

# How motor elements at 3 months influence motor performance at the age of 6 months

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## Abstract

One of the most important achievements of infancy is mobility, through which the child gradually becomes independent and can discover new places and objects. One form of mobility that occurs in a child's development is rolling over from supine-to-prone.

The assumption of the work was to check whether all particular motor elements from the 3rd month had a comparable effect on development in the 6th month of life.

The study population included 119 children, 69 born at term, and 50 born preterm. Children were born at week  $38 \pm 3$  (born at term  $40 \pm 1$ /preterm  $34 \pm 3$ ), with a mean body weight of  $3100 \pm 814$  g (born at term  $3462 \pm 505$ /preterm  $2282 \pm 788$ ). Pre-term children were assessed at the corrected age. The physiotherapeutic qualitative assessment at the age of 3 months was performed in the prone and supine positions, and the qualitative assessment included 15 elements in the prone position and 15 in the supine position. A detailed mathematical analysis was then performed. Values of Cramer's V coefficient with confidence range, Goodman–Kruskal's coefficient, and the values of the probability coefficient p were given.

The position of the scapulae and pelvis (3rd month) had the strongest impact on achieving proper support on the upper extremities in the 6th month of life, while the supine position was most significantly affected by the position of the head, spine, and pelvis.

**Keywords:** infant, motor performance, neurodevelopment, qualitative assessment, statistical analysis

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The examination was performed at the clinic of the Center for Child and Adolescent Neurology in the years 2011-2018 in accordance with the ethical standards of the 1964 Helsinki declaration and its later amendments. Informed consent was obtained from all the parents or caregivers of the subjects.

All parents or caregivers expressed their written consent for use of the personal data for data analysis and publication on the form used in local Medical University.

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The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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## 1. Introduction

In our earlier papers, we focused on global quality, that is, the sum of points a particular child achieved in the 3rd month of life and how it was related to his/her future motor skills (in the 6th, 8th, and 9th month).<sup>[1-4]</sup> Currently, we have focused on a detailed mathematical analysis of the impact of individual elements of the qualitative assessment from the third month of life on the individual elements of the qualitative assessment investigated in the sixth month of life. The assumption of the work was to check whether all elements from the 3rd month have a comparable effect on development in the 6th month of life, or whether the presence or absence in the 3rd month clearly determines the appearance of individual elements in the prone and supine positions in the 6th month, respectively.

One of the most important achievements of infancy is mobility, through which the child gradually becomes independent and can discover new places and objects. One form of mobility that occurs in a child's development is rolling over from supine-to-prone.

Opinions about the moment when this skill is developed are different. Illingworth, based on his own experience, believes that a properly developing child performs it around the 28th week (6.5 months),<sup>[5]</sup> and the same is claimed by Piper and Darrah,<sup>[6]</sup> while subsequent studies suggest that it occurs earlier,<sup>[7]</sup> that is, according to Touwen between 4 and 6 months<sup>[8]</sup> or according to others around the 5th month of life. It is believed that these differences are related to cultural influences or educational patterns of children, as is the case in Japan or China, where children are not left lying on the stomach; therefore, the occurrence of rotation is noticed later.<sup>[9-11]</sup> Nelson claims that even positioning a baby on the stomach while sleeping may affect the age when rolling over from a supine-to-prone appearance (studies carried out in Hong Kong).<sup>[12]</sup>

Recent scientific reports suggest that from 4 to 5 months onwards, infants start to explore rolling movements, from supine to prone and vice versa, and in prone they explore goal-directed progression,<sup>[13–15]</sup> which is associated with socio-emotional changes (becoming more autonomous). Early (already in the 4th month of life) achievement of rotation skills has an impact on the early achievement of independent walking. It becomes a predictor, which is important in medical and physiotherapeutic practice, as it helps to predict the child's achievement of further motor skills.<sup>[16]</sup>

The qualitative assessment of focuses on the individual partial elements that make up one global pattern, and is thus an accurate analysis of the kinesiological content of movement patterns.<sup>[17]</sup> As most authors agree that all healthy children roll over from supine-to-prone correctly (consciously, repetitively, and frequently) on their own when completing 6 months, this time point was adopted as the baseline for the study. At the same time, it was assumed that failure to perform this activity up to this point should already be considered as a delay in motor development.<sup>[17,18]</sup> It is worth emphasising that this does not indicate rolling over as a separate milestone, but about showing that, on the trajectory of motor development, it is an important element of the transition from lying on the back to the crawl position, and then to walking on all fours, upright posture, and independent gait.

The symmetrical position on the back is the condition for rolling over the longitudinal axis of the body. At the age of 4.5 months, when performing a deliberate grip, the body's center of gravity is displaced laterally, the pelvis is slanting in the frontal plane, and the activity of the lower extremities is differentiated. This change in body posture is a condition for performing rolling over from supine-to-prone at the age of 6 months, and at the same time, it is the culmination of this process.<sup>[17]</sup>

In the prone position, in the sixth month, support on the extended upper extremities (pushing chest off the floor with extended arm support), which has already been considered by other authors, for instance, in terms of hypotension, was analyzed. Failure to perform this activity may be the reason for future delay in motor development,<sup>[19]</sup> and it seems that it may affect the crawl position and walking on all fours in the following month.<sup>[17,18]</sup>

From the point of view of the observer analyzing motor development, the third month of life is important, because the child learns to stabilize the head on the trunk<sup>[20]</sup> and learns to move itself through the environment, begins to make movements in an isolated way, for example, points the upper extremities towards the center line.<sup>[21]</sup> Stabilizing the head is the first sign of the proper muscle function necessary for a child to proceed with a more complex function. Many authors agree that the partial motor elements observed in the third month should be regarded as the basis for future motor skills. This is the basis for further proper development of physical activity, which is why it has become important to understand whether features occurring in the third month of life have an impact on physical activity in the sixth month of life.<sup>[3,17,18]</sup>

A previous study analyzed the impact of the occurrence of individual motor development elements, assessed qualitatively in a child at 3 months of age, on the global pattern of movement observed at 6 and 9 months of age.<sup>[4]</sup> Our intention was to show that not so much the achievement of individual milestones, but the correct performance of individual kinesiological patterns translates into an undisturbed trajectory of motor development.

### 1.1. Aim of the study

A detailed mathematical analysis of the relationship between motor development elements observed in the third month of life and motor development elements was examined in the sixth month of life.

## 2. Material and methods

The study group consisted of children who raised no suspicion of their motor development, born at term or preterm (between weeks 28 and 37) or children reported to the Clinic of Neurology, Poznan, Poland for a periodic assessment of the development with a referral from a general practitioner, a pediatrician, or because of parents' concerns (weak head control in the traction response or suspicion of delayed development).

The entire study population included 119 children, 69 born at term, and 50 born preterm. Children were born at week  $38 \pm 3$  (born at term  $40 \pm 1$ /preterm  $34 \pm 3$ ), with a mean body weight of  $3100 \pm 814$  g (born at term  $3462 \pm 505$ /preterm  $2282 \pm 788$ ). Pre-term children were assessed at the corrected age.<sup>[22]</sup>

The exclusion criteria were as follows: genetic or metabolic disorders, severe birth defects, or extreme preterm birth (<28 gestational weeks). None of the children with microcephaly or macrocephaly were included.

All examined children were evaluated after reaching the 3rd month of life (12–16 weeks after birth), and then after 6th months of life (24–30 weeks after birth).

### 2.1. Qualitative assessment in the 3rd month of life

In all children, the physiotherapeutic qualitative assessment of motor performance at the age of 3 months was performed in the prone and supine positions, as presented in previous papers.<sup>[1,2]</sup> The duration of the examination was 10 to 15 minutes. The examination was performed by a physiotherapist at the developmental assessment clinic.

The qualitative assessment included 15 elements in the prone position and 15 in the supine position (Tables 1 and 2, respectively). In the prone position the assessment involved isolated head rotation; arm in front, forearm in intermediate position, elbow outside of the line of the shoulder, palm loosely open, thumb outside, spinal cord segmentally in extension, scapula situated in medial position, pelvis in intermediate position, lower limbs situated loosely on the substrate, and foot in intermediate position. In the supine position, the assessment involved head symmetry, spinal cord in extension, shoulder in balance between external and internal rotation, wrist in intermediate position, thumb outside, palm in intermediate position, pelvis extended, lower limb situated in moderate external rotation, and lower limb bent at a right angle at the hip and knee joints, foot in intermediate position, lifting above the substrate. For symmetrical parts of the body, both sides were assessed to exclude asymmetry.

Each element was assessed as 0–performed only partially or completely incorrectly, and 1–performed correctly. Each assessed element was observed at least three–four times during the test. The result was expressed as the sum of points (0–15 for prone and 0–15 for supine position).

### 2.2. Qualitative assessment in the 6th month of life

The assessment of qualitative development at the age of 6 months in the prone position included the analysis of the following

**Table 1**

**The impact of qualitative elements assessed at the age of 3 months in the prone position on qualitative elements assessed at the age of 6 months in the prone position.**

Qualitative characteristics in the prone position	Side of the body	Support on RUE	Support on LUE	Unfolded RUE	Unfolded LUE	R metacarpal bones abducted	L metacarpal bones abducted
Isolated head rotation, Y/N	-	0.2222 (0.0773-0.3671); 0.0494; P=.0184 0.2887 (0.151-0.4259); 0.0833; P=.0029	0.2166 (0.0720-0.3611); 0.0469; P=.0201 0.2821 (0.1454-0.4189); 0.0796; P=.0029	0.2514 (0.1041-0.3986); 0.0632; P=.0075 0.03226 (0.1828-0.4624); 0.1041; P=.0004	0.2454 (0.0987-0.39921); 0.0602; P=.0084 0.3156 (0.1764-0.4548); 0.0996; P=.0005	0.3232 (0.1671-0.4794); 0.1045; P=.006 0.4070 (0.2589-0.5552); 0.1657; P=.0000	0.3232 (0.1671-0.4794); 0.1045; P=.006 0.4070 (0.2589-0.5552); 0.1657; P=.0000
Arm in front, forearm in the intermediate position, elbow outside of the line of the shoulder, Y/N	Right	0.3040 (0.1683-0.4389); 0.0924; P=.0015 0.2357 (0.1457-0.3257); 0.0556; P=.0140	0.3443 (0.2258-0.4628); 0.1185; P=.0002 0.2318 (0.1431-0.3204); 0.0537; P=.0147	0.2922 (0.1417-0.4427); 0.0894; P=.0017 0.2564 (0.1595-0.3533); 0.0657; P=.0054	0.3319 (0.1941-0.4697); 0.1102; P=.0003 0.2521 (0.1566-0.3476); 0.0636; P=.0061	0.3306 (0.1643-0.4969); 0.1093; P=.0005 0.3094 (0.1953-0.4236); 0.0957; P=.0011	0.3306 (0.1643-0.4969); 0.1093; P=.0005 0.3094 (0.1953-0.4236); 0.0957; P=.0011
Palm loosely open, Y/N	Right	0.2173 (0.1280-0.3065); 0.0472; P=.0289 0.2173 (0.1280-0.3065); 0.0472; P=.0289	0.2136 (0.1257-0.3015); 0.0456; P=.0300 0.2136 (0.1257-0.3015); 0.0456; P=.0300	0.2363 (0.1400-0.3326); 0.0558; P=.0117 0.2363 (0.1400-0.3326); 0.0558; P=.0117	0.2324 (0.1375-0.3272); 0.0540; P=.0130 0.2324 (0.1375-0.3272); 0.0540; P=.0130	0.2852 (0.1714-0.3990); 0.0813; P=.0031 0.2852 (0.1714-0.3990); 0.0813; P=.0031	0.2852 (0.1714-0.3990); 0.0813; P=.0031 0.2852 (0.1714-0.3990); 0.0813; P=.0031
Thumb outside, Y/N	Right	0.2357 (0.1457-0.3257); 0.0556; P=.0140	0.2318 (0.1431-0.3204); 0.0537; P=.0147	0.2564 (0.1595-0.3533); 0.0657; P=.0054	0.2521 (0.1566-0.3476); 0.0636; P=.0061	0.3094 (0.1953-0.4236); 0.0957; P=.0011	0.3094 (0.1953-0.4236); 0.0957; P=.0011
Qualitative characteristics in the prone position	Side of the body	R palm support	L palm support	P unfolded hand	L unfolded hand	R metacarpal bones abducted	L metacarpal bones abducted
Spine in extension, Y/N	-	0.3587 (0.1968-0.5206); 0.1287; P=.0001	0.3815 (0.2229-0.5402); 0.1456; P=.0000	0.2464 (0.0731-0.4198); 0.0607; P=.0081	0.2687 (0.0971-0.4403); 0.0722; P=.0042	0.3942 (0.2248-0.5637); 0.1554; P=.0000	0.3942 (0.2248-0.5637); 0.1554; P=.0000
Scapula situated in the medial position, Y/N	Right	0.3060 (0.1564-0.4557); 0.0937; P=.0011	0.2979 (0.1484-0.4474); 0.0888; P=.0012	0.3479 (0.1969-0.4988); 0.1210; P=.002	0.3393 (0.1887-0.4900); 0.1151; P=.0002	0.4079 (0.2455-0.5703); 0.1664; P=.0000	0.4079 (0.2455-0.5703); 0.1664; P=.0000
	Left	0.3189 (0.1760-0.4617); 0.1017; P=.007	0.3546 (0.2238-0.4855); 0.1258; P=.001	0.3152 (0.1615-0.4688); 0.0993; P=.0007	0.3504 (0.2061-0.4946); 0.1228; P=.001	0.4123 (0.2534-0.5712); 0.1700; P=.0000	0.4123 (0.2534-0.5712); 0.1700; P=.0000
Pelvis in the intermediate position, Y/N	-	0.3499 (0.1931-0.5067); 0.1225; P=.0001	0.3395 (0.1825-0.4964); 0.1152; P=.0002	0.2561 (0.0851-0.4271); 0.0656; P=.0084	0.2452 (0.0741-0.4163); 0.0601; P=.0091	0.4217 (0.2544-0.5890); 0.1778; P=.0000	0.4217 (0.2544-0.5890); 0.1778; P=.0000
Lower limbs situated loosely on the substrate, Y/N	Right	0.3222 (0.2015-0.4430); 0.1038; P=.0003	0.3160 (0.1959-0.4360); 0.0998; P=.0007	0.3056 (0.1642-0.4470); 0.0934; P=.0009	0.2989 (0.1581-0.4397); 0.0894; P=.0011	0.3870 (0.2371-0.5370); 0.1498; P=.0000	0.3870 (0.2371-0.5370); 0.1498; P=.0000
	Left	0.3222 (0.2015-0.4430); 0.1038; P=.0003	0.3222 (0.2015-0.4430); 0.1038; P=.0003	0.3222 (0.2015-0.4430); 0.1038; P=.0003	0.2989 (0.1581-0.4397); 0.0894; P=.0011	0.3870 (0.2371-0.5370); 0.1498; P=.0000	0.3870 (0.2371-0.5370); 0.1498; P=.0000
Foot in the intermediate position, Y/N	Right	0.2598 (0.1338-0.3858); 0.0675; P=.0050	0.2545 (0.1291-0.3799); 0.0648; P=.0055	0.2318 (0.0820-0.3815); 0.0537; P=.0144	0.2261 (0.0769-0.3753); 0.0511; P=.0159	0.3003 (0.1417-0.4589); 0.0902; P=.0015	0.3003 (0.1417-0.4589); 0.0902; P=.0015
	Left	0.2672 (0.1518-0.4006); 0.0763; P=.0025	0.2607 (0.1469-0.3943); 0.0732; P=.0029	0.2514 (0.1041-0.3986); 0.0632; P=.0075	0.2454 (0.0987-0.3921); 0.0602; P=.0084	0.3232 (0.1671-0.4794); 0.1045; P=.0006	0.3232 (0.1671-0.4794); 0.1045; P=.0006

For each pair of variables, the values of Cramer's V coefficient along with confidence interval and Goodman and Kruskal Tau coefficient are given; along with the exact P value. The strongest relationship is marked in bold. L = left, LLE = left lower extremity, N = no (feature absent), R = right, RLE = right lower extremity, RUE = right upper extremity, Y = yes (feature present).

**Table 2**

**The impact of qualitative elements assessed at the age of 3 months in the supine position on qualitative elements assessed at the age of 6 months in the supine position.**

Qualitative characteristics in the supine position	Side of the body	R side shoulder and hip loading	L side shoulder and hip loading	RLE at the facial side is extended, it is flexed at the occipital side	LLE at the facial side is extended, it is flexed at the occipital side
Head symmetry Y/N	–	<b>0.3834</b> (0.2480–0.5188); 0.1470; <i>P</i> = 0.000	<b>0.3093</b> (0.2337–0.6021); 0.0957; <i>P</i> = .010	<b>0.3834</b> (0.2480–0.5188); 0.1470; <i>P</i> = 0.000	<b>0.3093</b> (0.2337–0.6021); 0.0957; <i>P</i> = .010
Spine in extension, Y/N	–	<b>0.4371</b> (0.2757–0.5895); 0.1910; <i>P</i> = 0.000	<b>0.4035</b> (0.2423–0.5647); 0.1628; <i>P</i> = 0.000	<b>0.4371</b> (0.2757–0.5895); 0.1910; <i>P</i> = 0.000	<b>0.4035</b> (0.2423–0.5647); 0.1628; <i>P</i> = 0.000
Shoulder in balance between external and internal rotation, Y/N	Right	0.2774 (0.1132–0.4417); 0.0770; <i>P</i> = .034	0.4942; 0.1310; <i>P</i> = .001	0.2774 (0.1132–0.4417); 0.0770; <i>P</i> = .034	0.4942; 0.1310; <i>P</i> = .001
	Left	0.3616 (0.2056–0.5176); 0.1308; <i>P</i> = .001	0.2901 (0.1271–0.4530); 0.0841; <i>P</i> = .019	0.3616 (0.2056–0.5176); 0.1308; <i>P</i> = .001	0.2901 (0.1271–0.4530); 0.0841; <i>P</i> = .019
Wrist in the intermediate position, Y/N	Right	0.2988 (0.1880–0.4096); 0.0893; <i>P</i> = .015	0.2838 (0.1779–0.3897); 0.0805; <i>P</i> = .024	0.2988 (0.1880–0.4096); 0.0893; <i>P</i> = .015	0.2838 (0.1779–0.3897); 0.0805; <i>P</i> = .024
	Left	0.2988 (0.1880–0.4096); 0.0893; <i>P</i> = .015	0.2838 (0.1779–0.3897); 0.0805; <i>P</i> = .024	0.2988 (0.1880–0.4096); 0.0893; <i>P</i> = .015	0.2838 (0.1779–0.3897); 0.0805; <i>P</i> = .024
Thumb outside, Y/N	Right	0.2988 (0.1880–0.4096); 0.0893; <i>P</i> = .015	0.2838 (0.1779–0.3897); 0.0805; <i>P</i> = .024	0.2988 (0.1880–0.4096); 0.0893; <i>P</i> = .015	0.2838 (0.1779–0.3897); 0.0805; <i>P</i> = .024
	Left	0.2988 (0.1880–0.4096); 0.0893; <i>P</i> = .015	0.2838 (0.1779–0.3897); 0.0805; <i>P</i> = .024	0.2988 (0.1880–0.4096); 0.0893; <i>P</i> = .015	0.2838 (0.1779–0.3897); 0.0805; <i>P</i> = .024
Palm in the intermediate position, Y/N	Right	0.2988 (0.1880–0.4096); 0.0893; <i>P</i> = .015	0.2838 (0.1779–0.3897); 0.0805; <i>P</i> = .024	0.2988 (0.1880–0.4096); 0.0893; <i>P</i> = .015	0.2838 (0.1779–0.3897); 0.0805; <i>P</i> = .024
	Left	0.3209 (0.2097–0.4320); 0.1030; <i>P</i> = 0.000	0.2371 (0.0921–0.3821); 0.0562; <i>P</i> = 0.000	0.3209 (0.2097–0.4320); 0.1030; <i>P</i> = 0.000	0.2371 (0.0921–0.3821); 0.0562; <i>P</i> = 0.000
Pelvis extended (neither anterior nor posterior flexion), Y/N	–	<b>0.4398</b> (0.2804–0.5993); 0.1935; <i>P</i> = .001	<b>0.4076</b> (0.2487–0.5665); 0.1661; <i>P</i> = .001	<b>0.4398</b> (0.2804–0.5993); 0.1935; <i>P</i> = .001	<b>0.4076</b> (0.2487–0.5665); 0.1661; <i>P</i> = .001
Lower limb situated in moderate external rotation, Y/N	Right	0.3620 (0.2502–0.4738); 0.1311; <i>P</i> = .0001	0.3438 (0.2366–0.4511); 0.1182; <i>P</i> = .0001	0.3620 (0.2502–0.4738); 0.1311; <i>P</i> = .0001	0.3438 (0.2366–0.4511); 0.1182; <i>P</i> = .0001
	Left	0.3814 (0.2694–0.4935); 0.1455; <i>P</i> = 0.000	0.3623 (0.2546–0.4699); 0.1312; <i>P</i> = .001	0.3814 (0.2694–0.4935); 0.1455; <i>P</i> = 0.000	0.3623 (0.2546–0.4699); 0.1312; <i>P</i> = .001
Lower limb bent at a right angle at hip and knee joints, foot in intermediate position – lifting above the substrate, Y/N	Right	0.3419 (0.2304–0.4534); 0.1169; <i>P</i> = .002	0.3247 (0.2178–0.4315); 0.1054; <i>P</i> = .004	0.3419 (0.2304–0.4534); 0.1169; <i>P</i> = .002	0.3247 (0.2178–0.4315); 0.1054; <i>P</i> = .004
	Left	0.3419 (0.2304–0.4534); 0.1169; <i>P</i> = .002	0.3247 (0.2178–0.4315); 0.1054; <i>P</i> = .004	0.3419 (0.2304–0.4534); 0.1169; <i>P</i> = .002	0.3247 (0.2178–0.4315); 0.1054; <i>P</i> = .004

For each pair of variables the values of Cramer's V coefficient along with confidence interval and Goodman and Kruskal Tau coefficient are given; along with the exact *P* value. The strongest relationship is marked in bold.

L = left, LLE = left lower extremity, LUE = left upper extremity, N = no (feature absent), R = right, RLE = right lower extremity, RUE = right upper extremity, Y = yes (feature present).

elements: support on the extended upper extremity on the right and left side, hand unfolding (open palm) on the right and left sides, and metacarpal bones in abduction on the right and left sides. In the supine position, the following tests were performed: correct shoulder and hip loading during rolling over on the right and left sides, and correct positioning of the lower extremities, that is straightening of the lower limb on the facial side and flexion on the occipital side, on the right and left sides, respectively (Tables 1–2).

### 2.3. Statistical methods

Due to the nature of the variables, the results were presented as medians with quartiles (Me, Q25–Q75) and analyzed with non-parametric tests (Mann–Whitney U test). The assumed statistical significance level was set to  $P < .05$ .

To assess the association between pairs of nominal categorical variables, the following tests were conducted.

1. To scale the magnitude of the association between 2 nominal variables without regard to the dimensions of the  $r \times c$  contingency table), Cramer's V coefficient was used in place of Pearson's Chi-Squared statistics; the higher the coefficient, the stronger the association.
2. To measure the proportion of variation in one nominal variable attributable to another, the Goodman–Kruskal's test was used; the higher the result, the stronger the influence of one variable on another.

In both cases, exact values of probability (exact *p*-values instead of asymptotic *P* values) were calculated with StatXact-11 Cytel Studio Version 11.1.0.

### 3. Results

Children born at term achieved 15 (13–15) in the prone position and 15 (15–15) in the supine position, whereas children born preterm achieved 15 (11–15) and 15 (15–15), respectively. The difference was not statistically significant; thus, the group was analyzed as a whole.

In the tables describing the results, 1 for the prone position and 2 for the supine position, respectively, values of Cramer's V coefficient with confidence range (the higher the values, the stronger the association), Goodman–Kruskal's coefficient values (the lower the values, the lower the risk that the observed association is random), as well as the values of the probability coefficient *p* (indicating whether the observed association is incidental or non-incidental) were given for each pair of variables.

The highest values of Cramer's V coefficient with the confidence range, with Goodman–Kruskal's coefficient, respectively, and at a significant *P* value are marked in bold in the tables.

In the prone position, the position of the scapula and pelvis in the 3rd month of life had the strongest impact on achieving proper support on the upper extremities in the 6th month of life.

Similarly, in the supine position, the strongest impact on the occurrence of individual qualitative elements of rolling from



supine-to-prone in the 6th month was observed for the position of the head (symmetry means the position in the axis of the spine), the spine in the correct position (proper curvatures present), and the intermediate position of the pelvis (without anterior or posterior flexion) in the 3rd month of life.

Then, we calculated how features in the prone position at the age of 3 months affect features in the supine position at the age of 6 months, and vice versa: how features in the supine position at the age of 3 months affect features in the prone position at the age of 6 months. The results, highlighted in a similar manner, are presented in Tables 3 and 4. It is worth noting that the features in the prone position at the age of 3 months most significantly affected features in the supine position at the age of 6 months included the position of the shoulder girdle and pelvis; with the inverse relationship, the position of the shoulder girdle in the 3rd month did not affect the support at the age of 6th months, but it affected the abduction of the metacarpal bone, while the position of the pelvis and lower limbs in the 3rd month of life in the supine position had an impact on all the features observed in the prone position in the 6th month of life.

#### 4. Discussion

Assessment of motor development can be twofold: either only the presence of certain skills (zero-one determination of whether the child has already acquired them or not), or in the form of a detailed analysis of the kinesiological content that makes up the ability to properly perform a given activity. The first assessment

makes it possible to determine whether a child is developing properly or if the child's motor development is delayed. The second method of assessment emphasises the elements necessary to perform a given activity, and therefore does not exist without the first method of assessment. At the same time, both assessment methods are the reference points for physiotherapy.

Based on the suggestions contained in the work of Soska,<sup>[23]</sup> we assumed that motor development is a continuum in which it is possible to distinguish specific skills, but their acquisition is gradual and consists of small kinesiological elements investigated in the qualitative assessment.

For example, based on Vojta's concept, correct, symmetrical support on the medial condyles of the humerus, occurring as the basis for further motor development, determines the emergence of gradually asymmetrical support on the elbow (around the age of 4.5 months), then support on the wrists and almost extended upper extremities (around the age of 5 months), and finally support the extended upper extremities and open palms (completely at the age of 6 months).<sup>[17]</sup>

Similarly, in the supine position at the age of 3 months, a child acquires the skills of isolated head rotation and hand contact in the center line. A diagonal grip and sideways rolling over at the age of 4.5 months predict the emergence of rolling over from supine-to-prone skill at the age of 6 months,<sup>[6,17]</sup> although some authors suggest earlier timing of this skill.<sup>[17]</sup>

In several developmental scales following further functions are depicted, though there is no common consensus neither to their

**Table 3**

**The impact of qualitative elements assessed at the age of 3 months in the prone position on qualitative elements assessed at the age of 6 months in the supine position.**

Qualitative characteristics in the prone position	Side of the body	R side shoulder and hip loading	L side shoulder and hip loading	RLE at the facial side is extended, it is flexed at the occipital side	LLE at the facial side is extended, it is flexed at the occipital side
Isolated head rotation, Y/N	-	0.3638 (0.2270-0.5007); 0.1324; <i>P</i> =.0001	0.3432 (0.2095-0.4769); 0.1178; <i>P</i> =.0002	0.3638 (0.2270-0.5007); 0.1324; <i>P</i> =.0001	0.3432 (0.2095-0.4769); 0.1178; <i>P</i> =.0002
Arm in front, forearm in the intermediate position, elbow outside of the line of the shoulder, Y/N	Right	0.3416 (0.1837-0.4994); 0.1167; <i>P</i> =.0001	0.4150 (0.2860-0.5439); 0.1722; <i>P</i> =.0000	0.3416 (0.1837-0.4994); 0.1167; <i>P</i> =.0001	0.4150 (0.2860-0.5439); 0.1722; <i>P</i> =.0000
	Left	0.4569 (0.3261-0.5877); 0.2088; <i>P</i> =.000	0.2901 (0.1271-0.4530); 0.0841; <i>P</i> =.0019	0.4569 (0.3261-0.5877); 0.2088; <i>P</i> =.000	0.2901 (0.1271-0.4530); 0.0841; <i>P</i> =.0019
Palm loosely open, Y/N	Right	0.2988 (0.1880-0.4096); 0.0893; <i>P</i> =.0015	0.2838 (0.1779-0.3897); 0.0805; <i>P</i> =.0024	0.2988 (0.1880-0.4096); 0.0893; <i>P</i> =.0015	0.2838 (0.1779-0.3897); 0.0805; <i>P</i> =.0024
	Left	0.2754 (0.1650-0.3858); 0.0759; <i>P</i> =.0040	0.2616 (0.1561-0.3670); 0.0684; <i>P</i> =.0059	0.2754 (0.1650-0.3858); 0.0759; <i>P</i> =.0040	0.2616 (0.1561-0.3670); 0.0684; <i>P</i> =.0059
Thumb outside, Y/N	Right	0.2754 (0.1650-0.3858); 0.0759; <i>P</i> =.0040	0.2616 (0.1561-0.3670); 0.0684; <i>P</i> =.0059	0.2754 (0.1650-0.3858); 0.0759; <i>P</i> =.0040	0.2616 (0.1561-0.3670); 0.0684; <i>P</i> =.0059
	Left	0.2988 (0.1880-0.4096); 0.0893; <i>P</i> =.0015	0.2838 (0.1779-0.3897); 0.0805; <i>P</i> =.0024	0.2988 (0.1880-0.4096); 0.0893; <i>P</i> =.0015	0.2838 (0.1779-0.3897); 0.0805; <i>P</i> =.0024
Spine in extension, Y/N	-	0.4725 (0.3110-0.6340); 0.2233; <i>P</i> =.0000	0.3953 (0.2288-0.5619); 0.1292; <i>P</i> =.0001	0.4725 (0.3110-0.6340); 0.2233; <i>P</i> =.0000	0.3953 (0.2288-0.5619); 0.1292; <i>P</i> =.0001
Scapula situated in the medial position, Y/N	Right	0.3454 (0.1782-0.5127); 0.1193; <i>P</i> =.0002	0.3594 (0.1992-0.5196); 0.0777; <i>P</i> =.0037	0.3454 (0.1782-0.5127); 0.1193; <i>P</i> =.0002	0.3594 (0.1992-0.5196); 0.0777; <i>P</i> =.0037
	Left	0.3933 (0.2355-0.5511); 0.1547; <i>P</i> =.0000	0.2787 (0.1098-0.4477); 0.0777; <i>P</i> =.0037	0.3933 (0.2355-0.5511); 0.1547; <i>P</i> =.0000	0.2787 (0.1098-0.4477); 0.0777; <i>P</i> =.0037
Pelvis in the intermediate position, Y/N	-	0.3968 (0.2292-0.5643); 0.1574; <i>P</i> =.0000	0.3609 (0.1931-0.5287); 0.1302; <i>P</i> =.0001	0.3968 (0.2292-0.5643); 0.1574; <i>P</i> =.0000	0.3609 (0.1931-0.5287); 0.1302; <i>P</i> =.0001
Lower limbs situated loosely on the substrate, Y/N	Right	0.3209 (0.1611-0.4808); 0.1574; <i>P</i> =.0000	0.3481 (0.2025-0.4937); 0.1211; <i>P</i> =.0002	0.3209 (0.1611-0.4808); 0.1574; <i>P</i> =.0000	0.3481 (0.2025-0.4937); 0.1211; <i>P</i> =.0002
	Left	0.3209 (0.1611-0.4808); 0.1574; <i>P</i> =.0000	0.3481 (0.2025-0.4937); 0.1211; <i>P</i> =.0002	0.3209 (0.1611-0.4808); 0.1574; <i>P</i> =.0000	0.3481 (0.2025-0.4937); 0.1211; <i>P</i> =.0002
Foot in the intermediate position, Y/N	Right	0.2302 (0.0609-0.3994); 0.0530; <i>P</i> =.0153	0.2676 (0.1137-0.4216); 0.0716; <i>P</i> =.0048	0.2302 (0.0609-0.3994); 0.0530; <i>P</i> =.0153	0.2676 (0.1137-0.4216); 0.0716; <i>P</i> =.0048
	Left	0.2544 (0.877-0.4210); 0.0647; <i>P</i> =.0074	0.2889 (0.1374-0.4484); 0.0835; <i>P</i> =.0022	0.2544 (0.877-0.4210); 0.0647; <i>P</i> =.0074	0.2889 (0.1374-0.4484); 0.0835; <i>P</i> =.0022

For each pair of variables, the values of Cramer's V coefficient along with confidence interval and Goodman and Kruskal Tau coefficient are given; along with the exact *P* value. The strongest relationship is marked in bold. L = left, LLE = left lower extremity, LUE = left upper extremity, N = no (feature absent), R = right, RLE = right lower extremity, RUE = right upper extremity, Y = yes (feature present).

**Table 4**

**The impact of qualitative elements assessed at the age of 3 months in the supine position on qualitative elements assessed at the age of 6 months in the prone position.**

Qualitative characteristics in the supine position	Side of the body	P dłoń podpór	L dłoń podpór	P rozfaldowana dłoń	L rozfaldowana dłoń	P kosci środkowa w odwróceniu	L kosci środkowa w odwróceniu
Head symmetry Y/N	-	0.1352 (-0.0320-0.3025); P=0.183; P=0.1642	0.1816 (0.0249-0.3383); P=0.0330; P=0.0841	0.1658 (-0.0025-0.3340); P=0.0275; P=0.0884	0.2117 (0.0536-0.3698); P=0.0448; P=0.0246	0.2385 (0.0639-0.4132); P=0.0569; P=0.0172	0.2385 (0.0639-0.4132); P=0.0569; P=0.0172
Spine in extension, Y/N	-	0.1760 (0.0038-0.3481); P=0.0310; P=0.0625	0.2046 (0.0355-0.3737); P=0.0419; P=0.0357	0.2256 (0.0537-0.3976); P=0.0509; P=0.0208	0.2539 (0.0851-0.4227); P=0.0645; P=0.0067	<b>0.3429 (0.1696-0.5163); P=0.1176; P=0.003</b>	<b>0.3429 (0.1696-0.5163); P=0.1176; P=0.003</b>
Shoulder in balance between external and internal rotation, Y/N	Right	0.1362 (-0.0320-0.3025); P=0.183; P=0.1642	0.1292 (-0.0379-0.2964); P=0.0167; P=0.2534	0.1658 (-0.0025-0.3340); P=0.0275; P=0.0884	0.1596 (-0.0083-0.3275); P=0.0255; P=0.0952	0.2385 (0.0639-0.4132); P=0.0569; P=0.0172	0.2385 (0.0639-0.4132); P=0.0569; P=0.0172
	Left	0.1631 (-0.0035-0.3297); P=0.0266; P=0.1225	0.2032 (0.0446-0.3618); P=0.0413; P=0.0387	0.1514 (-0.0216-0.3244); P=0.0229; P=0.1267	0.1912 (0.0240-0.3584); P=0.0365; P=0.0370	0.2346 (0.0566-0.4127); P=0.0551; P=0.0170	0.2346 (0.0566-0.4127); P=0.0551; P=0.0170
Wrist in the intermediate position, Y/N	Right	0.2357 (0.1457-0.3257); P=0.0556; P=0.0140	0.2318 (0.1431-0.3284); P=0.0537; P=0.0147	0.2564 (0.1595-0.3533); P=0.0657; P=0.0054	0.2521 (0.1566-0.3476); P=0.0636; P=0.0061	<b>0.3894 (0.1953-0.4236); P=0.0957; P=0.0011</b>	<b>0.3894 (0.1953-0.4236); P=0.0957; P=0.0011</b>
	Left	0.2357 (0.1457-0.3257); P=0.0556; P=0.0140	0.2318 (0.1431-0.3284); P=0.0537; P=0.0147	0.2564 (0.1595-0.3533); P=0.0657; P=0.0054	0.2521 (0.1566-0.3476); P=0.0636; P=0.0061	<b>0.3894 (0.1953-0.4236); P=0.0957; P=0.0011</b>	<b>0.3894 (0.1953-0.4236); P=0.0957; P=0.0011</b>
Thumb outside, Y/N	Right	0.2357 (0.1457-0.3257); P=0.0556; P=0.0140	0.2318 (0.1431-0.3284); P=0.0537; P=0.0147	0.2564 (0.1595-0.3533); P=0.0657; P=0.0054	0.2521 (0.1566-0.3476); P=0.0636; P=0.0061	<b>0.3894 (0.1953-0.4236); P=0.0957; P=0.0011</b>	<b>0.3894 (0.1953-0.4236); P=0.0957; P=0.0011</b>
	Left	0.2357 (0.1457-0.3257); P=0.0556; P=0.0140	0.2318 (0.1431-0.3284); P=0.0537; P=0.0147	0.2564 (0.1595-0.3533); P=0.0657; P=0.0054	0.2521 (0.1566-0.3476); P=0.0636; P=0.0061	<b>0.3894 (0.1953-0.4236); P=0.0957; P=0.0011</b>	<b>0.3894 (0.1953-0.4236); P=0.0957; P=0.0011</b>
Palm in the intermediate position, Y/N	Right	0.2531 (0.1624-0.3438); P=0.0641; P=0.0067	0.2489 (0.1595-0.3383); P=0.0619; P=0.0072	0.2753 (0.1778-0.3729); P=0.0758; P=0.0024	0.2707 (0.1746-0.3669); P=0.0636; P=0.0028	0.2636 (0.1129-0.4143); P=0.0695; P=0.0062	0.2636 (0.1129-0.4143); P=0.0695; P=0.0062
	Left	0.2215 (0.0542-0.3887); P=0.0490; P=0.0190	0.2514 (0.0886-0.4142); P=0.0632; P=0.0095	0.2689 (0.1016-0.4362); P=0.0723; P=0.0050	0.2984 (0.1355-0.4613); P=0.0890; P=0.0013	0.4233 (0.2574-0.5872); P=0.1783; P=0.0000	0.4233 (0.2574-0.5872); P=0.1783; P=0.0000
Pelvis extended (no anteversion, no retroversion), Y/N	-	0.2856 (0.1935-0.3776); P=0.0815; P=0.0015	0.2808 (0.1900-0.3716); P=0.0788; P=0.0017	0.3106 (0.2119-0.4093); P=0.0965; P=0.0005	0.3054 (0.2081-0.4028); P=0.0933; P=0.0006	0.3749 (0.2599-0.4898); P=0.1405; P=0.0000	0.3749 (0.2599-0.4898); P=0.1405; P=0.0000
Lower limb situated in moderate external rotation, Y/N	Right	0.3009 (0.2082-0.3936); P=0.0905; P=0.0007	0.2959 (0.2044-0.3873); P=0.0875; P=0.0008	0.3273 (0.2280-0.4266); P=0.1071; P=0.0002	0.3218 (0.2239-0.4198); P=0.1036; P=0.0003	0.3950 (0.2799-0.5101); P=0.1560; P=0.0000	0.3950 (0.2799-0.5101); P=0.1560; P=0.0000
	Left	0.2697 (0.1783-0.3611); P=0.0727; P=0.0032	0.2652 (0.1751-0.3553); P=0.0703; P=0.0035	0.2933 (0.1952-0.3915); P=0.0861; P=0.0011	0.2885 (0.1917-0.3852); P=0.0832; P=0.0013	0.3540 (0.2393-0.4688); P=0.1253; P=0.0001	0.3540 (0.2393-0.4688); P=0.1253; P=0.0001
Lower limb bent at a right angle at hip and knee joints, foot in intermediate position - lifting above the substrate, Y/N	Left	0.2697 (0.1783-0.3611); P=0.0727; P=0.0032	0.2652 (0.1751-0.3553); P=0.0703; P=0.0035	0.2933 (0.1952-0.3915); P=0.0861; P=0.0011	0.2885 (0.1917-0.3852); P=0.0832; P=0.0013	0.3540 (0.2393-0.4688); P=0.1253; P=0.0001	0.3540 (0.2393-0.4688); P=0.1253; P=0.0001

For each pair of variables, the values of Cramer's V coefficient along with confidence interval and Goodman and Kruskal Tau coefficient are given; along with the exact P value. The strongest relationship is marked in bold. L = left, LLE = left lower extremity, LUE = left upper extremity, R = right, RLE = right lower extremity, RUE = right upper extremity, Y = yes (feature present).

order nor the detailed time they should appear. The most commonly described functions (“milestones”) are: independent seating, crawling, independent standing near support and side walking, independent walking.<sup>[17,18]</sup>

However, apart from the global assessment, it is worth noting which specific kinesiological elements emerging at individual stages of development determine the emergence of subsequent elements, which were also analyzed in detail. Therefore, the assumption of the study was to analyse how the qualitative assessment at the age of 3 months translates into qualitative analysis at the age of 6 months.

It seems that the adoption of the correct position by the vertebral column and pelvis in the 3rd month determines all subsequent stages of motor development. Undoubtedly, distal features, including manual dexterity, are also necessary for completely correct development, but at least at the stage of achieving basic early motor skills, the proper position of axial elements is crucial.<sup>[3]</sup> Observations of the spine, scapulae, and pelvis abnormalities should be a part of every scale assessing early motor development and should be the primary therapeutic goal if abnormalities are detected. To our knowledge, this is the first report on how isolated motor elements contribute to the proper progression of motor development.

It can be seen that in the prone position, the strongest impact on achieving the correct support on the upper extremities is exerted by adopting the correct position of the vertebral column and pelvis (position of the scapulas and pelvis at the age of 3 months of life). It is worth noting that the relationship with the distal elements of the upper extremity is weaker, although they are undoubtedly necessary for proper support.

Similarly, in the supine position, the strongest relationship between the elements of rolling over in the 6th month and the elements of assessment from the 3rd month of life were shown for the position of the head (symmetry means the position in the axis of the spine) and the spine in the correct position (proper curvatures present), as well as the intermediate position of the pelvis (without anterior or posterior flexion).

If, in turn, the impact of features from the 3rd month in the supine position on the features that the child should manifest in the 6th month, but in the prone position is analyzed, another regularity is revealed: rolling over and support depend primarily on the correct position of the pelvis and stabilization of the lower extremities on the ground. Adoption of correct curvature of the spine and mobility of the thoracolumbar transition in the 3rd month is therefore a condition for the later emergence of rolling over.

What is crucial for the assessment at the age of 3 months, which is to have a predictive value for further motor development, and which is to be the basis for therapeutic activities, are the features associated with the position of the axial elements of the skeleton: head position, curvature of the spine, and position of the pelvis. This has already been described in our publications,<sup>[2,3]</sup> and it has been confirmed by a mathematical analysis conducted using another method. Until now, our attention has been focused on the long-term perspective assessment, and we now want to show that even over a time span of 3 months, which separates the examination dates, such a relationship can be demonstrated.

It should be noted that the highest values of Cramer’s V coefficient (showing what percentage of the feature variation in the 6th month corresponds to a specific element from the 3rd month) are around 0.4371 for the spine. Therefore, there is no 100% correspondence (guarantee) that the occurrence of correct

features in the 3rd month guarantees the appearance of their consequences in later months, which we have already tried to show earlier.<sup>[1]</sup> The authors<sup>[17,18]</sup> raised the issue that the motor development of healthy children is genetically determined only to some extent and proceeds in a fixed way, equally over time for all children, are therefore right. Early development seems to be programmed to some extent, but it can still be influenced by external factors such as social interactions, stimulation, general nutritional status, and other factors that can change motor development with regard to physiology (apart from diseases, defects, other damaging injuries which disturb or delay this development, but this is always a sign of a pathology).<sup>[24]</sup> Obviously, motor development is also influenced by intellectual development (correct initiation of activities and stimulation by the received stimuli), but also vice versa. Proper motor functioning certainly contributes to proper intellectual development. This also applies to emotional and social well-being, but these elements cannot be assessed in one research project.

A healthy child will thus achieve consecutive motor function, probably even without special help. Nevertheless, any extra stimulation: freedom of safe movement, interesting environment, vivid contact with parents / care-givers will enable the full progress. If any abnormalities in the motor development are noticed (as early as possible), special help is indispensable. Properly planned and strictly followed rehabilitation should help the child to achieve as much independence as possible in his/her particular case.

## 5. Conclusions

In the supine position, the strongest impact on the occurrence of individual qualitative elements of rolling over from supine-to-prone in the 6th month of life was reported for the proper curvatures of the spine, and the pelvis was in the intermediate position in the 3rd month of life.

In the prone position, the position of the scapula and pelvis in the 3rd month of life had the strongest impact on achieving proper support on the upper extremities in the 6th month of life.

The position of the pelvis and lower extremities in the 3rd month of life in the supine position had an impact on all the features observed in the prone position at the age of 6 months.

Among the features in the prone position at the age of 3 months, the features in the supine position at the age of 6 months were most significantly affected by the position of the head, spine, and pelvis.

## Author contributions

**Conceptualization:** Ewa Gajewska, Paweł Kroll, Magdalena Sobieska.

**Data curation:** Ewa Gajewska, Magdalena Sobieska.

**Formal analysis:** Ewa Gajewska, Jerzy Moczko.

**Methodology:** Ewa Gajewska, Jerzy Moczko, Magdalena Sobieska.

**Writing – original draft:** Ewa Gajewska, Mariusz Naczka, Alicja Naczka, Magdalena Sobieska.

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