity (Njiokiktjien et al., 1986), and to the enriched experience that the child has within its environment (sports, familial stimulations, activities in school and daycare) (Krombholz, 1997).

Age was not significantly correlated with postural tremor and postural sway in static positions, which are *involuntary/static* measures of movement. Developmental factors might have less impact upon this type of measure. This hypothesis will have to be confirmed with future studies. Lebiedowska and Syczewska (2000) studied the role of structural growth of the human body (age, height, body mass) on sway parameters in children aged between 7 and 18 years. They also found that those developmental factors did not affect sway amplitude in a task similar to our static condition on force platform. However, a decrease in postural sway with age is observed in several studies, markedly in very young children (Usui et al., 1995).

There was no noticeable difference between the performance of boys and girls on manual tasks (tremor, alternating and pointing movements, reaction time). However, differences were observed on static and dynamic balance tasks. Sway parameters were larger in boys than girls. Boys also obtained more item failure on global motor scores. There is no consensus on sex differences in sway properties. Several studies observed larger sway amplitude in boys than girls (Usui et al., 1995) but this is not corroborated by other studies (Lebiedowska and Syczewska, 2000). Using three tests from the Neurobehavioral Examination System (NES) with children 7 years of age, Dahl et al. (1996) obtained a better performance in boys than girls for finger tapping, reaction time and eye–hand coordination tasks. However, boys had more experience with computers and joysticks. When this variable was controlled, the difference almost disappeared. The manual tasks selected in the present study do not involve any direct use of either a computer screen or joysticks.

Correlations Between Motor Tasks

Correlations were obtained between the global clinical motor measures and the quantitative tests (Table 6). Three global tasks were more often associated with quantitative measures: jumping on one foot and walking in tandem on a line forward and backward. Dissociation between voluntary and involuntary motor measures was observed (Table 7). On the one hand, *voluntary/active* movements (alternative movements, pointing movements, and reaction time) are inter-correlated. On the other hand, the *involuntary/static* tasks (postural tremor, postural sway) are also inter-correlated. It is probable that voluntary and involuntary aspects of movements are functionally dissociated despite sharing several common neuronal circuitries.

Influence of Behavior

Since children of preschool age have a limited attention span, it is a challenge to keep them motivated for the entire length of the experimentation. Several measures were indirectly associated to the child's behavior during the experiment. In fact, pointing movements as well as postural sway proved to be linked to attention scores (Table 5). Among some of the obstacles to be overcome during the evaluation of children, Letz (2003) highlights the importance of motivational influences that can affect the reliability and the validity of the tests. This is also true for quantitative motor tests especially with young children whose collaboration is harder to maintain. Since the child's behavior is an important covariate that is susceptible to affect the results in a significant fashion, it should be controlled in all motor evaluation.

Kroes et al. (2002) found that qualitative aspects of motor performance in dynamic balance, diadochokinesis and manual dexterity were predictive of attention-deficit-hyperactivity disorder (ADHD). The authors defined quantitative aspects of a movement in terms of speed or countable units, and qualitative aspects as the pattern of a movement (e.g., movement quality, overflow movements, associated movements, coordination problems). In the present study, several movement patterns are recorded and quantified with neuromotor tests (e.g., regularity of movements, accuracy, tremor, associated movements). Thus, it is not surprising that several quantitative measures were associated with the attention score.

Almost all of the children were successful in the pointing movement test. However some difficulties were noted. First, for some younger children, the handling or grip of the stylus with the non-preferred hand was difficult and the assistance of the evaluator was required. The second difficulty was the comprehension of the verbal instruction (touching the targets as rapidly and precisely as possible). Many of the children only took into account precision and consequently this greatly diminished the number of target hits within the 20 s time frame. Rival et al. (2003) found that by 6 years of age, children were able to comply with the verbal instructions on the speed-accuracy trade-off in order to find the best compromise between speed and precision. They observed significant improvement in movement time of pointing movements from 6 to 10 years. This improvement could be related to a decrease in attentional cost of pointing movements between age 6 and 8 (Olivier et al., 2003). Since no information is available for younger children, the pointing movement test (Eurythmokinesimeter) must be interpreted with precaution with children under 6 years of age.

CONCLUSION

Both the feasibility and relevance of quantitative neuromotor tests of preschool aged children has been established by the present study. This suggests that a more exhaustive normalization should be undertaken on a wider sample from preschoolers to adolescents. The present results indicate that several confounding variables will have to be examined such as other developmental factors (e.g., age of first steps, language), the familial situation (e.g., stimulation at home, socio-economic status), spare-time and sports activities (e.g., piano, ballet, gymnastics). These elements are likely to influence the motor performance of the children (Krombholz, 1997). It has been determined that quantitative neuromotor tests are related to global motor measures. It would now be useful to study them in relation to other functional activities such as playing ball, skipping rope, racing, calligraphy and drawing. Moreover, it would be interesting to study the relationship between performance during neuromotor tests and the children's academic performance.

Following the present normalization, the selected neuromotor tests were used with a group of preschool aged Inuit children living around the Nunavik region (in the northern part of the province of Quebec, Canada). The goal of this study was to examine the effects of chronic exposure to mercury (Hg), polychlorinated biphenyls (PCBs) and lead (Pb). Several confounding variables were examined. The same neuromotor tests proved to be sensitive enough to detect the harmful effects of blood Pb concentration below 10 μg/dl on several motor functions (Després et al., 2005).

Those motor tests can be used in conjunction with other clinical tests or cognitive tests. It can also be useful in domains other than neurotoxicology research. Approximately 6% of school age children have coordination problems serious enough to interfere with academic performance and social integration (Hamilton, 2002). The proposed tests could help in the early detection of children at risk for developmental delay. The tests can also be used for the evaluation and follow up of various conditions involving to motor functions (cerebral palsy, muscular dystrophy, prematurity) and in the evaluation of the effects of medication or drugs (alcohol, tobacco, cocaine). Moreover, the observation of different aspects of a movement (speed, accuracy, regularity of movement) could be indicative of the specific neuronal circuitry affected by the neurotoxic agent or by the illness.

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