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Original article

NEURODEVELOPMENTAL PROFILE OF 6-MONTH-OLD INFANTS

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ABSTRACT:

Purpose: The first months of life are a critical period for brain development. This study assessed neurodevelopment in 6-month-old infants using the Ages and Stages Questionnaire, Third Edition (ASQ-3), and examined variability across developmental domains.

Material/Methods: A cross-sectional observational study was conducted in Bulgaria between August and December 2025. A total of 146 term infants aged 6 months (±2 weeks) were assessed with the 6-month ASQ-3, covering communication, gross motor, fine motor, problem-solving, and personal-social development. Descriptive statistics, chi-square tests with post-hoc standardized residuals, and independent-samples t-tests were applied.

Results: The highest mean scores were observed in Problem Solving (54.0 ± 8.2) and communication (51.0 ± 7.5), while Gross Motor had the lowest mean score (41.1 ± 11.9). The Gross Motor domain also had the highest proportion of infants requiring monitoring or further assessment (31.5%). Item-response distributions differed significantly within all domains (all $p < 0.001$), with greater variability in several more complex skills. No statistically significant sex differences were found.

Conclusions: Neurodevelopment at 6 months shows substantial domain-specific variability, with basic skills generally more established than complex abilities. Standardized screening with ASQ-3 may support early identification of infants requiring monitoring or further assessment.

Keywords: Child Development, Neurodevelopment, Infant, Mass Screening, Surveys and Questionnaires, Motor Skills,

INTRODUCTION

Early childhood, particularly the first 1000 days of life, represents a critical "window of opportunity" during which the fundamental architecture of the human brain is established [1]. This period is characterized by remarkable neuroplasticity, and cognitive development results from the dynamic interaction between biological maturation and environmental influences [1, 2]. By the age of 6 months, the infant brain undergoes intensive structural and functional changes that form the basis for subsequent neurodevelopment [3].

Contemporary understanding of neurodevelopment is based on the model of interactive specialization, according to which brain structures become functionally organized through active interaction with the social and physical environment [4]. In this context, motor development plays a central role as a driver of cognitive progress. Acquisition of new motor skills during infancy expands opportunities for environmental exploration and supports social, communicative, and cognitive development [5, 6].

Neurodevelopment during early infancy is characterized by individual variability across domains, with basic skills generally emerging before more complex abilities. Developmental processes are increasingly understood as dynamic developmental cascades in which early sensorimotor experiences can shape later cognitive, language, and social functioning [5, 6]. The World Health Organization emphasizes the importance of nurturing care, including responsive caregiving, adequate nutrition, a safe environment, and opportunities for early learning [7]. This highlights the importance of early developmental screening for timely identification of developmental deviations and implementation of early intervention strategies [8]. Accordingly, international recommendations stress the need for systematic developmental surveillance and screening using standardized tools within pediatric and primary health care [8].

One of the most widely used instruments for this purpose is the Ages & Stages Questionnaires, Third Edition (ASQ-3), which evaluates development across five key domains: communication, gross motor, fine motor, problem-solving, and personal-social development [9, 10]. The instrument has demonstrated validity as a developmental screening tool in international cohorts [10].

Despite the significance of early developmental screening, available data regarding the Bulgarian population remain limited, particularly concerning the application of standardized tools such as ASQ-3. This necessitates local studies aimed at better characterizing normal developmental variability and optimizing early diagnostic and intervention approaches.

It is hypothesized that neurodevelopment in 6-month-old infants is uneven across developmental domains, with basic skills being more developed than more complex abilities.

The aim of the present study was to assess neurodevelopment in 6-month-old infants using ASQ-3, characterize developmental variability across domains and item-response patterns, and compare developmental outcomes by sex.

MATERIALS AND METHODS:

Study Design and Participants

A cross-sectional observational study was conducted between August and December 2025 at University Hospital for Active Treatment "Medica Ruse" Ltd., Bulgaria. Participants were enrolled during routine pediatric examinations at 6 months of age.

Initially, 159 infants were screened. After exclusion of cases with incomplete data across developmental domains, 146 validly completed Ages and Stages Questionnaire, Third Edition (ASQ-3) forms were included in the final analysis. The study sample consisted of 146 term infants (gestational age ≥37 weeks; birth weight ≥2500 g) with a mean age of 6.0 months (±2 weeks) at the time of assessment.

Ethical Considerations

The study was approved by the Ethics Committee of University Hospital "Medica Ruse" Ltd. (No. A-471/01. 08. 2025) and was conducted in accordance with the Declaration of Helsinki.

Written informed consent was obtained from all parents or legal guardians prior to participation in the study.

Developmental Assessment

Neurodevelopment was assessed using the 6-month version of the Ages and Stages Questionnaire, Third Edition (ASQ-3), a validated parent-completed developmental screening instrument. The principal investigator was certified in the administration and interpretation of the assessment tool.

The questionnaire evaluates five developmental domains: communication, gross motor, fine motor, problem-solving, and personal-social development.

Each domain consists of six items scored as 0 ("Not yet"), 5 ("Sometimes"), or 10 ("Yes"), with a maximum possible score of 60 points per domain. Higher scores indicate better developmental performance.

Classification of children into developmental zones ("above cutoff", "monitoring zone", and "below cutoff") was performed automatically through the ASQ-3 platform.

To ensure standardized assessment conditions, questionnaires were completed by parents in close temporal proximity to the routine pediatric examination.

Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics Version 19 (IBM Corp., Armonk, NY, USA). Descriptive statistics included means, standard deviations, frequencies, and percentages. Chi-square tests were used to assess differences in response distributions between items within each developmental domain, followed by post-hoc analysis using standardized residuals. Independent samples t-tests and chi-square tests were applied for sex comparisons. A p-value < 0.05 was considered statistically significant.

RESULTS:

The developmental profile of the study group is presented in Table 1. The highest mean scores were observed in the "Problem Solving" domain (54.0 ± 8.2), followed by "Communication" (51.0 ± 7.5), whereas the lowest scores were identified in the "Gross Motor" domain (41.1 ± 11.9).

Table 1. Developmental Profile of the Study Group (N = 146)

Domain	n	Mean	SD	Below cutoff n (%)	Monitoring zone n (%)	Above cutoff n (%)
Communication	146	51	7.5	2 (1.4%)	7 (4.8%)	137 (93.8%)
Female	67	51.7	6.8			
Male	79	50.3	8			
Gross Motor	146	41.1	11.9	16 (11.0%)	30 (20.5%)	100 (68.5%)
Female	67	42.8	12.9			
Male	79	39.6	11.6			
Fine Motor	146	49.5	12.2	9 (6.2%)	14 (9.6%)	123 (84.2%)
Female	67	51	12.7			
Male	79	48.3	11.9			
Problem Solving	146	54	8.2	1 (0.7%)	4 (2.7%)	141 (96.6%)

Female	67	53.7	8			
Male	79	54.1	8.3			
Personal-Social Development	146	48	9.6	2 (1.4%)	9 (6.2%)	135 (92.5%)
Female	67	49.1	9.7			
Male	79	47.2	9.6			

Most children scored above the ASQ-3 cutoff across all domains. Problem Solving had the highest proportion above the cutoff (96.6%), while Gross Motor had the lowest (68.5%) and the highest proportion of children requiring monitoring or further assessment (31.5%).

No statistically significant sex differences were identified in mean domain scores or in the proportion of infants requiring follow-up (Table 2).

Table 2. Sex Comparison Across ASQ-3 Developmental Domains

Domain	**Female (n=67) Mean ± SD**	**Male (n=79) Mean ± SD**	**t**	**p (t-test)**	**Female requiring follow-up n (%)**	**Male requiring follow-up n (%)**	**χ^2**	**p**
Communication	51.72 ± 6.83	50.32 ± 8.02	1.124	0.263	5 (7.5%)	4 (5.1%)	0.361	0.548
Gross Motor	42.84 ± 12.29	39.62 ± 11.62	1.623	0.107	20 (29.9%)	26 (32.9%)	0.157	0.692
Fine Motor	51.04 ± 12.66	48.29 ± 11.85	1.356	0.177	11 (16.4%)	12 (15.2%)	0.041	0.839
Problem Solving	53.73 ± 8.04	54.11 ± 8.31	-0.281	0.779	2 (3.0%)	3 (3.8%)	0.072	0.788
Personal-Social Development	49.10 ± 9.65	47.15 ± 9.63	1.22	0.225	6 (9.0%)	5 (6.3%)	0.359	0.549

Note: *Requiring follow-up includes infants classified in either the monitoring zone or below the ASQ-3 cutoff.*

Item-level responses varied substantially within each ASQ-3 domain. Basic auditory, gross motor, fine motor, and exploratory skills were generally well established, whereas vocal imitation, supported sitting, crawling, and more precise manipulative abilities showed greater variability (Table 3).

Table 3. Distribution of ASQ-3 Item Responses Across Developmental Domains (N = 146)

Domain	**Developmental skill**	**Not yet n (%)**	**Sometimes n (%)**	**Yes n (%)**
Communication	High-pitched vocalization	2 (1.4)	18 (12.3)	126 (86.3)
	Low-pitched vocalization	5 (3.4)	24 (16.4)	117 (80.1)
	Sound localization	1 (0.7)	4 (2.7)	141 (96.6)
	Response to loud noise	1 (0.7)	7 (4.8)	138 (94.5)
	Syllable production (“ga”, “ka”, “ba”)	20 (13.7)	23 (15.8)	103 (70.5)
	Vocal imitation	28 (19.2)	74 (50.9)	44 (30.1)
Gross Motor	Leg lifting in supine position	3 (2.1)	10 (6.8)	133 (91.1)
	Prone chest elevation	8 (5.5)	17 (11.6)	121 (82.9)
	Rolling from back to stomach	9 (6.2)	12 (8.2)	125 (85.6)
	Supported sitting	62 (42.5)	38 (26.0)	46 (31.5)
	Supported standing	47 (32.2)	29 (19.9)	70 (47.9)
	Crawling position	84 (57.5)	20 (13.7)	42 (28.8)
Fine Motor	Sustained grasp of a toy	0 (0.0)	1 (0.7)	145 (99.3)
	Bilateral reaching/grasping	1 (0.7)	9 (6.2)	136 (93.2)

	Reaching for a small object	39 (26.7)	22 (15.1)	85 (58.2)
	Palmar grasp of a small toy	18 (12.3)	13 (8.9)	115 (78.8)
	Thumb–finger grasp attempt	45 (30.8)	34 (23.3)	67 (45.9)
	One-handed grasp	7 (4.8)	6 (4.1)	133 (91.1)
Problem Solving	Reaching for a toy with both hands	2 (1.4)	14 (9.6)	130 (89.0)
	Looking toward a dropped toy	6 (4.1)	15 (10.3)	125 (85.6)
	Attempting to retrieve a dropped toy	4 (2.7)	10 (6.8)	132 (90.4)
	Placing a toy in the mouth	0 (0.0)	2 (1.4)	144 (98.6)
	Transferring a toy between hands	14 (9.6)	26 (17.8)	106 (72.6)
	Banging a toy on a surface	20 (13.7)	18 (12.3)	108 (74.0)
Personal-Social Development	Smiling/vocalizing at mirror image	6 (4.1)	12 (8.2)	128 (87.7)
	Differentiation of strangers	16 (11.0)	57 (39.0)	73 (50.0)
	Grasping feet	9 (6.2)	12 (8.2)	125 (85.6)
	Reaching toward mirror	20 (13.7)	25 (17.1)	101 (69.2)
	Bringing foot to mouth	32 (21.9)	28 (19.2)	86 (58.9)
	Reaching for a distant toy	16 (11.0)	17 (11.6)	113 (77.4)

Table 4. Strongest Post-hoc Effects (|z| ≥3) Across Developmental Domains

Domain	Item	Response	z	Interpretation
Communication	Response to sound	Yes	4.1	Higher than expected
Communication	Vocal imitation	Yes	-5.2	Lower than expected
Communication	Vocal imitation	Sometimes	4.5	Higher than expected
Gross Motor	Lifts legs	Yes	5.2	Higher than expected
Gross Motor	Crawling position	Not yet	5.1	Higher than expected
Gross Motor	Crawling position	Yes	-4.4	Lower than expected
Fine Motor	Grasps toy	Yes	5.6	Higher than expected
Fine Motor	Pincer grasp	Not yet	3.5	Higher than expected
Fine Motor	Pincer grasp	Yes	-3.8	Lower than expected
Problem Solving	Places objects in mouth	Yes	5	Higher than expected
Problem Solving	Places objects in mouth	Not yet	-4.5	Lower than expected
Personal-Social Development	Mirror response	Yes	3.8	Higher than expected
Personal-Social Development	Foot in mouth	Not yet	3.4	Higher than expected
Personal-Social development	Foot in mouth	Yes	-3	Lower than expected

Item-level analysis demonstrated a consistent pattern of stronger performance in basic developmental skills and greater variability in more complex abilities. Auditory orientation was well established, whereas vocal imitation showed greater variability. Basic gross and fine motor skills were highly prevalent, while supported sitting, crawling, and more precise grasping movements were less consistently achieved. Problem-solving performance was strongest for exploratory object-related behaviors, whereas personal-social responses showed greater variability in stranger differentiation. Within each ASQ-3 domain, response distributions differed significantly across the six developmental items (χ^2 = 132.8–294.3; df = 10; all $p < 0.001$). Post-hoc analysis showed higher-than-expected frequencies of "Yes" responses for more established skills and higher-than-expected frequencies of "Not yet" responses for selected more complex abilities (Table 4).

DISCUSSION:

The results of the present study confirm substantial variability in neurodevelopment among 6-month-old infants, corresponding to contemporary concepts describing development as a dynamic and nonlinear proc-

ess [2, 6]. The observed differences between ASQ-3 domains reflect the complex interactions between biological maturation, motor activity, and the social environment.

The domain-specific profile observed in the present study is particularly noteworthy. Problem Solving and Communication showed the highest overall performance, whereas Gross Motor demonstrated the greatest proportion of infants requiring monitoring or further assessment. At the item level, this difference appears to reflect the developmental timing of specific abilities rather than a uniform delay within the domain. Basic gross motor skills, such as leg lifting and rolling, were well established, whereas supported sitting and the crawling position showed substantially greater variability. This pattern illustrates the asynchronous nature of early development, in which individual skills within the same developmental domain may emerge at different rates.

Motor and Cognitive Development

A central aspect of the present study is the relationship between motor and cognitive development. At this age, the acquisition of new motor skills, such as stable sitting, acts as an important driver of development [11, 12]. This not only changes the infant's perspective toward the environment but also frees the hands for active object manipulation, supporting the development of object knowledge and cognitive representations [12].

The variability observed in the fine motor domain likely reflects differences in the development of manipulative abilities. Contemporary studies demonstrate that early motor activity and exploration are associated with later language and cognitive development [5, 13], while fine motor proficiency has been linked to later neurodevelopmental and educational outcomes [14].

Social Interaction

Variability in the communication and personal-social domains may be explained by the transition from sensorimotor exploration to increasingly complex social interaction. At this age, behaviors such as gaze, gestures, and vocalizations become increasingly embedded in communicative exchanges with caregivers [15,16].

The quality of interaction between the child and caregiver, including conversational turn-taking, plays a substantial role in the development of language and social-communicative skills [16]. Previous findings indicate that early vocal interactions between infants and caregivers are associated with the functional development of language-related neural networks from early infancy [17].

Parent-infant interactions and associated biobehavioral regulation also play an important role in socio-emotional functioning [18]. Postpartum depression has also been associated with poorer socioemotional development in infancy [19].

Developmental Variability

Across all developmental domains, a consistent pattern was observed in which basic skills were more developed, whereas more complex abilities demonstrated greater variability. This pattern is consistent with developmental systems perspectives, in which emerging abilities build on earlier sensorimotor experiences and contribute to developmental cascades [5, 6].

Sex Differences

The absence of statistically significant sex differences in the present study is consistent with the broader "gender similarities hypothesis", which proposes that males and females are similar on most psychological variables [20]. This finding emphasizes the importance of individual experience and environmental quality as developmental determinants.

Global Context and Significance

The findings of the present study align with the global framework for early childhood development, which emphasizes the importance of the first years of life for long-term health and developmental outcomes [1, 7]. These findings underscore the necessity of implementing strategies for early developmental assessment and intervention during infancy.

Methodological Value of ASQ-3

The use of ASQ-3 in the present study is based on its established framework and evidence supporting its validity as an early developmental screening instrument [9, 10]. The parent-completed format enables assessment within the child's natural environment, making it particularly suitable for developmental screening in clinical practice.

From a clinical perspective, the findings also illustrate the value of examining both domain-level scores and individual item-response patterns. A total domain score may identify infants who require monitoring, whereas item-level analysis provides additional information about which specific developmental abilities are emerging or remain less established. This distinction may be particularly useful during routine pediatric follow-up, where developmental screening is intended to support surveillance rather than establish a definitive developmental diagnosis.

Strengths and Limitations

The present study provides data regarding neurodevelopmental variability among Bulgarian 6-month-old infants assessed using a standardized developmental screening instrument. However, several limitations should be acknowledged, including the single-center design and the cross-sectional nature of the study, which do not allow assessment of longitudinal developmental trajectories. In addition, developmental outcomes were based on parent-reported measures, which may introduce reporting bias.

CONCLUSIONS:

Neurodevelopment in 6-month-old infants demonstrates substantial variability across developmental domains. Basic developmental skills are generally better established, whereas more complex abilities emerge gradually and show greater individual variability.

The absence of statistically significant sex differences suggests that neurodevelopment at this age progresses similarly in boys and girls.

The findings emphasize the importance of early developmental screening using standardized tools such as ASQ-3 for timely identification of developmental deviations and referral for intervention. These findings support the implementation of standardized developmental screening in pediatric clinical practice.

Abbreviations:

ASQ-3 – Ages and Stages Questionnaire, Third Edition

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Conflict of interest:

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