Neuromotor development from 5 to 18 years. Part 2: associated movements

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Associated movements (AMs) are the most frequently assessed parameters of movement quality in children with motor dysfunctions. In this article, reference curves of duration and degree of AMs from 5 to 18 years are provided. In a cross-sectional study of non-disabled children (n=662) duration and degree of AMs were estimated at six specific ages while children performed repetitive finger, hand, and foot movements, alternating hand and foot movements, diadochokinesis, sequential finger movements, pegboard, stress gaits, and dynamic balance. Moderate-to-high intraobserver and interobserver reliability for the assessment of AMs were noted. Duration and degree of AMs displayed a non-linear developmental course that was a function of the motor task’s complexity. AMs decreased most with age in repetitive movements, less in alternating and sequential movements, and least in the pegboard and dynamic balance. Reference curves demonstrated large interindividual variations for duration and degree of AMs. Both the variable developmental course and large interindividual variation need to be taken into account in the assessment of movement quality of school-age children. In contrast to timed performance, considerable sex differences for AMs were observed.

Movement quality is regularly examined in children suspected of having mild to moderate motor dysfunction. Although routine in daily clinical practice for many years, the assessment of movement quality is still a major methodological challenge. How reliably can movement quality be estimated? What amount and duration of associated movements can be regarded as ‘normal’ in a 7-year-old child? Interobserver and test–retest reliability have been investigated in only a few studies, and have been found to be moderate to low for some motor items, and even insufficient for others (Quitkin et al. 1976, Werry and Aman 1976, Vitto et al. 1989). In children with motor problems, associated movements (AMs), in particular contralateral AMs, are the most frequently assessed parameters of movement quality. Due to the fact that AMs are not only present in children with motor problems, but may also occur in normally developing children, they ought to be quantified for a reliable judgement. Age-specific normative values for movement quality parameters are still lacking. In this article AMs are described in two dimensions: duration and degree. Duration of AMs during a defined time period was estimated on a 11-point scale (e.g. a score of 5 means there were AMs during half of the timed period). Degree, which refers to the extent to which AMs were expressed during the defined time period, was assessed on a 4-point scale (e.g. a score of 2 = moderate AMs). In a cross-sectional study (N=662 participants), duration and degree of AMs were estimated by means of the Zürich Neuromotor Assessment (ZNA) at six specific ages while children performed repetitive finger, hand, and foot movements, alternating hand and foot movements, diadochokinesis, sequential finger movements, pegboard, stress gaits, and dynamic balance tasks. The principal aim of this article was to provide a description of duration and degree of AMs between 5 and 18 years with respect to developmental course, interindividual variation, and sex differences. In a previous article, timed performance was analysed in a similar manner (Largo et al. 2001a).

Method

Participants
In a cross-sectional design, 662 children were tested at the mean ages of 5.8, 7.2, 9.3, 12.5, 15, and 18.1 years. The study population is described in detail in the companion paper to this one (Largo et al. 2001a).

Neuromotor Testing
In the ZNA 12 distinct motor tasks were assessed with regard to timed performance, duration, and degree of AMs of the contralateral and ipsilateral extremity, face, head, and body (Table I). Children’s performances on all motor tasks were videotaped. Informed consent was obtained from children and their parents after the testing procedure and goals of the study had been fully explained.

The assessment of handedness and the testing procedure for repetitive, alternating, and sequential movements, pegboard, dynamic, and static balance are reported in the companion study to this one (Largo et al. 2001a). (A manual with detailed instruction from 5 to 18 years is available from the corresponding author upon request.)

Testing procedures for diadochokinesis and stress gaits are described. For each task, the examiner gives verbal instructions while demonstrating the expected performance. Brief untimed practice follows, without specifying which side the
child should try first. No effort was made during the practice or timed trials to control whether the child looked at his/her own performing limb or spoke while carrying out the activity. To measure the task at full exertion, after practising with both extremities, the examiner said, 'When I say “go”, do the same thing as fast as you can until I stop you.'

**Diadochokinesis**
Children stood with one arm relaxed at their sides and the other flexed at the elbow at an angle of 90°. The elbow touches the body. The head is centred, arms and shoulders are relaxed. Children were asked to quickly pronate and supinate the hand and forearm as fast as possible.

**Stress gait**
The child was instructed to walk and return a distance of 3 metres on their (1) toes; (2) heels; (3) outer soles; and (4) inner soles of the feet, while arms and hands hang initially loosely at the sides.

**SCORING OF AM**
Duration and degree of AMs for contralateral and ipsilateral extremity, face, head, and body were scored from video recordings. In this article, data on duration and degree of AMs of the contralateral extremity are presented for repetitive finger, hand, and foot movements, alternating hand and foot movements, diadochokinesis, sequential finger movements, and pegboard. For dynamic balance and stress gaits, duration and degree of AMs of the upper extremity are provided. In stress gaits, form-specific associated posture and movements were selectively scored. Form specific, as used here, indicates that movements and posture of the upper extremities mirrors that of the lower extremities: walking on toes (extension of arms and anteflexion of wrists in a backward direction); walking on heels (extension of arms and dorsiflexion of wrists in a forward direction); walking on outer soles (flexion of elbows, anteflexion of wrists and extension of fingers); walking on inner soles (adduction of arms, dorsiflexion of wrists and extension of fingers).

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**Estimation of reliability**
Intraobserver reliability was assessed by one examiner. Within an interval of 8 weeks, all motor tasks were timed twice using video recordings of 30 children. Interobserver reliability was assessed from videotapes by two examiners (AAM, JAC).

**Table I: Motor tasks of the Zürich Neuromotor Assessment**

<table>
<thead>
<tr>
<th>Motor task</th>
<th>Duration</th>
<th>Degree</th>
<th>Duration</th>
<th>Degree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repetitive finger movements</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Sequential finger movements</td>
<td>0.90</td>
<td>0.73</td>
<td>0.82</td>
<td>0.68</td>
</tr>
<tr>
<td>Repetitive hand movements</td>
<td>0.80</td>
<td>0.82</td>
<td>0.85</td>
<td>0.67</td>
</tr>
<tr>
<td>Alternating hand pro-/supination</td>
<td>0.78</td>
<td>0.74</td>
<td>0.71</td>
<td>0.75</td>
</tr>
<tr>
<td>Diadochokinesis</td>
<td>0.88</td>
<td>0.89</td>
<td>0.78</td>
<td>0.65</td>
</tr>
<tr>
<td>Pegboard</td>
<td>0.73</td>
<td>0.65</td>
<td>0.60</td>
<td>0.51</td>
</tr>
<tr>
<td>Repetitive foot movements</td>
<td>0.83</td>
<td>0.75</td>
<td>0.70</td>
<td>0.57</td>
</tr>
<tr>
<td>Alternating foot movements</td>
<td>0.77</td>
<td>0.74</td>
<td>0.55</td>
<td>0.55</td>
</tr>
<tr>
<td>Side-to-side jumping</td>
<td>0.80</td>
<td>0.81</td>
<td>0.87</td>
<td>0.85</td>
</tr>
<tr>
<td>Forward jumping</td>
<td>0.68</td>
<td>0.68</td>
<td>0.76</td>
<td>0.68</td>
</tr>
<tr>
<td>Walking on toes</td>
<td>0.55</td>
<td>0.61</td>
<td>0.78</td>
<td>0.68</td>
</tr>
<tr>
<td>Walking on heels</td>
<td>0.67</td>
<td>0.62</td>
<td>0.57</td>
<td>0.55</td>
</tr>
<tr>
<td>Walking on outer soles of feet</td>
<td>0.54</td>
<td>0.82</td>
<td>0.73</td>
<td>0.77</td>
</tr>
<tr>
<td>Walking on inner soles of feet</td>
<td>0.74</td>
<td>0.57</td>
<td>0.51</td>
<td>0.57</td>
</tr>
<tr>
<td>Walking on inner soles of feet</td>
<td>0.66</td>
<td>0.62</td>
<td>0.54</td>
<td>0.55</td>
</tr>
</tbody>
</table>

*p<0.001: r>0.60.*

Associated Movements from 5 to 18 Years Remo H Largo et al. 445
Figures 1: Reference curves for duration of contralateral associated movements (AMs) of six motor tasks in females (---) and males (——) performing with their dominant upper extremity. Scoring of AM duration: below 1, no AMs; 1–5, AMs for up to half of timed period; 6–9, AMs for more than half of timed period, above 10, AMs during whole timed period.

446 Developmental Medicine & Child Neurology 2001, 43: 444–453
STATISTICAL ANALYSIS

Scores for degree and duration of AMs are discrete measurements. While degree was clearly assessed on an ordinal scale with four levels, duration was initially more finely graded on a percentage scale with 11 levels. It turned out, however, that not all levels were consistently used, so that the levels of duration were grouped into four ordered categories: 0, no AMs; 1 to 5, AMs for up to half of the timed period; 6 to 9, AMs for more than half of the timed period; 10, AMs during the whole timed period.

Owing to the fact that degree and duration are ordered measurements with few levels, the customary representation of the developmental course and variability by empirical, age-dependent centiles is not adequate. Instead we decided to calculate cumulative multinomial logits (Agresti 1990) and to represent the corresponding cumulative probabilities as a function of age. The cumulative logits were modelled as quadratic polynomials in age: for duration, different polynomials were required for males and females, while for degree an additive model, i.e. a shift on the logit scale, was sufficient to account for the sex differences. In the graphical representation chosen, the height of each curve gives the percentage of participants, as modelled by cumulative logits, having a score for duration below that indicated by the label of the curve. For example, the height of the curve labelled 1 represents the percentage of children, at a given age, without AMs, and the height above the curve labelled 10 indicates the percentage of those children who displayed AMs during the whole timed period. Thus, the reference curves indicate improvement of movement quality by a raising of curves corresponding to a low degree or a short duration of AMs. For the estimation of the reference curves only right-handed children were included.

Figure 2: Reference curves for duration of contralateral associated movements (AMs) in repetitive and alternating foot movements performed with dominant lower extremity and of AMs of upper extremities in side-to-side and forward jumping in females (—) and males (—). Scoring of AM duration: below 1, no AM; 1–5, AMs for up to half of timed period; 6–9, AMs for more than half of timed period; above 10, AMs during whole timed period.
Spearman's rank correlations were used to estimate intraobserver and interobserver reliability.

**Results**

First, data on test reliability are presented, then reference curves of duration and degree of AMs for the various motor tasks are provided. For the sake of brevity, only reference curves of the active dominant extremity are shown. The following aspects of duration and degree of AMs will be addressed here: developmental course, interindividuation variation, and sex differences. (Reference curves and normative data tables of duration and degree of AMs from 5 to 18 years are available from the first author upon request).

**RELIABILITY**

To estimate intraobserver and interobserver reliability Spearman’s correlations for duration and degree of AMs were calculated (Table II).

With respect to intraobserver reliability, moderately to highly significant correlations for duration and degree of AMs were observed ($r=0.54$ to $0.90$, and $0.57$ to $0.89$, respectively). Some of the correlations between observers tended to be lower, but most were comparable to the intraobserver correlations ($r=0.51$ to $0.87$ for duration, and $0.53$ to $0.85$ for degree, respectively).

**DURATION OF AMS**

The duration of AMs in the upper extremity showed a non-linear developmental course that was highly variable (Fig. 1). Timing and extent of reduction of duration were a function of the complexity of the motor task. Duration of AMs for repetitive hand and finger movements was largely reduced already at early school age, while those of alternating and sequential hand movements decreased considerably during...
Figure 4: Reference curves for degree of contralateral associated movements (AMs) of six motor tasks in females (---) and males (-----) performing with dominant upper extremity. Scoring of AM degree: below 1, no AMs; 1–2, barely visible AMs; 2–3, moderate AMs; above 3, marked AMs.
puberty. A major decrease of AMs duration was observed in the pegboard task between 5 and 10 years. However, thereafter AMs duration increased again.

Between 5 and 7 years, the interindividual variability was large in all motor tasks. During this age period, 30 to 40% of the children performing the repetitive finger movements showed no AMs, while 10 to 15% displayed AMs constantly. By 18 years, 70% of the adolescents had no AMs at all, while 10% showed AMs during the whole timed period. At kindergarten age, less than 10% of children did not display any AMs when performing sequential finger movements. At 18 years, no AMs were observed in 75% of the adolescents, and 5% displayed AMs during the whole timed period. The extent to which interindividual variability changed with age varied considerably among the motor tasks. In simple motor tasks, such as repetitive movements, AMs duration was markedly reduced at an early age, while it remained largely unchanged in alternating hand movements and the pegboard (Fig. 2).

With regard to the lower extremity, the developmental course and interindividual variation of AMs duration was again a function of the complexity of the movement pattern. AMs duration for repetitive foot movements decreased at early school age and displayed an increasingly narrow range, while for side-to-side and forward jumping, developmental course of AMs duration showed changes up to the age of 18 years, and variability increased with age.

In the four types of stress gaits, duration of form-specific posture and movements of the upper extremities also displayed a variable developmental course and a large interindividual variation (Fig. 3). Duration was shorter and decreased earliest when the children walked on their tip-toes. Long duration and least change was noted when the children walked on

![Figure 5: Reference curves for degree of contralateral associated movements (AMs) in repetitive and alternating foot movements performed with dominant lower extremity and of AMs of upper extremities in side-to-side and forward jumping in females (—) and males (----). Scoring of AM degree: below 1, no AMs; 1–2, barely visible AMs; 2–3, moderate AMs; above 3, marked AMs.](image-url)
the inner or outer soles of their feet.

Sex differences for AMs duration were noted in two aspects: females tended to display less AMs at most ages; an exception was forward jumping during puberty. Second, reduction of AMs duration occurred earlier in females than in males. Sex differences of AMs duration were less pronounced for the lower than for the upper extremities. AMs duration for walking on toes showed a peculiar sex difference, not seen for any other parameter. While for females, it decreased gradually with age, for boys it remained fairly constant up to the age of 13 years, to abruptly shrink to practically 0 duration in the following 2 years. This prevented fitting a quadratic polynomial to the cumulative logits of males; a straight line was instead fitted to the logits for the age of 5 to 13 years.

**DEGREE OF AMs**
The AMs degree showed similar developmental characteristics as AMs duration. With regard to the upper extremity, the degree of AMs decreased up to the age of 18 years in all motor tasks, with the exception of the pegboard (Fig. 4). In the latter an increase of AMs degree was again noted beyond 11 years. As already observed for AMs duration, AMs degree displayed less interindividual variability in repetitive movements than in alternating and sequential movements, diadochokinesis, and particularly in the pegboard.

Developmental course and interindividual variability of degree of AMs for repetitive and alternating movements in the lower extremities were similar to those of the upper extremities (Fig. 5). Variability of AMs degree was lowest in repetitive and alternating foot movements while it was large and even increased during school age in side-to-side and forward jumping.

For the four types of stress gaits, a variable decline of form-specific movements and posture of the upper extremities

**Figure 6:** Reference curves for degree of form-specific movements and posture AMs in upper extremities in females (—) and males (—–) performing stress gaits. Scoring of AM degree: below 1, no AMs; 1–2, barely visible AMs; 2–3, moderate AMs; above 3, marked AMs.
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ance of examiner (1979). When the manual was the only
method used, which are imperfect measures of reliability.

Spearman's correlation coefficients for overflow movements and dysrhythmias, which were more
validity were examined only in a few studies (Neeper and
Kakebeeke and coworkers (1993). They estimated the inter-
observer reliability of the well-standardized
standardized testing instrument is used and the examiners
are well trained.

Discussion

For the assessment of movement quality, well-standardized
neurological test instruments have been developed (Touwen
and Prechtl 1979, Denckla 1985). Although they have been
widely used by clinicians and researchers, their reliability and
validity were examined only in a few studies (Neuper and
Greenwood 1987). Quijano and coworkers (1976) found some
neurological soft signs indeed proved reliable (kappa
coefficient >0.5) among examiners (e.g. finger–thumb mir-
or overflow, left-sided pronation–supination, foot-tapping),
while others (e.g. finger–thumb opposition or pronation–supination mirror overflow) were unreliable. In the same
study, few very few signs were stable at retesting. Using the
revised version of the Neurological Examination for Subtle
Signs (NESS), Vitello and colleagues (1989) analysed interob-
server and test–retest reliability of neurological subtle signs.
Reliability was sufficient for continuous variables, but was low
for overflow movements and dysrhythmias, which were more
dependent on subjective interpretation. Test–retest reliability
at 2 weeks was unsatisfactory for most of the categorically
scorred items, including some classic subtle signs, such as over-
flow or dysrhythmias (kappa and intraclass correlation coeffi-
cients <0.50). The authors recommended that researchers
and clinicians should rely more on subtle signs that can be
assessed on continuous scales.

In our study, intraobserver and interobserver reliability
for duration and degree of AMs was moderate to high for the
majority of the motor tasks. In agreement with Vitello and
colleagues (1989) reliability for AMs was found to be lower
than for timed performance (Largo et al. 2001a). For comparison with previous studies Spearman’s correlation coefficients were calculated, which are imperfect measures of reliability.
In a forthcoming paper we will present a more sophisticated
and detailed statistical analysis of reliability as well as validity.
Given these methodological limitations, our results as well
as those of previous studies indicate that acceptable reliabil-
ity for movement quality can only be achieved when a highly
standardized testing instrument is used and the examiners
are well trained.

The significance of training was investigated recently by
Kakebeeke and coworkers (1993). They estimated the inter-
observer and test–retest reliability of the well-standardized
Touwen examination (1979). When the manual was the only
reference for instruction, acceptable levels of reliability were
not achieved. The reliability estimates for the total test scores
were satisfactory, while interobserver reliability for the nine
groups of items and the individual tasks within these groups
was poor. When methodology and interpretation of performance
was agreed among observers, these disagreements
diminished. Short-term stability of the total scores was good,
but reliability for group and individual item scores remained
poor.

There is a general agreement that AMs decrease with age.
Age related changes of contralateral AMs from kindergarten
age to adolescence have been reported for various fine motor
tasks. In the finger lifting method, ipsilateral and contralateral
AMs were recorded when the child was asked to move a speci-
fied finger (Zazzo 1960, Abercrombie et al. 1964, Connolly
and Stratton 1968). In the clip-pinching method, AMs in the
central hand were judged when the child exhibited a
certain degree of pressure with the thumb (Abercrombie et al.
1964, Connolly and Stratton 1968). Touwen and Prechtl
(1979) provided some semi-quantitative data for AMs in chil-
dren performing tasks such as finger opposition, diadochoki-
nesis, or walking on heels. Wolff and colleagues (1983, 1985)
reported on age-specific changes of AMs in distinct motor
tasks. Vitello and coworkers (1989) noted a dramatic decrease
in the total score of subtle signs at about 6 years of age. They
pointed out that this decrease occurs at the very age when chil-
dren are expected to enter school and learn skills for which a
higher level of coordination is required.

Our study provided two major insights in the develop-
ment of AMs between kindergarten age and adolescence.
First, duration and degree of AMs do not regularly decrease
with age. A non-linear course of both duration and degree
was observed that was a function of the complexity of the
individual motor task, e.g. duration and degree of AMs
decreased much earlier in repetitive than in alternating and
sequential movements. A peculiar developmental course
was observed in the pegboard. In contrast to timed perfor-
ance which improved up to 18 years, duration and degree of
AMs decreased up to 12 years of age and increased again
between 12 and 18 years. Second, a large interindividual
variation for duration and degree of AMs was found in all
motor tasks at most ages. Variation again depended on the
complexity of the individual motor task. It decreased rapidly
in repetitive movements and increased in dynamic balance.
For a reliable assessment of AMs in clinical practice and
research, the non-linear course, the interindividual varia-
tion, and the variability among motor tasks need to be taken
into consideration. Comparisons between motor tasks (e.g.
between repetitive foot movements and forward jumping)
indicate that developmental course and variation determine
the clinical relevance of a specific motor task. Thus, depend-
ing on the age of the child, different motor tasks should be
applied. There are more questions which need to be
answered in order to improve sensitivity and specificity of a
neuromotor assessment. For example, is duration or degree
of AMs of higher clinical significance? Preliminary results sug-
gest that neither duration nor degree, but the product of
both is the most powerful indicator for movement quality.
In contrast to timed performance (Largo et al. 2001a),
major sex differences for duration and degree of AMs were
noted. Females displayed less frequent and less pronounced
AMs and, therefore, appeared to be better coordinated than
males. Females also exhibited the decrease in AMs earlier
than males. A comparable sex shift has been reported in the
development of mental abilities and somatic growth (Waber
1977). These sex differences most probably reflect the differ-
ent maturation rate for females and males. A more detailed
analysis of these differences, as well as of laterality and
handedness will be presented in a forthcoming article. In conclusion, duration and degree of AMs between 5 and 18 years are characterized by a non-linear developmental course, a large interindividual variation, and considerable sex differences.

Accepted for publication 14th December 2000.

Acknowledgements
We thank Oski Jenni, Tanja Kakebeeke, Gerhard Neuhauser and Kurt von Siebenthal for their helpful comments and criticisms. This work was supported by the Swiss National Science Foundation (Grant No. 5200-045829.95/2).

References


