SHORT REPORT

A study on the body coordination of preschoolers during crawling movements based on kinematic analysis

Wulong Zhang*, Lejia Zhang

College of Physical Education and Sport, Beijing Normal University, Beijing, China.

Received: May 26, 2026; **accepted:** September 14, 2026; **published:** October 27, 2026.

The ages of 3 to 6 are a crucial period for the formation of basic motor skills in children. However, research on the kinematic characteristics of crawling movements in children of this age group is relatively limited. The objective of this study was to explore the body coordination of preschoolers aged 3 - 6 years old during crawling and identify differences among children at different crawling levels through kinematic analysis. A hand-knee crawling test was conducted on 235 children aged 3 - 6 years. High-speed cameras were used for filming, and the Dartfish video analysis software was used to analyze changes in joint angles during the hand-knee crawling process. In terms of hand-knee crawling, the 3 - 4 years old group was mainly at the primary level of 47.69%, while the 5 – 6 years old group was mainly at the advanced level of 49.41%. The distribution differences among age groups were significant ($\chi^2 = 16.83$, $P = 0.002$). At the moment of lifting off and touching the ground, the angles of the shoulder and knee joints in the advanced group were significantly larger than those in the primary group, while the angle of the ankle joint was significantly smaller than that of both the primary and intermediate groups ($P < 0.05$). There were no significant differences in the angles of the elbow, wrist, and hip joints among the three groups. The results indicated that there were differences in the level of crawling among children aged 3 - 6. Advanced level children showed more complete forward extension of the shoulder joint, stronger knee extension, and more reasonable ankle support during crawling. Their movements were smoother and more efficient. This study provided some quantitative indicators for the assessment of crawling movements in preschool children, which was helpful for the early identification of individuals with developmental abnormalities.

Keywords: kinematics; preschooler; crawling movement; body coordination.

***Corresponding author:** Wulong Zhang, College of Physical Education and Sport, Beijing Normal University, Beijing 100875, China. Email: nl83880@163.com.

Introduction

The earliest movement for infants and toddlers to achieve autonomous displacement is crawling. Through crawling, they acquire more movements such as walking and running. Crawling is a way of moving forward on all fours. During this process, the limbs move alternately, and displacement is achieved through the coordinated efforts of the upper and lower limb joints, demonstrating the coordination and balance of the body [1]. Preschool children aged 3 - 6 are in a sensitive period for motor development [2]. During this period, the formation of children's basic motor skills will have a long term impact on their future athletic performance and the learning of other skills [3]. A study reported that early gross motor skills such as crawling, standing, and walking were associated with more advanced pre-language and social abilities [4]. Crawling is the

earliest movement that children develop and encounter. Conducting research on it is of great significance.

At present, crawling has been studied to some extent in physical exercise and rehabilitation [5]. Li *et al*. analyzed surface electromyography signals in 30 muscles of ten healthy adults during hand-knee crawling to explore muscle synergies in crawling [6]. Bai *et al*. investigated the impact of crawling training on cognitive function in children with cerebral palsy and found that cognitive, language, intelligence, memory, and attention abilities of the patients were all improved after crawling training treatment, demonstrating clinical application value [7]. Zhou analyzed the effect of home crawling training on improving behavioral performance in young children. Through a ten-week intervention, it was found that crawling and rhythmic exercises could significantly improve behavioral performance in young children with the effect of crawling exercise being more significant [8]. Yamamoto *et al*. analyzed the variability of crawling ability in infants and compared the differences between typically developmental infants and those with developmental delay. They discovered variability throughout the entire crawling period and greater variability in the timing of limb movement among typically developmental infants during belly crawling [9]. Kim *et al*. compared the body sway data of crawling and gait movements between healthy adults and children with cerebral palsy and found significant differentiation between healthy individuals and cerebral palsy patients ($P < 0.05$) [10]. There are still some shortcomings in the existing research. Most of the current studies on crawling movements focus on adults [11], while studies on children mainly concentrate on those with developmental delays such as cerebral palsy [12]. There are relatively few studies on normally developing children, and the quantitative analysis of the kinematic characteristics and body coordination of crawling movements is insufficient, making it difficult to provide clear reference indicators for the early assessment of motor development. Crawling movements are classified depending on the body parts touching the ground. Hand-foot crawl is defined as the child landing on the ground with hands and feet, supporting by the hands and feet, and coordinating the force to move forward. Hand-knee crawl is defined as the child moving forward with palms, knees, and toes on the ground while torso being parallel to the ground. Belly crawl is defined as the child closing the abdomen to the ground and moving forward by pushing off the ground with the tips of both feet and pulling with both hands.

This study focused on the hand-knee crawling movement of children aged 3 to 6 years old. By using high-speed cameras for filming and combining with the Dartfish video software, the kinematic parameters of children at different crawling levels were analyzed and quantified. The results of this study provided references for the early identification of children's abnormal motor development, offered some scientific support for the formulation of targeted intervention plans, and also enabled a more scientific understanding of the motor development patterns of school-age children.

Materials and methods

Research subjects

The subjects were selected from children aged 3 - 6 in Chang'an District No. 5 Kindergarten, Yuhua District No. 3 Kindergarten, and Gaoxin District No. 2 Kindergarten in Shijiazhuang City, Hebei, China. All participants had no history of neuromuscular disorders, were able to perform continuous crawling movements, and could cooperate with the experiment. All the parents of participants were aware of the purpose and process of the experiment and signed the informed consent. A total of 235 children were recruited for this research, which included 33 boys and 32 girls in age group of 3 - 4 years old with a height of 102.66 ± 4.16 cm and a weight of 15.87 ± 2.41 kg, 42 boys and 43 girls in age group of 4 - 5 years old with a height of 108.45 ± 3.26 cm and a weight of 19.03 ± 2.27 kg, and 42 boys

and 43 girls in age group of 5 - 6 years old with a height of 116.07 ± 5.33 cm and a weight of 21.12 ± 3.39 kg. All procedures of this research were approved by Ethics Committee of Beijing Normal University (Beijing, China) with the approval number of TY20240620.

Classification of crawling movements

Based on the observations, the preschoolers had varying levels of hand-knee crawling, which were classified into three different levels. The primary level was defined by manifestations such as noticeable lateral trunk swaying, unstable weight-bearing direction in the lower limbs, lifting of the lower legs, and outward extension of the elbows and wrists during crawling, indicating poor body coordination. The intermediate level was defined as having no significant trunk swaying during crawling, though the upper trunk exhibiting a certain degree of forward lean. The advanced level was defined as the trunk being straight and showing good stability and the joints of the upper and lower limbs coordinating to exert force, suggesting good body coordination.

Research methods

Before the test, the basic information of the children was recorded. All participants were dressed in tight clothes that were convenient for movement. Two high-speed Casio EXILIM EX-FH25 cameras (Casio, Tokyo, Japan) were positioned 3.5 meters to the left and right sides of the crawling mat to record the entire process of the children' hand-knee crawling movements. Before the formal test, the children were led to do adequate warm-up exercises and had them crawl along the mat in a straight line for about ten cycles to familiarize themselves with the movements. During the formal test, children were required to begin hand-knee crawling from the start line upon hearing the start command and continue until reaching the eight-meter finish line. Each child completed three trials of hand-knee crawling, and the best one was selected for analysis. The video captured was split into frames for analysis by using Dartfish video analysis software (Dartfish SA, Fribourg, Canton of Fribourg, Switzerland) [13]. Since the crawling movement was symmetrical, the right-forward crawling phase within a complete crawling cycle was selected for analysis, and the joint angles of the left upper limb and the right lower limb at the moment of leaving/touching the ground were analyzed.

Statistical analysis

SPSS 26.0 software (IBM Corp., Armonk, NY, USA) was employed for the statistical analysis of this study. The data were presented as the mean ± standard deviation. Chi-square test was used to analyze the differences in the distribution of different crawling levels among children of different ages. Bonferroni correction method was used for post hoc comparisons. One-way analysis of variance (ANOVA) was employed to compare the differences in joint angles during hand-knee crawling among children of different levels [14], and the LSD method was used for post hoc tests. The significance level was set at 0.05.

Results and discussion

Levels of hand-knee crawling movement in preschoolers

The results showed that the proportion of the primary level in age 3 - 4 years group was significantly higher than that in age 4 – 5 and 5 - 6 years group ($P < 0.01$), while the proportion of the advanced level in age 3 – 4 years group was significantly lower than that in age 4 – 5 and 5 – 6 years group ($P < 0.01$). There was no significant difference between age 4 – 5 years group and age 5 - 6 years group in each level (Table 1). The results indicated that, as children grew older, their ability to control their limbs was enhanced, and their body coordination during hand-knee crawling movements was also improved.

Analysis of time for children to complete a crawling cycle

The results demonstrated that, as crawling level increased, the time taken by children to complete a crawling cycle gradually decreased ($P < 0.001$). The primary level used 0.69 ± 0.11 s,

Table 1. Distribution of hand-knee crawling movement levels among children of different ages.

	3 - 4 years old	4 - 5 years old	5 - 6 years old
Primary	31 (47.69%)	18 (21.18%)	15 (17.65%)
Intermediate	19 (29.23%)	31 (36.47%)	28 (32.94%)
Advanced	15 (23.08%)	36 (42.35%)	28 (49.41%

Table 2. Analysis of the upper and lower limb joint angles at the moment of leaving the ground.

Joint	Primary (°)	Intermediate (°)	Advanced (°)	F-score	*P* value
Shoulder	38.72 ± 6.05	39.52 ± 6.64	44.82 ± 11.78	8.21	< 0.001
Elbow	130.09 ± 9.97	132.67 ± 8.64	133.35 ± 9.27	1.76	0.174
Wrist	120.17 ± 6.45	118.55 ± 5.27	117.76 ± 6.68	2.04	0.131
Hip	112.35 ± 9.56	107.21 ± 9.33	105.59 ± 8.71	3.12	0.055
Knee	47.33 ± 6.89	72.21 ± 8.23	75.07 ± 8.02	187.54	< 0.001
Ankle	116.45 ± 14.69	124.71 ± 12.09	87.33 ± 13.37	114.36	< 0.001

which was significantly longer than that of 0.54 ± 0.18 s in advanced level. The intermediate level used 0.67 ± 0.11 s, which was also significantly longer than that of the advanced level ($P < 0.001$).

Analysis of the angles of joints at the moment of leaving the ground

The angles of each upper or lower limb's joint at the moment of leaving the ground in different levels showed that, at the moment of landing the ground, there were significant differences in the angles of the shoulder joint ($P < 0.001$), knee joint ($P < 0.001$), and ankle joint ($P < 0.001$) among the different levels (Table 2). The angle of the shoulder joint at the advanced level was significantly greater than that at the primary and intermediate levels, while there was no significant difference between the primary and intermediate levels. The shoulder joint angle gradually increased with the improvement of crawling movement level in children. Children at the primary level tended to place their hands close to their body while crawling, and as the level increased, they made greater use of the flexibility of the shoulder joint to gain a longer grip distance and move their body forward. The elbow joint remained at around 130°, while the wrist joint at around 120°, indicating that the elbow and wrist joints mainly played a supporting role and underwent change less during crawling. Among the lower limb joints, the hip joint was around 110°. As the level increased, the hip joint angle gradually decreased, indicating that the children were able to maintain a lower body center of gravity, thereby reducing trunk swaying when the upper limbs were supported. The knee joint angle at the primary level was significantly smaller than that at the intermediate and advanced level, while no significant difference was observed between the intermediate and advanced levels. Children at the primary level showed a smaller knee joint angle during crawling, during which the lower limbs were passively supported and had difficulty generating forward propulsive force. In contrast, as the crawling level increased, the knee angle increased, generating a forward propulsive force through calf extension. Therefore, children at intermediate and advanced levels required less time to complete a crawling cycle. In terms of the difference in ankle angles, there were significant differences when comparing children of different levels with each other. Children at the primary level kept their instep pressed to the ground and had difficulty exerting force, while children at the intermediate level also kept their instep pressed down but tried to exert force through ankle dorsiflexion. In contrast, children at the advanced level were able to exert force well through ankle flexion. Overall, advanced children exhibited

Table 3. Analysis of the angles of the upper and lower limb joints at the moment of touching the ground.

Joint	Primary (°)	Intermediate (°)	Advanced (°)	F-score	*P* value
Shoulder	74.78 ± 7.48	78.81 ± 7.59	80.26 ± 8.11	5.67	0.004
Elbow	153.33 ± 7.16	151.67 ± 6.15	149.76 ± 6.83	2.34	0.098
Wrist	121.51 ± 6.56	123.13 ± 6.49	124.35 ± 5.71	1.82	0.163
Hip	100.01 ± 5.47	90.75 ± 5.78	94.71 ± 7.12	2.67	0.072
Knee	46.78 ± 5.94	62.96 ± 7.05	65.18 ± 12.27	58.23	< 0.001
Ankle	115.21 ± 18.03	132.56 ± 11.23	85.15 ± 12.26	95.41	< 0.001

excellent body coordination. During crawling, they increased their stride length by fully extending their upper limbs and exerted force by extending and flexing their lower limbs, achieving smoother and faster movements.

Analysis of the angles of joints at the moment of touching the ground

There were significant differences in the angles of the shoulder joint ($P < 0.01$), knee joint ($P < 0.001$), and the ankle joint ($P < 0.001$) among the different levels (Table 3). In terms of shoulder joint angle, the advanced level was significantly larger than the primary level, and the intermediate level had no remarkable difference with the primary and advanced levels. Children at the advanced level showed a smaller elbow angle of 149.76 ± 6.83°, but the difference was insignificant. The wrist joints also played a supporting role, suggesting less variation. Regarding the lower limb joints, children at the primary level exhibited an excessive upward tilt of the back and a larger hip joint angle, while those at the intermediate level showed excessive folding of the lower limb and a smaller hip joint angle, neither of which was conducive to overall stability. However, the difference of the hip joint angle was insignificant. In terms of knee angle, the primary level was significantly smaller than the intermediate and advanced levels, and there was no remarkable difference between the intermediate and advanced levels. It indicated that, as the level of movement increased, children flexed the knee joint more significantly at the moment of touch for cushioning. In terms of ankle angle, there were significant differences when comparing children of different levels with each other. The results indicated that advanced children kept the ankle in dorsiflexion position and used the proximal end of the instep to make more stable contact with the ground, thereby providing more stable support and force for the body.

Conclusion

The results showed that children aged 3 – 6 years old exhibited different levels in hand-knee crawling. Children at the primary level exhibited poorer body coordination during hand-knee crawling and demonstrated no significant changes in the upper and lower limb joints. They displayed straight arms and high kneeling posture when touching the ground, suggesting support mainly provided by four limbs, therefore, they generated less propulsive force when moving and required longer time to complete one crawling cycle. Children at the intermediate level extended their upper limbs forward and stretched their lower limbs during the crawl, but they still exhibited some incoherent and inefficient force application patterns. Children at the advanced level demonstrated better body coordination. Their upper and lower limb joints worked together, providing cushioning through slight flexion of the joints when touching the ground and achieving full extension when leaving the ground, consequently, they required less time to complete a crawling cycle. The results showed that, as the physical coordination improved, children's crawling skills became more proficient and advanced. In practice, by analyzing the crawling levels of children, their early motor development could be better understood.

References

1. Kawashima K, Funabiki Y, Ogawa S, Hayashi H, Soh Z, Furui A, *et al*. 2020. Video-based evaluation of infant crawling toward quantitative assessment of motor development. Sci Rep. 10(1):1-12.
2. Zhao P, Ji Z, Wen R, Jiang G. 2021. Biomechanical characteristics of walking and running in children aged 3-6 years. Proc Comput Sci. 187(6):224-228.
3. Zhao R, Li X, Wang J, Zhang L. 2023. Effect of basic motor skill intervention on executive function in 3-6 years old children. Med Sci Sport Exer. 55(9S):1051-1051.
4. Gallen A, Taylor E, Salmi J, Haataja L, Vanhatalo S, Airaksinen M. 2025. Early gross motor performance is associated with concurrent prelinguistic and social development. Pediatr Res. 98:1016-1022.
5. Yozu A, Hasegawa T, Ogihara N, Ota J. 2023. Peak vertical ground force of hand–knee crawling in human adults. J Phys Ther Sci. 35:306-310.
6. Li C, Chen X, Zhang X, Chen X, Wu D. 2023. Muscle synergy analysis of eight inter-limb coordination modes during human hands-knees crawling movement. Front Neurosci. 17:1135646.
7. Bai Y, Gao MY. 2022. Effect of crawling training on the cognitive function of children with cerebral palsy. Int J Rehabil Res. 45(2):184-188.
8. Zhou Z. 2023. Effects of crawling exercises at home on improving young children's behavioral performance during the COVID-19 outbreak. J Pediatr Nurs. 73:311-318.
9. Yamamoto S, Matsumura U, Yeonghee L, Tsurusaki T. 2023. Variability in infant crawling with typical development and risk of developmental delay. Early Child Dev Care. 193(8):979-991.
10. Kim H, You JSH. 2022. Dynamic postural instability in children with cerebral palsy: A primary investigation of the validity and reliability of PostureRite measure. Arch Phys Med Rehab. 103(3):e33.
11. Li C, Chen X, Zhang X, Wu D. 2024. Research on the electromyography-based pattern recognition for inter-limb coordination in human crawling motion. Front Neurosci. 18:1349347.
12. Yamamoto S, Lee Y, Matsumura U, Tsurusaki T. 2025. Infant crawling variation related to subsequent development. Infant Young Child. 38(2):127-137.
13. Holland S, Straatman L, MacDermid J, Sinden K, Lalone E. 2020. The development of a novel grip motion analysis technique using the Dartfish movement analysis software to evaluate hand movements during activities of daily living. Med Eng Phys. 85:104-112.
14. Gonca M, Özel MB. 2025. Use of X means and C4.5 algorithms on lateral cephalometric measurements to identify craniofacial patterns. BMC Oral Health. 25(1):1246.