AGE DIFFERENCES IN THE MAGNITUDE OF ASSOCIATED MOVEMENT

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The phenomenon under investigation in this study has been termed associated movement (Fog and Fog 1963, Abercrombie *et al.* 1964, Zülch and Müller 1969), motor overflow (Yensen 1965, Stern *et al.* 1976) or synkinetic movement (Cambier and Dehen 1977). They all describe extraneous or unintended movements accompanying an intentional action. For example, in young children, movement of one hand is often unintentionally mirrored in the other hand.

The developmental trend for associated movement has consistently been reported to decrease in frequency and intensity with age (Fog and Fog 1963, Cohen *et al.* 1967, Connolly and Stratton 1968). However, for methodological reasons the shape of the developmental trend remains obscure. Three issues are of particular concern: (1) the use of dichotomous or multi-level subjective scales that reflect only the observable frequency of the act; (2) the failure to control for individual differences in the exertion level of the primary or intended act; and (3) trial-to-trial variability in the force exerted. Often studies have used a common apparatus for different ages but did not regulate force. If one assumed that all subjects performed to the same criterion force, then stronger subjects would have performed at a lower percentage of their maximum volitional force, thus confounding any developmental trend. However, since exertion level was not regulated, it is difficult to know how pronounced this effect would be.

In a recent study the magnitude of the intended act has been found to directly affect the intensity of associated movements (Todor and Lazarus 1986). To control for individual differences, each child performed a finger-thumb squeezing task at fixed percentages of his/her own maximal volitional force (MVF). This type of task has been used in several studies investigating developmental trends (Fog and Fog 1963, Connolly and Stratton 1968). Todor and Lazarus (1986) addressed the methodological issues mentioned above and still found a relationship between exertion level and the magnitude of associated movement. These results support the view that this factor needs to be taken into account because of variations in absolute strength both between and within individuals.

Although the primary manifestation of an associated movement during a unilateral movement is found in the contralateral symmetrical (homologous) muscle group, some authors have noted associated movement in the contralateral asymmetrical (heterologous) muscle group (Hellebrandt and Waterland 1962, Fog and Fog 1963, Missiuro 1963, Todor and Lazarus 1986). While the developmental trend of homologous *vs.* heterologous movements remains unresolved, it is clear that efforts to understand the developmental nature of associated movement during a given task should consider both patterns of its manifestation.

The rôle of inhibitory processes in the development of motor competence has previously been underplayed. A systematic look at the pattern of associated movement across ages may give insight into how children develop the ability to inhibit or modulate basic neuromotor synergies to comply with task demands and to allow for greater movement complexity. The purpose of this study, therefore, was to investigate age differences in the magnitude of homologous associated movements in children and adolescents, under conditions in which previously identified methodological problems were controlled. In addition, heterologous associated movements were monitored in order to determine the extent to which they occurred at different ages.

TABLE I
Age distribution of sample

Group	*Mean age: (yrs)*	*Mean age: mths*	*(SD)*	*N*
A	6·5	78·1	(3·29)	31
B	8·5	102·1	(3·27)	28
C	10·4	125·2	(3·78)	36
D	12·4	148·6	(3·25)	23
E	16·5	198·0	(5·63)	22
Total				140

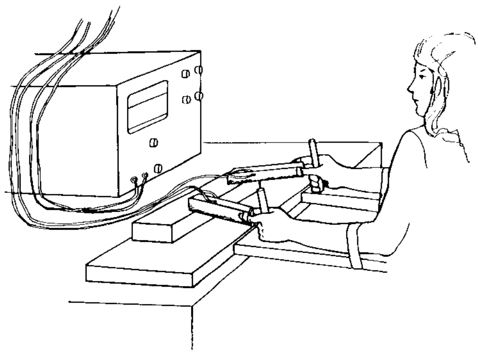

Fig. 1. Apparatus for assessment of associated movement.

Method

Subjects

Five age-groups of male children participated in this experiment (Table I). All the children were in regular classrooms and wrote with their right hand.

Apparatus

The apparatus used was the modified version of the clip-pinching task of Fog and Fog (1963), developed by Todor and Lazarus (1986) (Fig. 1). Two parallel steel bars were attached to a wooden platform which was secured to a desk. Attached to the wooden platform were adjustable armrests with Velcro straps for arm positioning and near-vertical wooden dowels for stabilizing the non-involved fingers. Velcro straps attached to the proximal ends of the steel bars were used to secure the thumb and index finger in a standardized location. Desk and chair height were adjusted for each child.

Strain gauges mounted on the inner surface of the lateral bar for each hand detected force applied to the bars. The output of the strain gauges was amplified by a Beckman R511A polygraph and the output from the right ('active hand') squeeze bars was displayed on an oscilloscope (Telequipment type D54) as a horizontal line which rose in proportion to the force of the contraction of the active hand. The signal was routed to an analogue-to-digital converter of a microcomputer. On-line analogue-to-digital sampling occurred every four milliseconds. Each trial was visually displayed on a graphics monitor before being stored on a floppy disk. This allowed the experimenter to reject trials in which the subject failed to reach and/or maintain the criterion force level. The data were transferred after collection to the Michigan Terminal System and the Michigan Interactive Data Analysis System for statistical analysis.

Procedures

The right hand was chosen as the active hand in order to obtain the dependent measure under conditions in which experience would have optimized

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biological potential. Left-hand overflow was used as the dependent measure.

Each child was seated on a chair facing the apparatus with the forearms positioned and secured by Velcro straps to the armrests. They were instructed to place the thumb and index finger of each hand on the outside of the squeeze bars in a standardized position, marked by masking tape. The thumbs were positioned so that they were in alignment with the radial side of the forearm, restricting the squeezing movement to flexion of the index finger at the metacarpophalangeal joint. The index finger and thumb were then secured in position by Velcro straps so that extension (heterologous movements) could be detected as a negative signal from the strain gauge. The remaining three fingers of each hand were placed around the wooden dowels projecting from the armrests.

Each child was instructed to raise the line on the oscilloscope as high as they could by squeezing the bars with the right hand as hard as possible and to hold it for three to four seconds. The left hand was to remain in position but kept inactive. The peak value on the oscilloscope was used as the child's MVF.

Each child was then asked to squeeze the bars to 50, 75 and 100 per cent of their MVF. A second, stationary, horizontal line on the oscilloscope indicated to the child how high to raise the line to achieve the desired force level. Three trials were performed at each level in ascending order. An individual trial lasted six seconds, giving ample time for all children to reach and maintain the desired force level. Trials were separated by a 30-second rest interval while the data were being stored on a floppy disk.

Analysis

The positive force output recorded from the left (passive) hand was used to represent the magnitude of homologous associated movement. The onset of positive force output from the right (active) hand triggered an eight-second sampling algorithm which computed the average force output of each hand during consecutive time-intervals, or bins, of 0·4, 1·1, 1·1, 1·1, 1·1, 1·1, 1·1, 1·0 seconds. Before statistical analysis, corrections were made for differences in D/C offset, signal amplification and the sensitivities of the two strain gauges. For the purpose of analysis of homologous associated movement, trials containing heterologous movements greater than an absolute value of $-2 \cdot 0$ (in the negative direction) were treated as missing data. The criterion value of $-2 \cdot 0$ was selected because of experimenter variability in setting the D/C signal at zero.

The data obtained in the first bin (0·4 seconds) was excluded from analysis since it contained adjustments associated with attaining the desired force level. To ensure that overflow values were associated with a given exertion level, at least 80 per cent of the desired active hand force had to be maintained for a minimum of three consecutive sampling bins (*i.e.* 3·3 seconds). Trials that did not were excluded from the analysis. Further, for each trial, only bins meeting the performance criterion were analyzed. An associated movement was defined as the highest value across bins qualifying in that trial. This value was considered more appropriate than the over-all average because there was trial-to-trial variation in the number of bins meeting the performance criterion, and the qualifying bins may have occurred early or late in the trial. Todor and Lazarus (1986) had observed the intensity of the associated movement to increase as a function of the duration of the active hand contraction, so an average value for overflow would not be representative, underestimating on trials of short duration or those in which the peak overflow occurred early in the six-second period.

The number of heterologous associated movements (extension of the thumb and/or index finger) was noted. Since they occurred infrequently, their intensity was not analysed statistically.

Results

A 5×3 (age-group×active hand force level) analysis of variance with repeated measures was performed on the peak bin value for associated movements for each qualifying trial. There was a significant main effect for force level ($F(2,268) = 96 \cdot 83$, $p < 0 \cdot 001$), indicating an increase

TABLE II

Magnitude of associated movements by age-group and % MVF (expressed in grams)

MVF	6·5	8·5	10·4	12·4	16·5
			Age-group (yrs)		
Cell means					
50%	437·08	166·05	52·55	141·13	302·73
75%	1191·46	521·13	297·72	506·51	475·03
100%	1778·94	1236·15	1521·95	1417·22	2409·30
Standard deviations					
50%	738·73	312·73	207·30	522·38	606·79
75%	1440·96	962·30	575·19	981·25	711·54
100%	1348·01	1197·56	1294·74	1457·78	2602·08
Anova—F values					
Age 2·45*		Level 96·83***			Age × level 2·53**

*p<0·05, **p<0·01, ***p<0·001.

in the magnitude of associated movements as the intensity of the active hand force level increased from 50 per cent MVF to 100 per cent MVF (Table II).

The main effect of age was significant ($F(4,134)=2\cdot45$, $p<0\cdot05$) and there was a significant age × active hand force level interaction ($F(8,268)=2\cdot53$, $p<0\cdot01$). A *post hoc* analysis (Scheffé) performed at the 0·05 alpha level revealed that at the submaximal force levels (50 and 75 per cent MVF) the six-year-olds exhibited the most intense or forceful associated movements, (significantly different from eight-, 10- and 12-year-olds at 50 per cent MVF and from eight-, 10-, 12- and 16-year-olds at 75 per cent MVF). However, at the maximal level (100 per cent MVF) the magnitude of the associated movements of the 16-year-olds surpassed all other age-groups and was significantly different from the eight-year-olds.

A second 5 × 3 analysis of variance with repeated measures was performed to control for the large variations in active hand force across the five age-groups (Table III). In this case the dependent measure (associated movement) was expressed as a percentage of that individual's active hand force value for that individual trial. Due to unequal cell variances, the 5 × 3 Anova, as well as the *post hoc* Scheffé, were performed on logarithmic transformed data. The statistical effects remained unchanged,

TABLE III

Range of active hand force by age-group (100% MVF)

Age-group (yrs)	*Mean force (g)*	*Minimum*	*Maximum*
6·5	2020	1153	2790
8·5	2200	1071	3557
10·4	2650	1589	4945
12·4	3050	1496	5185
16·5	4940	2413	7349

while the log transformation succeeded in equalizing the cell variances (Table IV).

As with the absolute value analysis, there was a significant main effect for active hand force level ($F(2,268)=50\cdot44$, $p<0\cdot001$); the magnitude of associated movement increased disproportionately with increasing intensity of the active hand force level. The main effect for age-group was also significant ($F(4,134)=5\cdot97$, $p<0\cdot001$). As shown in Figure 2, a dramatic decrease in the magnitude of associated movement occurred beyond six years, with little difference being evident in the four older age-groups. There was no significant age × active hand force level interaction.

Figure 3 illustrates the difference scores in the magnitude of associated movement (75 to 50 per cent MVF and 100 to 75 per cent MVF). One-way analysis of variance on the 75 to 50 per cent MVF difference score revealed that the six-year-olds

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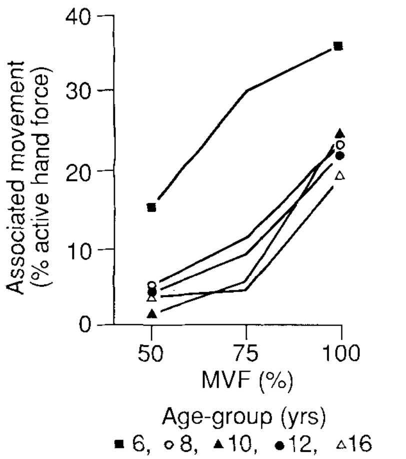

Fig. 2. Associated movement by age and active hand force (expressed as a percentage of active hand force).

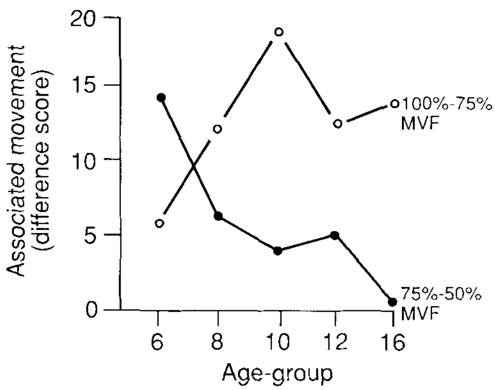

Fig. 3. Effects of incremental increases in active hand force by age.

displayed a significantly larger difference score than all other age-groups ($p<0 \cdot 01$). One-way analysis of variance on the 100 to 75 per cent MVF difference score indicated that the six-year-olds displayed a significantly smaller difference score than the 10- and 16-year-olds ($p<0 \cdot 01$), and the eight-year-olds displayed a significantly smaller difference score than the 10-year-olds ($p<0 \cdot 05$).

Extension of the thumb and/or index finger (heterologous movement) occurred in 1·67 per cent of the trials (21 occurrences in 1260 trials). 10 of the 21 heterologous movements were observed in the 16-year-old group (Table V).

Discussion

The results of this study confirmed previous findings by Todor and Lazarus (1986) that homologous associated movements during a finger-thumb *squeezing task increased in magnitude* with the force exerted by the active hand across a wide age-range (6·5 to 16·5 years). The same two authors, in a study of college-aged adults, have extended and confirmed this relationship between exertion level and intensity of associated movement (unpublished data).

The present study demonstrated the magnitude of the effect to decrease dramatically between the ages of 6·5 and 8·5 years. Beyond 8·5 years, no significant differences in the magnitude of associated movement were found. The dramatic decline that occurred between the ages of 6·5 and 8·5 years differed from findings previously reported in the literature. Using Fog and Fog's original clip-pinching task, Fog and Fog (1963) and Connolly and Stratton (1968) reported decreases in the occurrence of associated movement in children and adolescents between the ages of five and 15 years, and between two and 16 years, respectively. The issue of importance here is whether the measures of the frequency of observation (Connolly and Stratton and Fog and Fog) versus the measure of intensity of the effect (this study) reflect the same inhibitory control process. The possibility exists that under certain conditions one can inhibit associated movement to the degree that would affect a frequency measure, as no overt movement would occur. But in fact low-level muscular activity may be present which would be reported in terms of an intensity measurement. The theoretical question then is, when associated movements are not completely inhibited, as in the detection of low levels of force, is this intensity measurement a better indicator of the degree of inhibitory control?

Cohen *et al.* (1967) observed the amount of overflow movement to diminish systematically with age and to be infrequent in normal children by the age of nine years. Those results concurred with the present study, in that a plateau in overflow occurred at a similar age-range. However, Cohen and colleagues used

TABLE IV
Magnitude of associated movements by age-group and % MVF (expressed as percentage of active hand force)

MVF	*6·5*	*8·5*	*Age-group (yrs)* *10·4*	*12·4*	*16·5*
Cell means					
50%	15·58	4·79	1·45	4·00	3·88
75%	30·21	11·16	5·54	9·15	4·43
100%	36·08	23·54	24·56	21·76	19·32
Standard deviations					
50%	28·00	7·98	6·32	15·27	6·76
75%	36·16	19·42	10·33	18·01	5·70
100%	27·57	24·06	22·78	29·14	19·41
Anova—F values					
Age 5·97*		Level 50·44*		Age×level 1·15, NS	

*p<0·001.

composite scores consisting of different measures of the phenomenon, which may not be mediated by the same mechanism and may not follow the same developmental time-course. Wolff *et al.* (1983) were careful to point out the danger of this technique, especially if it is used to measure developmental state. In the current study, a single measure (index finger-thumb flexion) was used to investigate the developmental trend in order to avoid this problem. It is recognized that inferences regarding all forms of associated movement should be avoided. However, for at least this task, the mechanism mediating the inhibition of such movements appears to be in place and functioning more efficiently by the age of 8·5 years.

The 6·5-year-old age-group displayed the greatest increase in the magnitude of associated movement at submaximal levels of force (between 50 and 75 per cent MVF). All other age-groups increased most markedly between 75 per cent MVF and the maximal level of force (100 per cent MVF). Since the magnitude of associated movement increased with increasing active hand force, one might postulate that the mechanism of inhibiting the involuntary contractions becomes progressively harder to invoke at higher exertion levels. Thus it is conceivable that the 6·5-year-old children differ from older children in two ways: (1) they exhibit more intense associated movements at all levels of exertion; and (2) their process of or potential for inhibiting is less effective and thus breaks down at lower exertion levels. It is not clear whether an immature nervous system, less developed cognitive control processes, or an interaction of these two factors limits the youngest group in the spontaneous inhibition of associated movement.

TABLE V
Number of heterologous movements in 'passive hand'

MVF	*6·5*	*8·5*	*Age group (yrs)* *10·4*	*12·4*	*16·5*	*Total*
50%	3	0	0	0	0	3
75%	1	1	0	1	7	10
100%	1	2	2	0	3	8
Total	5	3	2	1	10	21

The clinical literature has been primarily responsible for addressing the issue of associated movement, while parallel development in the motor-control literature has given much attention to the rôle of natural synergies or linkages in the nervous system (Sherrington 1947, Bernstein 1967, Easton 1972, Kelso *et al.* 1979, Gallistel 1981, Lee 1984). Simultaneity of action between the two limbs (such as the occurrence of homologous associated movement) could be viewed as an outcome of organizing muscles into functional groups or

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synergies that are controlled as units. This would serve to reduce the degrees of freedom of a system by delegating control to lower-level subsystems (*i.e.* subcortical or spinal). Accordingly, early in development, when higher level cortical maturation is incomplete (Yakovlev and Lecours 1967, Gazzaniga and LeDoux 1978), various subsystems or synergies would tend to dominate movement. This is demonstrated behaviorally by Elliott and Connolly (1973) and Maxwell (1981), who found that the strategies employed by younger children in response to varied task demands clearly reflected the preference for symmetrical hand-movements. In the Maxwell study, for example, younger children had considerable difficulty in not slipping from alternating to simultaneous symmetrical tapping. The propensity to use symmetrical movements may reflect the innate tendency for motor overflow to symmetrical body parts, and the increasing use of asymmetrical movements may be indicative of a greater ability to inhibit this tendency as neural mechanisms become increasingly differentiated with age through the development of cortical inhibition.

A secondary manifestation of associated movement was found in the contralateral antagonist muscle-group on a few trials. The fact that nearly 50 per cent of the heterologous movements occurred in the oldest age-group (16·5 years) suggests that it may be a compensatory strategy activated to override mirroring (contralateral homologous contraction). These findings concur with Fog and Fog (1963) and Lazarus and Todor (unpublished data), who observed the frequency of heterologous associated movement to be greater in older children and adults, respectively. Given that the older group was able to exert a greater amount of force than the younger groups (Table III), it is conceivable that exertion level contributed to the breakdown of the mechanism of inhibition, resulting in the use of an alternative strategy (or the emergence of an alternative synergy) in the form of heterologous associated movement.

Children and adults with signs of neurological dysfunction often demonstrate an increase in both the frequency and intensity of associated movement (Abercrombie *et al.* 1964, Cohen *et al.* 1967, Hopf *et al.* 1974, Cambier and Dehen 1977). The use of a quantified intensity measurement, such as that used in this study, may help determine the degree of inhibitory control in these populations and serve as a marker of functional change throughout the course of recovery.

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SUMMARY
Using a quantitative measure of unintended mirror-movements in the contralateral limb during a unimanual task, the magnitude of associated movement across the ages from six to 16 years was determined. Male children in five age-groups (means 6·5, 8·5, 10·4, 12·4 and 16·5 years) were asked to squeeze their index finger and thumb together to various percentages of their own maximal volitional force. Results indicate that the 6·5-year-old group differ from all other age-groups, exhibiting significantly greater associated movements at all levels of force. The results are discussed in terms of the development of inhibitory control over innate neuromotor synergies.

RÉSUMÉ
Différence d'âge dans l'amplitude des syncinésies
L'amplitude des mouvements associés a été appréciée à l'aide d'une mesure quantitative de syncinésies involontaires en miroir sur le membre contralatéral durant une tâche monomanuelle, pour les âges de 6 à 16 ans. Des garçons regroupés en cinq groupes d'âge (moyenne de 6·5, 8·5, 10·4, 12·4 et 16·5 années) ont été priés de presser leur pouce sur leur index avec des pourcentages variés de leur force volontaire maximale. Les résultats ont montré que le groupe d'âge de 6·5 années différait de tous les autres groupes d'âge, produisant des mouvements associés significativement plus

importants pour tous les degrés d'expression de force. Les résultats sont discutés en terme du développement du contrôle inhibiteur sur les synergies neuromotrices innées.

ZUSAMMENFASSUNG
Altersunterschiede bei assozierten Bewegungen
Unter Verwendung einer quantitativen Messung unbeabsichtigter Spiegelbewegungen auf der contralateralen Seite bei einer unimanuellen Aufgabe wurde das Ausmaß assoziierter Bewegung in verschiedenen Altersgruppen von sechs bis 16 Jahre bestimmt. Jungen aus fünf Altersgruppen (Durchschnittsalter 6·5, 8·5, 10·4, 12·4 und 16·5) wurden aufgefordert, ihre Zeigefinger und Daumen mit unterschiedlicher Kraft zusammenzudrücken. Die Ergebnisse zeigen, daß die 6·5 Jahre alten Jungen sich von allen anderen Gruppen unterscheiden, indem sie signifikant stärkere assoziierte Bewegungen in allen Kraftstufen aufwiesen. Die Ergebnisse werden diskutiert unter dem Aspekt der Entwicklung inhibitorischer Kräfte zur Kontrolle angeborener neuromotorischer Synergien.

RESUMEN
Diferencias de edad en la magnitud de movimientos asociados
Utilizando una medición cuantitativa de movimientos en espejo no intencionados en la extremidad contralateral, durante la realización de una tarea con una sola mano, se examinó la magnitud de movimientos asociados a lo largo de las edades de seis a 16 años. A chicos de cinco grupos según la edad (con un promedio de 6·5, 8·5, 10·4, 12·4 y 16·5 años) se les pidió que apretaran los dedos indice y pulgar el máximo que pudiese dar de si su fuerza volitiva. Los resultatdos indican que le grupo de 6·5 años diferia de todos los otros, mostrando un nivel significativamente más alto de movimientos asociados en todos los niveles de fuerza. Los resultados se discuten en términos de una inhibicioń del control sobre las sinergias innatas neuromotoras.

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