The applied ability in infant crawling and the importance of prone motor experience for subsequent development

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Research Article

Keywords: Infant, Crawling, Variation, Variability, Motor learning

Posted Date: April 17th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-393194/v1>

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Abstract

Background: In the process of motor learning in human, many movement patterns, that is, many variations, are tried first, and more efficient movements come to be selected based on experience of trial and error. Although this process for selection (i.e., variability) is particularly active in infancy neurodevelopment and motor development, few studies have explored the variation / variability of infant crawling.

Aims: The first is to investigate the difference in the variability of hands-knees crawling between typically developing infants with and without belly crawling experience. The second is to examine the relationship between development after 2 years of age and crawling variability.

Study design: This study was longitudinal. Crawling variability was evaluated by encoding crawling variation in infants not pointed out neurological or orthopedic problems. We investigated the differences in the quantity and content of hands-knees crawling variation between infants with and without belly crawling experience. Further, we retrospectively explored the difference in the whole quantity of crawling variation during both belly and hands-knees crawling stages between two groups, suspicious and normal in DENVER Ⅹ conducted after 2 years of age.

Results: The quantity of hands-knees crawling variation was significantly smaller in the group with belly crawling experience than the group without the experience. On the other hand, the content of hands-knees crawling variation was almost the same between these two groups. In addition, there was a significant difference in the whole quantity of crawling variation between the suspicious and the normal group.

Conclusions: The current study shows that infants improve the learning efficiency and variability of hands-knees crawling movements by applying skills acquired through belly crawling experience, which provides one interpretation of the importance of sensorimotor experience in the prone position in infancy. Furthermore, this study suggests a link between crawling variability and subsequent development.

1. Introduction

In the process of gross motor development, the first mobility that infants usually acquire is crawling [1], which promotes the development of the body's sensory and motor systems [2]. There are different types of infant crawling called belly crawling, hands-knees crawling etc. [3]. Belly crawling is the action in which infants move by drawing the body along the ground on the abdomen [4]. Hands-knees crawling means moving by lifting the abdomen up on both arms and knees. Hands-knees crawling, which appears typically after belly crawling, has long been regarded as important for subsequent development. It has been suggested that hands-knees crawling may be involved not only in motor development but also in psychological development [2, 5–8]. However, not all infants follow a similar crawling process.

The frame work called the neuronal group selection theory (NGST) is often used to understand human motor development [9–11]. In this theory, typical motor development includes some elements such as

repertoire, variability and variation. Repertoire means the intrinsic movement patterns individual has, and variability denotes the capacity to select the movement that fits the situation best from the repertoire. Variation means the movement patterns observed as a result of motor behavior, indicating the presence and expression of a broad repertoire of behaviors for a specific motor function [10]. In addition, according to the NGST, motor development is characterized by two phases: primary and secondary variability, and the borders of variability are determined by genetic instructions [12]. During the primary variability phase, motor behavior is characterized by abundant variation, which is induced by exploratory activity of the nervous system. After shifting primary to secondary variability, the nervous system begins to use the afferent information produced by behavior and experience for selection of the appropriate motor behavior, and the variation gradually converges [10]. There have been many exploratory studies on the variability of movements such as sucking, sitting and general movements [13–19]. On the other hand, there are still unclear points regarding the variability of infant crawling although its diversity has been revealed so far [11, 20].

Since the 1930s, researchers have described belly and hands-knees crawling as a series of postural stages [21, 22]. However, some infants experience both belly crawling and hands-knees crawling, others experience only hands-knees crawling [23]. Previous studies have explored some relationship between belly crawling and hands-knees crawling. Interestingly, it has been shown that infants who formerly belly-crawled showed more proficient hands-knees crawling (in terms of velocity etc.) than those who skipped the belly crawling period [24]. It has also been reported that infants who spent a greater amount of awake time in the prone position achieved hands-knees crawling earlier [25]. The results of these previous studies imply the possibility that crawling changes the forms and becomes sophisticated as the variability matures. With this background, belly crawling experience is considered to be involved in the variability of hands-knees crawling and to affect subsequent development. To our knowledge, however, the effect of belly crawling experience on the variability of hands-knees crawling and subsequent development has not been investigated. Therefore, it is needed to reveal these relationships in the present study.

In addition, there are previous studies linking delayed motor development in infancy with subsequent developmental delay. For instance, individuals who are markedly late in achieving developmental milestones are at high risk for a subsequent diagnosis of learning disability/mental retardation [26, 27]. It has been also found that the developmentally delayed infants could be preliminarily distinguished from the typically developing (TD) infants by the features of inter-joint synergy during their crawling stage [28]. These results indicate that it is possible that some factors to predict infant's subsequent development may be hidden in crawling variability.

Therefore, the purpose of this study is the following two. The first one is to investigate the difference in the variability of hands-knees crawling between TD infants with and without belly crawling experience. The second is to explore the relationship between development after the age of 2 and crawling variability.

It should be noted that we decided to focus on the quantity and content of variation as the evaluation index of variability in this study. Then, we decided to investigate the quantity of crawling variation and the content of variation that appears commonly or frequently among infants, and to compare these between infants. In addition, “variation” is used similar to “pattern” as a word to describe the type of crawling movement from the following.

2. Material And Methods

2.1. Design and participants

The design of this study was longitudinal. The subjects were infants who had no diagnosis of any kind at the time of crawling stage (e.g., no neurological or orthopedic problems), and were recruited at two nurseries. As a result, 42 infants participated in this study.

2.2. Measures

In this study, we referred to previous studies to quantify crawling variation [20, 29, 30]. We used six local area network-compatible cameras (Qwatch TS-WLCAM; IO DATA, Kanazawa, Japan) to film crawling simultaneously from the front, back, left, right, and top (two directions) (Fig. 1). The filming was performed inside the nurseries or our laboratory at 1–2-week intervals and continued from the time when infants began crawling until the acquisition of independent walking. We regarded the time when most of locomotion in the nursery shifted from hands-knees crawling to walking independently as the end point for hands-knees crawling (the acquisition of independent walking). This point was judged by physical therapists and nursery teachers. One cycle of crawling was defined as the interval between the left (or right) upper limb leaving the floor and the trunk moving until the left (or right) upper limb left the floor again. Approximately 10 cycles were filmed in each session. After that, the crawling movement in the video was coded objectively using the “the Criteria for Crawling Motion Analysis” previously developed by physical therapists to investigate the crawling variation for each infant [30]. A prior study has demonstrated the reliability between and within observers in the criteria [29]. The explanation about coding is described below. First, for each crawling cycle, the movements observed in each segment are digitized according to these criteria. These criteria consist of a total of 24 items, including 6 items for the upper limbs, 5 items for the head, 7 items for the trunk, and 6 items for the lower limbs. By arranging the numbers assigned to each item in order to make a 24-digit number, it is a code that represents the movement pattern of the whole body per cycle of crawling (Fig. 2). We examined the cumulative number of code’s types for each infant in the period of crawling and considered this number as the cumulative number of crawling variations, i.e. the quantity of crawling variation. In this study, the cumulative number of belly crawling variations and hands-knees crawling variations are described as CNBCV and CNHKV, respectively.

After evaluation of crawling variability, developmental evaluation was performed using DENVER II (Japanese Edition DENVER Ⅱ) [31, 32] when the target infants became older than 2 years old. DENVER II is comprised of four subdomains: personal–social, fine motor/adaptive, language, and gross motor, and

assesses the development of children to assign the dichotomous outcomes of “normal” or “suspicious” based on the assessment. In this study, for the cases suspected of having developmental delay in DENVER II and the cases of preterm birth / low birth weight were excluded from the analysis to compare the CNHKV and the contents of hands-knees crawling codes between groups with and without belly crawling experience. In addition, for children with suspected developmental delay in DENVER II, we retrospectively explored the difference in the total cumulative number of crawling variations, which is the sum of CNBCV and CNHKV, between them and children without subsequent developmental delay.

2.3. Statistical analysis

We used JMP Pro 15 (SAS Institute Japan, Ltd., Tokyo, Japan) for the data analysis. Independent *t*-test was used to examine differences in the developmental data (e.g., CNHKV) between genders, and to examine the difference in CNHKV between groups with and without belly crawling experience, and to examine the difference in the total cumulative number of crawling variations between the normal group and the suspicious group in DENVER II. Differences between groups were considered significant if the *p*-value was less than 0.05.

3. Results

Figure 3 shows the flow-diagram of this study. we excluded infants/children including shuffling babies (*n* = 2) who did not perform crawling, and who were not evaluated for crawling or subsequent development due to lack of data (poor physical condition), leaving nursery, and analyzed the remaining 21 infants (15 males, 6 females) who completed both the crawling evaluation and the subsequent developmental evaluation. Among these 21 participants, 13 infants experienced belly crawling and hands-knees crawling, and 8 infants experienced only hands-knees crawling. Only one case (case F) was a preterm birth and low birth weight infant (33 weeks, 1884 g). In addition, as a result of DENVER II, 5 (including case F) out of 21 children were suspected of having developmental delay after the age of two.

Table 1 shows the developmental characteristics and cumulative number of crawling variations for each case. A wide range of data were observed for each item, and individual differences were apparent. There were no statistically significant differences for all data (e.g., the age at crawling, CNHKV) between genders.

The CNHKV was significantly lower in the group with belly crawling experience than in the group without belly crawling experience, as shown in Table 2 (*p* = 0.029). This result indicated that infants who had belly crawling experience tended to express fewer variations of hands-knees crawling than those who had no experience of belly crawling.

The following are the results of analyzing the crawling code (i.e., variation) shown by TD infants in this study. The total CNBCV in all cases was 217 (*n* = 11), and the total CNHKV in all cases was 389 (*n* = 16), both of which showed many patterns of crawling. Also, while there was no code common between cases in the belly crawling code, there were more than 5 types of code common between cases in the hands-

knees crawling code. Table 3 shows the top five codes of hands-knees crawling common to infants in each group of with and without belly crawling experience, and it was found that these common codes basically appears more frequently in the second half of hands-knees crawling stage. For example, the appearance rates of the codes "211121-13131-2222233-221111" and "211121-13131-2222244-221111" increased by about 4 points in the second half compared to the first half (10% → 14%, 8% → 12%). As shown in Table 3, there was not much difference in the contents of the common variation of hands-knees crawling between the groups with and without belly crawling experience because the top three codes with the most common cases were equal between the two groups.

In table 4, there is a statistically significant difference in the total cumulative number of crawling variations including both CNBCV and CNHKV between the normal group and the suspicious group ($p = 0.024$). That is, the suspicious group had fewer number (smaller amount) of crawling variations.

4. Discussion

We conducted a longitudinal study to investigate the variability of TD infant crawling, especially the relationship between belly crawling and subsequent hands-knees crawling. Further, we retrospectively investigated the difference in crawling variability between children suspected of having developmental delays and children who developed normally during the subsequent growth processes. The key outcome measures in this study were the cumulative number and the content of crawling variations which each infant showed during the crawling stage. The results in this study indicated that infants who had belly crawling experiences acquired hands-knees crawling more smoothly and efficiently later. Regarding the content of the crawling variation, it was found that there was not much difference in the contents of the variation of hands-knees crawling between the groups with and without belly crawling experience. We also found that there was some relationship between whole quantity of crawling variation and subsequent development in early childhood.

As shown in Table 1, the greatest age (days) for independent walking was 490 (Case C), which was within the age range specified by the World Health Organization for independent walking among TD infants [1]. Therefore, we considered that none of the recruited infants had any delays in motor development at the end of crawling. In addition, the belly crawling experience rate for infants in this study was 62 % (13 out of 21), which almost matched the result of previous study [24].

4.1. Difference in variability of hands-knees crawling between infants with and without belly crawling experience

The result in Table 2 indicated that infants who had belly crawling experience tended to express fewer variations at hands-knees crawling stages than those who had no experience of belly crawling. It is thought that this is because the experience of belly crawling promoted the maturation of hands-knees crawling's variability. Generally, infancy is the period of transition from primary variability to secondary variability (i.e., from motor behavior that cannot be adapted to task-specific conditions to adaptive motor

behavior). This transition of variability occurs at function-specific ages [10]. A recent observational study indicated that the transition of variability in abdominal progression occurs between 8 and 15 months [15]. Based on the above, it is considered that infants in the belly crawling stage have already begun to fully learn how to move their bodies in the prone position through the experience of primary variability and secondary variability. In particular, the process of selecting the proper motor behavior, which is characteristic of secondary variability, is based on active trial and error experiences [33, 34], which means that motor behavior with its associated sensorimotor experience plays an important role in motor development [35, 36]. In this study, because the sensorimotor experience at the belly crawling stage strengthened subsequent hands-knees crawling's secondary variability, infants with belly crawling experience did not require much trial-and-error experience and were considered to have efficiently mastered adaptive hands-knees crawling. In addition, it should be considered that the amplification of the motor repertoire caused by the exploratory motor experience in belly crawling's primary variability may have contributed to the learning efficiency of hands-knees crawling movement. As a result of these above, it is considered that the group with belly crawling experience had significantly smaller CNHKV in this study. In other words, infants begin learning how to crawl on their hands-knees in advance throughout the belly crawling stage. On the other hand, infants who had had no experience with belly crawling faced the challenge of locomotion in prone position for the first time at hands-knees crawling stage. Therefore, it seems that they had to try more variations before implementation of stable hands-knees crawling is possible, and as a result, the CNHKV increased relatively in the group without belly crawling experience. Previous studies have also shown that many variants are attempted during belly crawling in TD infancy [24, 37, 38], and that crawling on the hands-knees is more proficient in infants who explore belly crawling substantially with a wide variety of postures than in those with limited belly crawling experience [24]. Taking these into account, we considered that our results support the previous findings mentioned above, which suggested the relationship between belly crawling and hands-knees crawling. Further, in this study, we demonstrated that belly crawling experience promoted the development of variability in hands-knees crawling.

We also analyzed the contents of crawling codes to investigate how the variation of belly crawling was utilized at the stage of hands-knees crawling. First, the total CNBCV in all cases was 217 ($n = 11$), and the total CNHKV in all cases was 389 ($n = 16$), both of which showed lots of patterns of crawling. However, while there was no code common between cases in the belly crawling code, there were more than 5 types of code common between cases in the hands-knees crawling code. Especially, among the hands-knees crawling codes, the code "211121-13131-2222233-221111" was common to 14 cases (Case A, D, G, I, J, K, L, M, N, O, P, R, T, U), and the usage of this code increased by 4 points in the second half compared to the first half of hands-knees crawling stage. In addition, it was found that the variations often observed in hands-knees crawling were almost the same regardless of experience with belly crawling. (Table 3). Therefore, these results mean that each infant, who showed a unique crawling movement pattern at belly crawling stage, began to show common physical usage among the infants at hands-knees crawling stage, regardless of their experience with belly crawling, and its common movement patterns gradually increased toward the end of crawling period. In addition to this result, considering the result of Table 2

that infants with belly crawling experience utilize the experience to improve the efficiency of motor learning in hands-knees crawling, the motor learning in the prone position in infancy could be explained as follows. That is, infants with belly crawling experience have a repertoire of various movements at the belly crawling stage. Afterwards, when they learn hands-knees crawling (that is, higher difficulty or applied motor skills), they select the appropriate variations at the body part level from the individual-specific repertoire that they have accumulated through belly crawling experience, and coordinate typical or adaptive whole body movements by combining the partial body variations more efficiently. Therefore, this study showed that in the process of learning new motor skills for infants, they improve the learning efficiency by skillfully extracting and combining the necessary body movements partially from the motor repertoire they have accumulated so far. A previous study using electromyography (EMG) reported that the synchrony of the upper and lower limbs may gradually improve as the spinal circuit matures in infant crawling movements [39], which is considered to be one of the factors that belly crawling experience improved the coordination of partial body variations in hands-knees crawling in this study. It has also been revealed the process of learning to select the most adaptive sitting postural adjustment from the repertoire in infancy [14]. On the other hand, the relationship between human motor development and language development has been suggested in various research fields such as neurophysiology and behavioral studies [40–42]. Recent findings indicate that infants possess powerful computational skills that allow them automatically to presume structured models of their environment from the statistical patterns they experience [43]. For example, infants use statistical patterns gleaned from experience to learn about both language and causation. Before the age of three, children use frequency distributions to learn which phonetic units distinguish words in their native language [44, 45], use the transitional probabilities between syllables to segment words [46], and use covariation to infer cause-effect relationships in the physical world [47]. These findings show the ability of infants to skillfully analyze their own experiences and efficiently adapt to their surroundings based on external feedback. Therefore, this study may also have demonstrated that infants in the crawling stage efficiently advanced motor learning from individual-specific belly crawling to typical hands-knees crawling based on interaction with the environment. It should also be noted that infants who showed only hands-knees crawling without experiencing belly crawling in this study have steadily advanced motor learning in the prone position through the motor experience other than belly crawling or the experience of hands-knees crawling because they were finally able to express the typical hands-knees crawling variations.

4.2. The relationship between crawling variability and subsequent development

While examining the relationship between crawling variability and subsequent development, we found that there were few crawling variations of children assigned to the suspicious group in DENVER II. Therefore, the averages of the total cumulative number of crawling variations, the sum of CNBCV and CNHKV, were compared between the two groups, suspicious and normal. As a result, the total cumulative number of crawling variations was significantly lower in the suspicious group than in the normal group, as shown in Table 4. This result indicated that infants with overall fewer movement variations (i.e., with the possibility of limited motor repertoire) during crawling stage were likely to have subsequent

developmental delay, especially in early childhood. It is generally known that motor variation is restricted in general movements in infants with cerebral palsy who show motor dysfunction [10]. In this study, the suspicion of developmental delay was confirmed in the subdomains of fine motor / adaptive and language in DENVER II. Based on these above, it is conceivable the association between crawling variability and subsequent language / fine motor development, but these relationships have not yet been investigated in detail in this study. Therefore, we would like to examine these relationships that may be useful for clinical practice in the future.

4.3. Clinical significance of this study

In recent years, the opportunity to experiment with movement in the wakeful prone position, termed “tummy time”, has been reported to be beneficial for infant development [48–50]. Tummy time is defined as an infant being placed on their stomach while they are awake and supervised [49]. The American Academy of Pediatrics has recommended a certain amount of tummy time while the infant is awake and observed to promote development [51, 52]. Evidence supports the relationship between tummy time and early motor skill acquisition in TD infants [53, 54]. The early implementation of tummy time has also been shown to be effective for reducing motor delay in not only young TD infants, with but also those with Down syndrome [55]. As mentioned above, it can be said that being in the prone position at an earlier stage is important for infant development. In addition, according to neurodevelopmental science, previous studies have documented the exuberant development of neural pathways throughout all brain regions in the early postnatal period [56, 57]. Further, based on the NGST, neural development in infancy is affected by not only motor experience, but also environmental factors [11, 43, 58]. It has also been reported that infants in the first months of life use early finger and hand movements to explore novel sensory stimuli that are placed in their hand demonstrating early use of somatosensory input to modify motor behaviors [59], and that infants at this time already control their posture during spontaneous movements and in response to perturbations [16, 60, 61]. Moreover, the ability of infants to coordinate the sensory, motor, and postural control systems improves with experience [62, 63]. These reports suggest the importance of sensorimotor experience from the early postnatal period, and this study further showed that motor skills accumulated by the sensorimotor experience are efficiently used in the process of learning new motor behaviors. Based on the above, it is considered that infants need to be exposed to various opportunities for motor experience at a younger age. Therefore, the results in this study not only supported the importance of activities in the prone position such as tummy time, but also suggested the necessity of sensorimotor experience in the prone position (during tummy time).

4.4. Limitations

This study had several limitations. First, the number of participants was small. Second, because the filming interval of crawling was 1–2 weeks, it was possible that the transition of crawling variation has not been completely reproduced. Further, the evaluation age of DENVER II was 2–5 years, which was inconsistent among children.

5. Conclusion

The results of this study show that infants facilitate the motor learning and variability of hands-knees crawling by efficiently applying the experience of belly crawling. In addition, a learning process is proposed in which infants partially select body movements from their existing repertoire and efficiently combine them to acquire new skills during crawling stage. Furthermore, this study suggests a link between crawling variability and subsequent development.

6. Declarations

6.1 Ethics approval and consent to participate

This study was approved by the Ethics Committee of the Nagasaki University Graduate School of Medical Facilities (Approval No. 18061431). Written informed consent was obtained after the content of the study was fully explained and well understood by the infants' parents. All methods were carried out in accordance with relevant guidelines and regulations.

6.2. Consent for publication

Informed consent to publish identifying images in an online open-access publication was obtained from infant's parents and other participants.

6.3. Conflicts of interest

The authors declare no conflicts of interest.

6.4. Funding

This work was supported by JSPS KAKENHI Grant No. JP18K02444.

6.5. Acknowledgments

We wish to thank the nurseries and staffs for their cooperation with this study, as well as all the mothers and infants who shared their experiences.

6.6. Authors' contributions

All authors were involved in the concept and design of the study. SY, TT and YL collected the data and SY wrote the manuscript. TT critically reviewed and revised the manuscript. All authors have read and approved the final manuscript and agree to be accountable for all aspects of the work. No form of payment was given to anyone to produce the manuscript.

6.7. Availability of data and materials

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

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Tables

Table 1. Developmental characteristics and cumulative number of crawling variations in each case (n=21).

Case	Belly crawling experience (Yes/No)	Age at crawling (days)	From belly to hands-knees (days)	Age at independent walking (days)	CNBCV	CNHKV	Total variations	Number of videos taken	Result of DENVER $\square$ (Normal/Suspicious)	Age at DENVER $\square$
A (M)	N	251		425		45	45	11	N	5y9m
B (M)	Y	245	273	386	13	36	49	13	N	5y8m
C (M)	N	363		490		31	31	9	S	5y10m
D (M)	Y	266	308	422	30	29	59	15	N	5y6m
E (F)	Y	267	274	421	8	30	38	10	S	5y5m
F (M)	Y	284	319	439	15	13	28	8	S	4y10m
G (F)	Y	286	307	392	7	19	26	8	N	4y9m
H (F)	N	284		450		46	46	11	N	4y1m
I (F)	Y	250	278	416	30	18	48	12	N	3y9m
J (M)	Y	219	307	363	43	11	54	13	N	3y8m
K (M)	N	197		325		42	42	15	N	3y11m
L (M)	Y	226	253	387	34	29	63	16	N	3y0m
M (M)	Y	215	229	336	5	22	27	16	N	2y6m
N (M)	Y	267	296	365	12	27	39	11	N	2y7m
O (M)	Y	263	326	480	20	18	38	21	N	2y6m
P (F)	Y	361	361	427	1	31	32	10	N	2y5m
Q (M)	N	251		314		12	12	7	S	2y1m
R (M)	Y	285	292	432	20	45	65	13	N	2y2m
S (M)	N	253		465		30	30	19	S	2y0m
T (M)	N	341		460		23	23	13	N	2y1m
U (F)	N	362		460		36	36	11	N	2y1m
Mean		273.1	294.1	412.1	18.3	28.2	39.6	12.5		
SD		46.9	32.4	49.1	12.2	10.6	13.4	3.5		

M: male, F: female, CNBCV: cumulative number of belly crawling variations, CNHKV: cumulative number of hands-knees crawling variations, Total variations: total cumulative number of crawling variations, SD: standard deviation.

*p < 0.05. CNHKV: cumulative number of hands-knees crawling variations, Total variations: total cumulative number of crawling variations, SD: standard deviation.

Table 2. Comparison of CNHKV between the groups with and without belly crawling experience.

	With Belly (n=11)	Without Belly (n=5)	Comparison
	Mean (SD)	Mean (SD)	p-value
Age at crawling	262 (40)	287 (66)	0.369
Age at independent walking	400 (40)	424 (57)	0.356
CNHKV	25 (9)	38 (9)	0.029*
Total variations	45 (14)	38 (9)	0.327

Table 3. Comparison of contents (codes) of hands-knees crawling variation between the groups with and without belly crawling experience. This table shows the top five common codes of hands-knees crawling among infants in each group.

With Belly (n=11)	Common cases
211121-13131-2222233-221111	D, G, I, J, L, M, N, O, P, R
211121-11111-2222233-221111	B, G, I, J, L, N, O, P
211121-13131-2222244-221111	B, D, M, N, O
211121-11111-2222244-221111	D, M, O
211121-13131-2222231-221111	B, P

Without Belly (n=5)	Common cases
211121-13131-2222233-221111	A, K, T, U
211121-11111-2222233-221111	A, H, K, T
211121-13131-2222244-221111	T, U
211121-13131-2212233-121131	K, T
211121-13131-2222233-221131	H, U

$p < 0.05$. Total variations: total cumulative number of crawling variations, SD: standard deviation.

Table 4. Comparison of total cumulative number of crawling variations between the groups, normal and suspicious.

Normal (n=16) Suspicious (n=5) Comparison			
	Mean (SD)	Mean (SD)	p-value
Age at crawling	269 (49)	283 (46)	0.59
Age at independent walking	407 (45)	425 (67)	0.501
Total variations	43 (12)	27 (9)	0.024*

Figures

Figure 1

Filming of infant crawling movement.

Example code of belly crawling:

112231-13131-2288233-332231

(upper limbs – head – trunk – lower limbs)

Example code of hands-knees crawling:

211121-13131-2222233-221111

(upper limbs – head – trunk – lower limbs)

Figure 2

Examples of coding crawling variation.

Figure 3

Flow diagram of this study.