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Original article

Involuntary left-right antagonism: a supposed archaic sign of neural maturation?

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Abstract

Aims: The aim of this study is to show that toddlers are not yet able to perform synchronous bilateral symmetrical hand and arm movements, and a minority even tends to perform involuntarily bimanual left-right antagonistic movements that are regarded as archaic 'trunk movements', which will disappear with age.

Method: Ninety-seven typical children, 49 toddlers (TD's) (3 yrs 0 months - 3 yrs 12 months) and 48 preschoolers (PS's) (4 yrs 0 months - 4 yrs 12 months), 48 boys and 49 girls, were asked to imitate two types of bilateral movements after a demonstration, namely proximal rotational movements of the arms in the sagittal plane and distal supination-pronation movements at low speed, followed by acceleration on request. The differences were calculated using logistic regression analysis.

Results: All the children were able to perform the movements, but TD's displayed less proximal arm synchronicity than PS's. Proximal antagonistic movements were more common in TD's than PS's, decreasing with age, and differences occurred more often after acceleration.

The differences were also indicative of a decrease in age in the case of distal bimanual movements, but fewer differences were found to be significant.

Conclusions: TD's have not yet fully reached the stage where bimanual movements are symmetrical and synchronous, but they attain the symmetrical stage in the limbs proximally before distally. A minority of the children, mainly TD's, revert to involuntary bimanual antagonism, thus confirming the hypothesis of Mesker, who referred to them as 'trunk movements.'

What this paper adds: It draws the attention to a relatively unknown infantile reflex pattern, antagonistic movements, the retention of which is a sign of immaturity. This could contribute to developmental coordination disorder (DCD).

Keywords: archaic left-right antagonisms; evolution-development principle; bimanual/bilateral motor development; neural maturation; trunk movements.

Introduction

As early as the 1950s, French clinicians observed transient reflex patterns in neonates and studied them in detail **[1, 2]**. Later, these reflex patterns were included in the full neonatal assessment **[3]** as well as assessments for toddlers and pre-school children **[4, 5, 6]**.

Persisting infantile reflexes and associated movements (synkineses) were referred to as ‘minor’, ‘soft’, or ‘subtle’ neurological signs. Their persistence, which can have a negative effect on motor function, reflects supposedly neurological maturation. Therefore, other studies focused on signs of absence of ‘neurological integrity’ from preschool age, referred to as ‘minor neurological dysfunction’ (MND) [**7, 8, 9].**

A number of neurological assessments of older children include the element of synkineses **[7 – 14].** Although the above-mentioned French clinicians described them in neonates, none of these authors gives a description of what we refer to as (antagonistic) archaic trunk movements. Some authors have noticed these movements **[15, 16, 17]**, but have not classified them as archaic or otherwise, nor did they give the movements clinical significance. There are two experimental studies that interpreted antagonistic involuntary movements in children as trunk movements **[18, 19]**.

The synkinetic patterns, studied in this article, are called archaic trunk movements, because they are supposedly phylogenetic vestiges of axial movements. By definition trunk movements are bilateral antagonistic, because they are established by the antagonistic action between homologous muscles on the left and right as in the rotation around the axis of the spine. When in primates the two limbs move simultaneously around their axis (as in supination-pronation), but opposite each other, this is equally a trunk movement (Fig. 2).

Archaic antagonistic movements by the limbs were called for the first time ‘trunk movements’ by the Dutch neuropsychiatrist Mesker **[20]**, who associated them with the elongated, prehensile nose of an elephant as the prolongation the head and body axis. He conceptualised the archaic nature as follows: The ontogenesis of human hand motor function has similarities with the symmetrically moving paired fins in fish and anterior limbs in amphibians (details in the discussion). Limb functions in amphibians for locomotion evolved in primates into two independently moving anterior limbs for actions. The anterior limbs initially show in human neonates archaic symmetrical as well as antagonistic trunk motor remnants (Mesker focused on the last only).

Examples: In the first few months after birth, manual motor function retains characteristics of involuntary archaic motor functioning. This is reflected not only in archaic symmetrical movements **[21]**, but also in involuntary dorso-ventral antagonistic flexion-extension, sometimes as the transient so-called asymmetrical tonic neck reflex (ATNR) (Fig. 1), but also in bimanual involuntary antagonistic pronation-supination (Fig. 2). Moreover, left-right antagonistic motor patterns are seen in neonates as transient left-right locomotor movements while being held upright **[1, 6]**, and transient involuntary crawling in prone position on an inclined plane **[1]**.

Fig. 1. Bimanual antagonistic flexion-extension movements of hands and lower arms	Fig 2. Bimanual antagonistic rotations of the lower arms
	
This six-week-old girl extends her right lower arm and hand, and simultaneously shows arm and hand flexion on the left side, while her head is turned to the right. This is both an involuntary dorso-ventral antagonistic trunk movement and an ATNR pattern.	This four-month-old boy makes pronation-supination movements with his right arm while watching it, and simultaneously pronates the left one. This is an involuntary antagonistic trunk movement.

Photographs are stills of films from the private collection of the second author, used with the parents' informed consent.

A second part of Mesker's concept (the subject of this study) relates to the details of further bimanual development, which falls broadly into three overlapping stages: (1) bimanual motor function, initially uncoordinated and unsynchronized in infants, with symmetrical as well as trunk movements, develops into asynchronous bimanual function with trunk remnants in TD's, then into (2) synchronous symmetrical bimanual function between the ages of three and five (the subject of this study), and finally into (3) stable independent unimanual function and optimal bimanual cooperation without archaic trunk remnants or other synkineses. That stage is attained in later childhood, after the ninth year, and was, together with stage 2 shown in 413 children aged three to ten **[22]**. At that stage actions incorporate also physiological trunk movement patterns.

Research question:

Infants display a shift from unimanual to bimanual reaching during the first year **[23]**, but this motor behavior only becomes stable in Mesker's symmetrical stage between three and five years of age. The bimanual symmetrical type of movement has been investigated mainly in adults, especially during supination-pronation movements, referred to as the 'default mode' **[24, 25]**, but has also been studied in children **[26, 27]**. At the beginning of the symmetrical development stage, TD's begin to perform bimanual symmetrical movements during spontaneous action, and are also able to do so during formal assessment (Fig. 3a and 3b). However, these movements are initially far from synchronous, and in TD's they easily revert to involuntary antagonistic movements (trunk movement). To date this has not been systematically investigated or interpreted as archaic and is the subject of this study.

Bimanual trunk movements of hands and arms (i.e. flexion/extension as in fig. 1) as well as bilateral rotatory trunk movements of the arms (fig. 2) in infants are transient, become less frequent at the symmetrical stage in PS's, and will normally have disappeared by then. This has not been studied systematically and is the subject of this study.

Strong acceleration of movements, speeded up on command, is interpreted as a type of stress that results in the motor system being unable to support that type of movement and reverting to an earlier developmental movement type, in this case trunk motor tendencies.

As trunk movements are rare in TD's, we questioned whether they are elicited by motor stress (acceleration), and whether this tendency is diminishing with age and absent in PS's.

If reverting to trunk movements under acceleration stress diminishes with age, is it different for the proximal (task 1) and the distal movement modes (task 2).

For all the variables examined, the question was whether the movements of the children as measured were dependent on age, gender, and/or hand preference.

N.B. People often speak of bimanual alternating or asymmetric movements, which are left-right antagonisms in muscle terms. In this article we do not use the terms 'alternating' or 'asymmetric'. The term 'trunk movements' in this article is always used in the sense of Mesker's concept.

Methods

Agreement with schools and parents: Parents were informed that trials would be filmed and the recordings would be destroyed after the study was published. and were asked to give written consent for the publication of some recordings, with or without the child being identifiable. The photographs in this article are stills from the recordings that were made.

The developmental model described here relates mainly to bimanual movements in a neurological assessment model.

Participants

Of the 105 children, eight were uncooperative: they were not rated (Table II). For the descriptive statistics on age, hand preference, and gender, see Statistics.

Testing set-up

Trial location and selection: Three nursery schools in Hasselt (Belgium) with typical young toddlers (TD's) and older toddlers (PS's). All the children in the schools (105) participated in the study.

Trial leaders: The trial was conducted by two occupational therapy students, mentioned in the acknowledgement section. They were aware only of the trial protocol, for which they had been trained, not of the hypotheses underlying the trial.

Trial environment: A trial leader's chair was placed in a corner of an empty classroom. In front of her was a table with a stool behind it. The second researcher stood to one side behind the trial leader with a camera.

Position for the trial: Each child stood in a hoop on the floor in order to restrict its movements to some extent.

Conduct of the trial

1. The child was told to sit on the stool (start of the recording).
2. The trial leader wrote the child's initials and subject number in large letters on an A4 sheet, and this was filmed. The paper was turned over and used as described in 3.
3. In front of the child, there was a pencil in the center of a table. The researcher said, "Please draw a circle on the paper with the pencil." The hand preference for drawing (left or right) was noted.
4. The table was moved aside, and the researcher said, "Please stand in the hoop?"
5. The child was then asked to perform hand motor tasks 1 and 2 in a regular sequence.
6. The entire session was filmed. Ratings were only assigned offline, while watching the recordings.

Figure 3a Bilateral circling arm movements in the sagittal plane (Task 1)

Figure 3b. Bimanual symmetrical supination-pronation movements (Task 2)

Drawings by Hans de Beer

Task 1: Bilateral circling arm movements in the sagittal plane (Fig. 3a). The trial leader says, “Can you copy me?” while demonstrating bimanual symmetrical movements in the sagittal plane for approximately four seconds at a slow speed of one complete cycle per second. The trial leader stops as soon as the child performs some movements and says, “Keep going ..,” “Keep going ..,” and after about five cycles “Can you go faster, ... faster?” The child is requested to stop after five seconds of accelerated movement. During all tasks the child moves in its own way and is never corrected.

Task 2: Bimanual supination-pronation movements (Fig. 3b). The child is asked to perform bimanual symmetrical supination-pronation movements after they have been demonstrated: The forearm is bent at an angle of 90º to the upper arm. The instructions and scoring are the same as in Task 1.

Table I shows all items that applied to both tasks 1 and 2.

Table I Offline rating of observed items for the two bimanuel motor tasks

Item	Task 1. Sagittal arm movements. The child … (items 1-7)	
1. | 8.	Immediately performs synchronous symmetrical movements (virtually in phase)	yes/no
2. | 9.	continues performing symmetrical sagittal movements	yes/no
	AFTER THE ACCELERATION REQUEST AND EFFECTIVE IMPLEMENTATION:	
3. | 10.	immediately performs other movements	yes/no
4. | 11.	after a few symmetrical movements switches to other movements	yes/no
5. | 12.	does not perform symmetrical movements (is slightly out of step)	yes/no
6. | 13.	performs clear antagonistic left-right movements	yes/no
7. | 14.	performs chaotic movements (not recognizable as consistently symmetrical or bilateral antagonistic)	yes/no
	Task 2. Supination-pronation movements. The child …(items 8-14)	

The numbered items are the same as numbered as in Table IV.

Assignment of ratings and criteria: The observations were rated in line with the protocol in Table I. The ratings were assigned to the task variables by four observers, namely the two students and the first and third author. Before this, everyone watched three recordings together in order to agree how ratings would be assigned. Movement types in the tasks were rated on the basis of the criterion that at least one complete cycle of a movement type (symmetrical agonistic or antagonistic) was seen.

• *Non-cooperation*: If one of the raters noted that a child refused to cooperate, that child was omitted from the data set for the task that it refused to perform, even if the other raters had the impression that the child was cooperating.

• *Consensus answer*: The four raters did not always give the same answer. We assumed that the majority answer was correct. If there was no majority, the answer given by the first and third authors was taken to be correct.

Statistics and data extraction

We initially divided the 97 children into four age groups, {36-41 m.}, {42-47 m.}, {48-53 m.}, and {54-60 m.} (Table II).

Table II Descriptive statistics on age, hand preference, and gender

Age classes	Frequency	Percentage
36-41 m.	25	25.77
42-47 m.	24	24.74
48-53 m.	20	20.62
54-60 m.	28	28.87
All children	97	100.00

m. = months

Preferred hand	Fre-quency	Percentage
Right-handed	83	85.57
Left-handed	9	9.28
Changing hands	5	5.15

Gender	Fre-quency	Percentage
Girls	49	50.52
Boys	48	49.48

Significance of values used: The cut-off value for statistical significance is 0.05. However, since gender scored a p-value between 0.05 and 0.10 five times with differences in one direction only, gender tends to be important as well. We therefore opted to show the results that are 'nearly significant', i.e. results with a p-value between 0.05 and 0.10.

This study intended to identify potential predictors rather than testing pre-set hypotheses. We also wanted to see if there are returning patterns of the predictors over the whole set of 16 items. Therefore we used a more liberal alpha level cutoff ($p<.10$) instead of the classical ($p<.05$). In order to see how age is related with the 16 items, we also tested which transformation of age has the most predicting power. When a binary form of age ([younger than age Z] versus [older than age Z]) has the most predictive power this suggests a 'jump' in performance on a given age. If age is used as a continuous variable (age can be any number between 36 and 60 months), age has the most predictive power, this suggests a slower, more steady increase in performance.

It is sometimes impossible to calculate a reliable logistic regression due to quasi-complete separation of the data points. In this study, this happened when only a small number of children were rated 'non-optimal' or 'bad' for performance of the variable, and all these children belonged to one specific group. If this problem occurred, we performed a Fisher's exact test.

In a logistic regression, the relationship between the X values and the Y value is non-linear. The increase or decrease in the probability of Y = 'optimal' cannot be deduced directly from the coefficients of the X variables. This can be calculated if absolutely necessary, but it would be complicated, and in this study doing so would not have increased our understanding of the children's behavior. In the case of the study presented here, it is relevant that a positive/negative coefficient of an independent variable Xi means that the probability of the dependent variable Y being 'optimal' increases/decreases.

As the analyses showed that this division in four groups failed to produce significant results, we divided the children into two equal age groups, {36-47 m.} and {48-60 m.} (Table III).

In some analyses, the dichotomy [36-47 m.] versus [48-60 m.], called Age Classification 1, produced the most significant results. However, some analyses most clearly found a significant trend when calculating based on the dichotomy [36-41 m.] versus [42-60 m.], called Age Classification 2, and some analyses produced clearer trends when all the age groups were combined without division in age classes (age can be any number between 36 and 60 months), here called 'age-continuous'.

Table III Subdivision of children into two equal age groups, called Age Classification 1

Number of participants: 97	Children rated				Dropouts
	Boys	Girls	Rated	Percentage	
TD's: 36-47 m.	23	26	49	51	
PS's: 48-60 m.	25	23	48	49	
	48 total	49 total	97 all children	100	8 refusals on 105.

Key: TD's = toddlers; PS's = pre-schoolers; m. = months

The analyses show only the subdivision with the most significant results (Table IV).
Using stepwise logistic regressions, the influence of age, gender and preferred hand (independent variables) was measured on the 14 ratings of the observed items for task 1 and task 2 (Table I) (dependent variables).

Results Various groupings of age and hand preference were tried in the statistical analyses. Table IV shows the groupings that produced the most significant results.

General conclusions for both task 1 and task 2 **(Table IV).**

- Hand preference never has an explanatory value.
- Gender is often only minimally significantly related to performance. In instances where there is a relation between gender and behavior, boys always perform worse.
- In instances where there is a relation between age and behavior, older children always perform better.
- There is either an age-related cut-off value for a given behavior (Age Classification 1 or Age Classification 2 = significant), or there is more gradual improvement (age-continuous = significant), or behavior that is 'performed well' is not significantly related to age.

Table IV Results of the stepwise logistic regression approach (and 1 Fisher's Exact test)

Dependent variables	Remarks	Gender	Age	Hand pref.
Items Task 1				
1.		Boys perform worse (P <0,10)	[42-60] perform better than [36-41] (p < 0,01)	n.s.
2.		n.s.	PS's perform better (continuous data, p <0,001)	n.s.
After acceleration				
3.		n.s.	PS's perform better (continuous data, P <0,001)	n.s.
4.		Boys perform worse (P <0,10)	[48-60] perform better than [36-47] (P < 0,05)	n.s.
5.		Boys perform worse (P <0,10)	[48-60] perform better than [36-47] (P < 0,05)	n.s.
6.		n.s.	[42-60] perform better than [36-41] (P < 0,01)	n.s.
7.	Quasi-complete separation of data points by gender	Boys perform worse (Fisher's Exact test: P <0,05)	n.s.	n.s.
Items Task 2				
8.		Boys perform worse (P <0,05)	[42-60] perform better than [36-41] (P < 0,05)	n.s.
9.		Boys perform worse (P <0,10)	[48-60] perform better than [36-47] (P < 0,05)	n.s.
After acceleration				
10.	nothing signifi-cant	n.s.	n.s.	n.s.
11.		Boys perform worse (P <0,10)	n.s.	n.s.
12.	nothing signifi-cant	n.s.	n.s.	n.s.
13.	nothing significant	n.s.	n.s.	n.s.
14.	nothing significant	n.s.	n.s.	n.s.

Legends: PS's = 48-60 m. or 42-60; TD's= 36-41m. The numbered variables are the same as in Table I. The age groups used for the calculation were either continuous from younger to older or dichotomized based on Age Classification 1, [36-47 m.] versus [48-60 m.] or Age Classification 2, [36-41 m.] versus [42-60 m.]. n.s. = not significant

Results for each task (from Table IV)

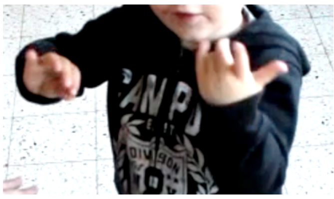
Task 1 *Bilateral arm movements in the sagittal plane before acceleration* (Table I, Items 1-7; results in Table IV): According to the calculation based on Age Classification 2, immediately after instruction TD's start performing symmetrical movements less often than PS's at the start of the sagittal movements (Item 1) and then, based on the continuous age measure (Table IV), less often continue performing symmetrical movements (Item 2).

Task 1 *Bilateral arm movements in the sagittal plane after acceleration.* Based on the continuous age measure, TD's far more often immediately perform movements other than the symmetrical movements required than PS's (Item 3), and the change is differentiated: Based on Age Classification 1, after a few symmetrical movements, TD's perform other non-symmetrical movements (Item 4) or even start antagonistic movements to some extent and getting out of step (Item 5) or, based on Age Classification 2), they more often clearly bilaterally antagonize (Item 6, Fig. 4) compared with PS's.

Fig. 4. Involuntary sagittal antagonistic movement by a 38-month-old boy

After acceleration, this TD performs antagonistic (trunk) movements in the sagittal plane.

Fig. 5. Involuntary antagonistic supination-pronation by the boy from Fig. 5



Spontaneous antagonistic movements after a few symmetrical pronation-supination movements at low speed. The right arm shows ipsilateral synkinetic elbow movements, which we refer to as ‘ipsilateral proximal synkinesis.’

Fig. 6. Supination-pronation ‘out of step’ after acceleration

TS, age 39 m. After acceleration the movements can become asynchronous without developing into a complete trunk cycle. When these movement types alternate rapidly, the overall impression is chaotic.

Task 2 *Bimanual supination-pronation movements* (Table I, Items 8-14): TD's display fewer significant differences than PS's in the whole of this task compared with Task 1. Based on Age Classification 2, TD's less often start immediately performing symmetrical movements than PS's at the beginning of the supination-pronation movements (Item 8), and based on Age Classification 1 they slightly more often perform movements other than those required (Item 9).
Task 2 *Bimanual supination-pronation movements after acceleration*. The effect of accelerating supination-pronation does not differ between TD's and PS's. After acceleration, some children get out of step (Item 12, Fig. 6).

Discussion

The differences between proximal and distal bilateral movements in TD's and PS's *before request to speed it up and after acceleration*:

In Task 1, the differences point in one direction: From the start of the task at low speed, TD's move less synchronously than PS's. After acceleration, synchronicity decreases, and the movement pattern even changes to bimanual antagonism (trunk movements), in TD's more than in PS's. Acceleration disrupts the movements immediately in more TD's than PS's (Item 3), as is the case with symmetrical movements getting out of step (Item 5) and the occurrence of antagonistic movements (Item 6). All this is indicative of more highly developed proximal movements with fewer antagonistic (trunk) movements in PS's. Taken together, there is an improvement in proximal synchronous upper arm movement stability with age and a decrease in the tendency to revert to antagonistic movements (Fig. 4).

In Task 2, TD's also perform less well at low speed than PS's. Acceleration stress disrupts their distal supination-pronation movements, but acceleration stress is unrelated to age differences. This suggests that with more distal movements PS's are still behaving like TD's, suggesting that the development of proximal-axial movements occurs earlier than that of distal rotational forearm movements.

All the children performed the required sagittal arm movements, but quality was poorer across the board in TD's than in PS's, also after acceleration. These findings are in line with the results reported by Van Grunsven *et al*. **[22]**, who found increasing synchronicity between the ages of three and five in the case of sagittal movements and a decline in trunk movements.

If we look at the data in detail, we find that children's stage of development varies: some TD's are already able to make good bimanual synchronous movements, also after acceleration, whereas some PS's have the motor skills of TD's. Mesker's pre-symmetrical and symmetrical motor stages are related to biological maturation and overlap if we take calendar age as an arbitrary criterion.

Although movements are often regarded with a 'clinical eye' as synchronous, in reality true synchronicity never occurs, not even in adults. In laboratory situations the non-preferred hand (generally the left one) lags slightly behind the preferred hand **[24, 28, 29].**

Chaotic movements occur apparently often after acceleration, with no difference between TD's and PS's. The slow motion video's, however, show that these movements consist of symmetrical movements that are suddenly interrupted by brief periods of antagonism (one movement cycle or shorter) or asynchronicity with one side lagging behind, after which the child returns to symmetrical movement. Antagonistic (trunk) movement was arbitrarily rated after a complete cycle, but sometimes one arm/hand lagged far behind the other, producing a picture of antagonism or being 'out of step'; in effect this resembles an incomplete cycle of antagonism (fig. 6).

The infantile and pre-symmetrical stage described by Mesker has been suggested today as well. Involuntary symmetrical tendencies start very early and are interspersed with antagonistic movements **[30]** . D'Souza *et al*. **[21]** investigated 'extraneous movements' in the non-active hand while grasping in 9 to 12-month-old infants: they considered these to be symmetrical in 1/8th of all actions, especially if the tasks were difficult and consider them to be "a vestige of our evolutionary past" (p. 11). In 7/8ths of all actions, there were other unnamed extraneous movements. In Fig. 1 of the article **[21]**, the baby under observation displays the same bimanual antagonism as in our Fig. 1.

The involuntary precursor of symmetrical voluntary movement can be found in the mirrored movements in unimanually manipulating 4.5- to 7.5-month-old infants **[31]**. However, Soska **[31]** wrote (personal communication to first author): "The vast majority of overflow movements were simply associative non-mirrored movements, not very exact. If some infants shook one wrist from left to right, the other wrist might move in the opposite direction; this was rare but did occur."

The phylogenetic vestiges of trunk movements (see Introduction). Cogill **[32]** wrote (1929, p. 20): "As the limbs of the amphibian salamander *Amblystoma* develop, they are at first used solely as a part of the trunk muscle system, having no power of independent movement." A new research line has shown that our hands most likely evolved from prehistoric fish fins indeed [**33]**, as extensions of the torso. Paired fins and eventually limbs evolved from a structure resembling the gill arch of cartilaginous fishes, the evidence of which is provided by the finding of the 'sonic hedgehog' gene (SHH). This shows that human limbs may indeed have evolved from sharks' gills **[34]**.

The clinical importance of trunk movements: The clinical and social significance of the retention of archaic remnants in the form of involuntary synkineses, including trunk movements, is that optimum motor function is not achieved. Developmental coordination disorder (DCD) has been defined in DSM-5 **[35]** as a clinical diagnostic entity, consisting of a spectrum of dysfunctions, one of them being the persistence of infantile reflex patterns. Therefore trunk movements could contribute to the DCD spectrum.

Conclusion

TD's have not yet fully reached the stage where bimanual movements are symmetrical and synchronous (the adult default mode), but they attain the symmetrical synchronous stage in the proximal parts before the distal parts of the limbs. Under acceleration stress, a minority of the children, more TD's than PS's, revert to involuntary bimanual antagonism (trunk movements). This occurs more in distal than in proximal limb movements.

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