Original Research

Evaluation of Fidgety Movements of Infants Based on Gestalt Perception Reflects Differences in Limb Movement Trajectory Curvature

Hirotaka Gima, Koji Shimatani, Hisako Nakano, Hama Watanabe, Gentaro Taga

Background. Infants aged 2 to 5 months show spontaneous general movements (GMs) of the whole body, which are referred to as fidgety movements (FMs). Although previous studies have shown that evaluation of GMs by the General Movement Assessment (GMA) has predictive value about later neurological impairments, it remains unknown whether raters consistently perceive and rate such complex kinematic information.

Objective. The purpose of this study was to construct a method to reveal which movement features are associated with each rater's evaluation of FMs based on the GMA.

Design. GMA scores of 163 healthy infants aged 11 to 16 weeks postterm were matched with data obtained from a 3-dimensional motion analysis system.

Methods. Three physical therapists performed the GMA and classified GMs into 9 types, from which we focused on 3 subtypes differing in the temporal organization of FMs (continual, intermittent, and sporadic FMs). We also calculated 6 movement indices (average velocity of limb movements, number of movement units, kurtosis of acceleration, jerk index, average curvature, and correlation between limb velocities) for arms and legs for each infant and analyzed which movement indices were associated with the ratings of the 3 FM subtypes by each rater.

Results. Only the average curvature differed significantly among the ratings of the 3 FM subtypes for all 3 raters. Each rater showed significant differences in the average curvature in either arms or legs.

Limitations. It is difficult to generalize the present results to raters with various levels of expertise and experience in using the GMA. This issue calls for further research.

Conclusions. The method used revealed commonality and individuality about the perceived movement features that can be associated with the rating of FMs.

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Human infants show a variety of spontaneous movements of the whole body in the first few months of life. Prechtl and collaborators called spontaneous movements of the whole body general movements (GMs).[1] GMs emerge in the fetus at 8 to 10 weeks of gestational age and continue to be present until 5 months of life.[2] From birth until the end of the second month of life, GMs have a writhing quality, characterized by small-to-moderate amplitude and speed. Thereafter, GMs occur as so-called fidgety movements (FMs), which are characterized as small continual movements of moderate speed and variable acceleration of the neck, trunk, and limbs in all directions.[1] There are numerous studies of the relation between GM quality and neurological deficit.[3–9] In particular, previous studies have shown that evaluation of FMs by the General Movement Assessment (GMA) predicts later neurological impairments.[10,11] Furthermore, research has revealed the relation between the subtypes of FMs (continual, intermittent, or sporadic) and later development.[6] The GMA has been increasingly used to predict motor dysfunction (especially cerebral palsy) in clinical practice and research. In a systematic review summarizing the clinical properties of neurodevelopmental assessment methods, the GMA showed the best predictive properties at an early age.[12,13] It is based on visual Gestalt perception of normal or abnormal movements of the whole body. However, it remains unclear what kinds of GM characteristics raters actually perceive.

In recent years, a growing number of computer-based movement assessments have quantified the characteristics of the spontaneous movements of the limbs at 2 to 3 months of age.[14–17] Several studies have shown that classifying normal or abnormal FMs is possible by using the computer-based quantified indices of limb spontaneous movement in addition to the GMA.[18–23] However, few studies have matched the GMA and computer-based movement assessments to reveal the commonality and individuality of perceived visual features and ratings of GMs by each rater. Such information would be valuable to improve the GMA.

Here we recorded the spontaneous movements of 163 healthy infants aged 11 to 16 weeks postterm using both 2-dimensional video recording and 3-dimensional (3D) motion analysis systems. Three physical therapists performed visual Gestalt assessment according to the GMA, and 3D movements of each of the 4 limbs were quantified using 6 different indices (average velocity of limb movements, numbers of movement units, kurtosis of acceleration, jerk index, average curvature, and correlation between limb velocities) calculated from the trajectory of markers attached to the limbs. We particularly focused on subtypes of FMs that differ in their temporal organization (continual, intermittent, and sporadic FMs). We aimed to examine the correlation between the FM rating based on the GMA by the raters, and the limb movement characteristics.

Methods

Participants

Figure 1 shows a flow diagram of the participants. All participants were recruited via the local Basic Resident Register. The Life Science Research Ethics and Safety committee of The University of Tokyo, and the local ethics committee of the Faculty of Regional Sciences, Tottori University, approved the study. All parent(s) signed an informed consent form before the measurements were taken. One hundred sixty-three healthy infants (77 males, 86 females; birth weight = 1750–4190 g; age = 11–16 weeks postterm) participated in this study. We recorded the spontaneous movements of all participants but excluded the data for 35 participants from the analysis because of crying or fussiness (n = 26), rolling over (n = 2), or recording errors (n = 7). Thus, the analyses were performed using data from 128 participants (67 males, 61 females).

Procedure

Measurement of spontaneous movements. The participants were measured in the laboratory at the Graduate School of Education, The University of Tokyo. Each was positioned supine on a baby mattress (120 × 70 cm) during the measurement. The movements of the distal parts of the participants' limbs in a 3D space were recorded using a real-time 3D motion capture system (Motion Analysis Co, Santa Rosa, CA, USA). Six charge-coupled device (CCD) monochrome-shuttered cameras (sampling frequency = 60 Hz) with electronically shuttered infrared light-emitting diode–synchronized strobe lights were placed around the mattress on which the participants were placed. Four spherical reflective markers (diameter = 3 cm; weight = 5 g) were attached to the wrists and lower thighs (right arm, left arm, right leg, left leg) of each participant. Spontaneous movements were measured for a maximum time of 10 minutes in the awake, active, and noncrying states, and the 3D position of each marker was tracked in real time. The participants could not see their parent(s) or the experimenters during the session. If the captured data included certain gaps, they were linearly interpolated. The marker-coordinated time-series data were smoothed using a 6-Hz recursive Butterworth filter algorithm. In addition to using the motion capture system, a video camera (DCR PC100; Sony Corp, Tokyo, Japan) was used to record 2-dimensional movement images of the participants' spontaneous movements of the whole body and the experimental situation. Figure 2 shows the process of recording the spontaneous movements for calculating the indices of the limb movements.

Data Analysis

Classification of GM type by GMA. First, we performed visual Gestalt perception using the GMA[2,6] to classify the

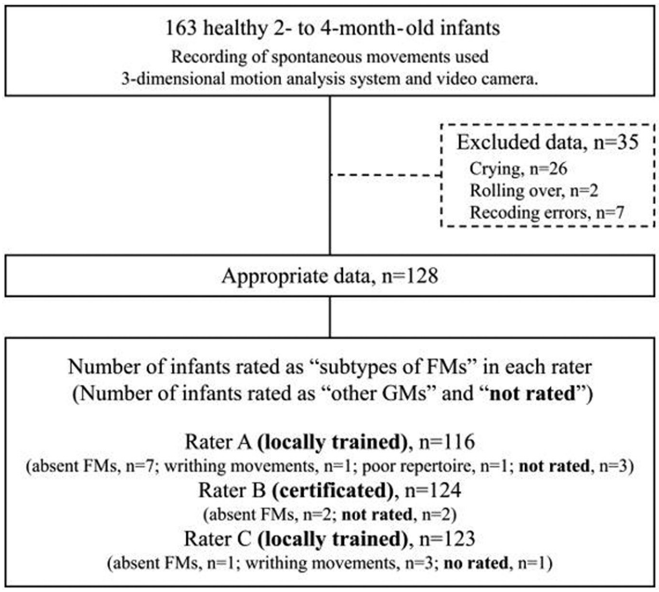

Figure 1.
Flow diagram of the study participants. FMs = fidgety movements; GMs = general movements.

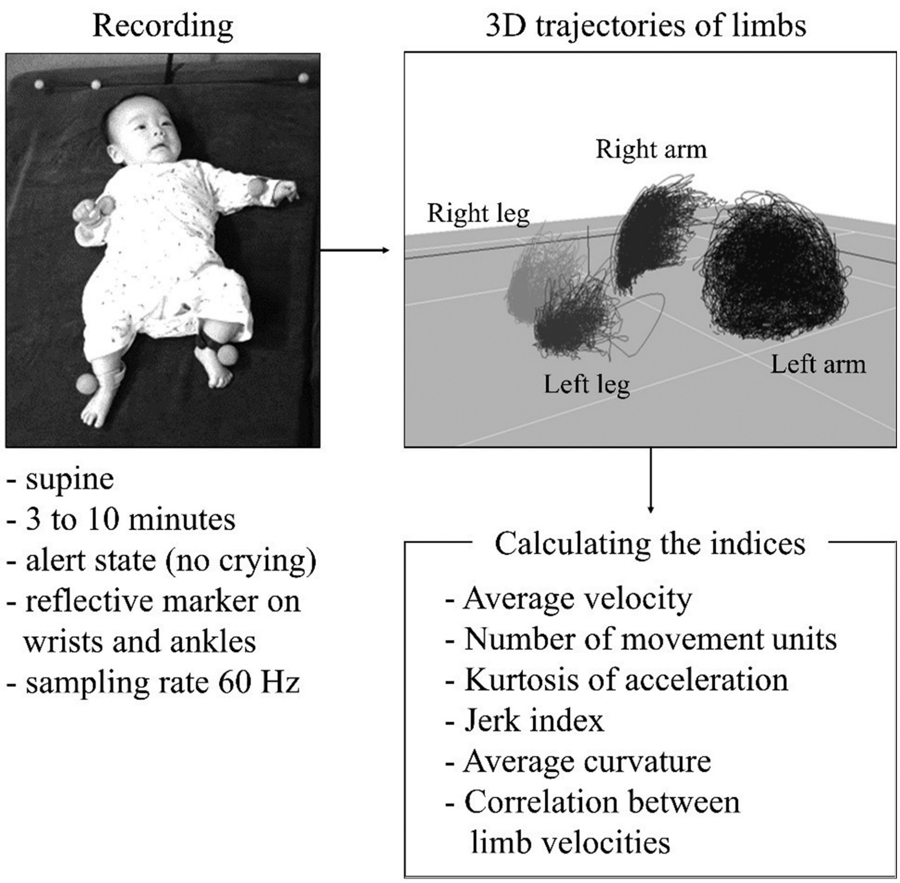

Figure 2.
Recording of spontaneous movements and calculating the indices of limb movements. 3D = 3-dimensional.

GM types. Continuous 2-dimensional videos for each participant, lasting at least 3 minutes, were used for the movement assessment. Three raters (H.G., K.S., and H.N.), who are physical therapists, performed the visual Gestalt assessment according to the GMA. One had GMA basic course certification, and the other 2 were locally trained. They were masked with regard to the participants' characteristics (sex, age, and birth weight). They independently observed the video images for all cases and classified them into 9 types of GMs (writhing movements, poor repertoire GMs, cramped synchronized GMs, chaotic GMs, continual FMs, intermittent FMs, sporadic FMs, abnormal FMs, or absence of FMs). Table 1 presents the classification and definition of each GM type. Any case posing difficulty in evaluation due to crying or arousal was judged as "not rated." We examined the interrater agreement for selecting FMs (continual, intermittent, or sporadic FMs) out of the 9 types of GMs. Further, we examined the interrater agreement in rating the 3 subtypes of FMs differing in the temporal organization, that is, continual, intermittent, and sporadic.We focused on the 3 subtypes of FMs for the group analysis in each rater because the number of movements that were categorized into other GM types was too small to constitute a group.

Calculation of the indices of spontaneous limb movements. We examined the following 6 indices from the 3D movement trajectories of all limbs: (1) average velocity of limb movements, (2) number of movement units (MUs), (3) kurtosis of acceleration, (4) jerk index, (5) average curvature, and (6) correlation between limb velocities. We used the 3D trajectory data of the same duration to assess GMs for calculating each index. Regarding indices 1 to 5, for the statistical analysis, we used the mean value of each index of the right and left arms as "arms," and those of the right and left legs as "legs." These indices were calculated as described in previous studies.[16,23–25]

(1) Average velocity of limb movements: The velocities $\dot{x}$, $\dot{y}$, and $\dot{z}$ were calculated based on the position data for each limb. We calculated 3D tangential velocities V. Next, we averaged the instantaneous V over time during the measurement period and obtained $\bar{V}$ (mm/s), which is referred to as average velocity.

(2) Number of MUs: The MU was detected when the increasing velocity exceeded the threshold value of 85 mm/s and when the decreasing velocity fell below the same threshold value. We employed the number of MUs per minute as an index.

(3) Kurtosis of acceleration: The kurtosis of acceleration, β, was calculated for each limb. A distribution with a larger β represents a more sharply peaked and heavily tailed form, meaning that the movements include intermittent bursts and deviate from the Gaussian distribution ($\beta = 3.0$).

(4) Jerk index: We calculated the time integral of the square of the magnitude of jerks per unit movement distance by adopting the following equation:

$$C = \frac{1}{2} \cdot \frac{\overline{\left(\dddot{x}^2 + \dddot{y}^2 + \dddot{z}^2\right)}}{\bar{V}},$$

where x, y, and z are the time-varying position coordinates of each limb, triple dots denote the third time derivate of position, and horizontal rule represents an average over a period of time. We used only the active period when the tangential velocity exceeded 85 mm/s for at least 1 of the limbs to calculate the jerk index values. Hereafter, we refer to C (mm/s^5) as the jerk index. A larger value of this index represents a jerkier movement.

(5) Average curvature: To quantify the geometrical feature of the limb movement trajectory, the time series of each curvature was calculated from 3D position data of each limb and the first and second derivatives of the position data. The time mean value K (1/mm) was obtained as follows:

$$K = \overline{\frac{\left\{\left(\dot{y}\ddot{z} - \dot{z}\ddot{y}\right)^2 + (\dot{z}\ddot{x} - \dot{x}\ddot{z})^2 + \left(\dot{x}\ddot{y} - \dot{y}\ddot{x}\right)^2\right\}^{\frac{1}{2}}}{\left(\dot{x}^2 + \dot{y}^2 + \dot{z}^2\right)^{\frac{3}{2}}}},$$

where x, y, and z are the time-varying position coodinates of each limb, single and double dots denote the first and second time derivative of position, and horizontal rule represents an average over a period of time. We used only the period when the tangential velocity exceeded 50 mm/s to calculate the mean curvature values for each limb.

(6) Correlation between limb velocities: To examine coordination among limb movements, we calculated cross-correlations with a 0 time lag between the tangential limb velocities. We used only the active period when the tangential velocity exceeded 85 mm/s for at least 1 of the limbs to calculate the correlation values. All combinations of cross-correlations between the limbs were calculated for each participant, resulting in 6 correlations: right arm and left arm (RA-LA), right arm and right leg (RA-RL), right arm and left leg (RA-LL), left arm and right leg (LA-RL), left arm and left leg (LA-LL), and right leg and left leg (RL-LL).

Data Analysis

We used the Statistical Package for the Social Sciences version 23 (SPSS; IBM Japan Inc, Tokyo, Japan). The method of statistical analysis for each dataset was chosen based on the Shapiro-Wilk test of normality. Regarding participant information, we used the χ^2 test for group comparisons of sex, and the Kruskal-Wallis test for group comparisons of gestational age and age at the time we recorded the spontaneous movements. We also used the 1-way analysis of variance (ANOVA) for group comparisons of birth weight. In indices of limb movements, for the group analysis of the average velocity, MUs, kurtosis of acceleration, jerk index, and average curvature, we conducted the Kruskal-Wallis test because most of the indices did not show a normal distribution based on the Shapiro-Wilk test. When the Kruskal-Wallis test showed significant results, the Steel-Dwass test was used for multiple comparisons. Since z-transformed correlations between limb velocities showed a normal distribution based on the Shapiro-Wilk test, we conducted a mixed 3 × 6 ANOVA (groups [continual FMs, intermittent FMs, and sporadic FMs] as intersubject variables × limb combination [RA-LA, RA-RL, RA-LL, LA-RL, LA-LL, and RL-LL] as within-subject variables). When the mixed ANOVA test and 1-way ANOVA test showed significant group differences, we used the Ryan procedure and Tukey

Table 1.
Classification and Definition of General Movements[2,6]

Classification[a]	Definition
Writhing movements	Writhing movements are characterized by small-to-moderate amplitude and by slow-to-moderate speed. Typically, they are ellipsoid in form, creating the impression of a writhing quality
Poor repertoire of GMs	The sequence of the successive movement components is monotonous, and movements of the different body parts do not occur in the complex way seen in normal GMs
Cramped synchronized GMs	Movements appear rigid and lack the normal smooth and fluent character; all limb and trunk muscles contract and relax almost simultaneously
Chaotic GMs	Movements of all limbs are of large amplitude and occur in a chaotic order, without any fluency or smoothness. They consistently appear to be abrupt
Continual FMs	FMs occur frequently but are interspersed with short pauses. Because FMs are, by definition, GMs, the movements involve the whole body, particularly the neck, shoulders, wrists, hips, and ankles
Intermittent FMs	Although intermittent FMs occur regularly in all body parts, their temporal organization differs from that of continual FMs. The pauses between FMs are prolonged, giving the impression that FMs are present for only half of the observation time
Sporadic FMs	Sporadic FMs are like intermittent FMs but interspersed with long pauses
Abnormal FMs	Abnormal FMs look like normal FMs, but their amplitude, speed, and jerkiness are moderately or greatly exaggerated. Abnormal FMs are rare
Absence of FMs	No FMs can be observed, although other movements can occur

[a]FMs = fidgety movements; GMs = general movements.

honestly significant difference test for multiple comparisons, respectively. In the statistical analyses, the cutoff level for significance was set at $P = .05$. Note that the statistical threshold was set at $P = .05/2, = .025$, on the basis of Bonferroni correction to consider multiple comparisons for the arms and legs of the limb movement indices.

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Results

Assessment of GMs Based on GMA

Rater A (locally trained), B (certified), and C (locally trained) rated that FMs appeared (including continual, intermittent, and sporadic FMs) in 116, 124, and 123 cases, respectively. The reason for judging "not rated" by each rater was that all the participant's arousal state was fussy. Note that among the raters, the interrater agreement rates about the presence of FMs were 89.1%, 86.7%, and 93.0% between raters A and B, A and C, and B and C, respectively. The interrater agreement rate of all 3 raters was 84.4%. Among the raters, the interrater agreement rates between the subtypes of FMs (continual, intermittent, and sporadic FMs) were 36.7%, 30.5%, and 43.0% between raters A and B, A and C, and B and C, respectively. The interrater agreement rate of all 3 raters was 14.8%.

The characteristics of the participants of each group determined by each rater are shown in Table 2. No significant intergroup differences were found for sex, gestational age, or age at the time of recording of spontaneous movements in any of the raters. In the grouping by rater B, birth weight in the intermittent FMs group was higher than that in the sporadic FMs group ($P < .05$). There were no significant intergroup differences in birth weight in the groupings of raters A and C.

Indices of Limb Movements

The median values of the 5 indices of each rater and each group are shown in Figure 3. In the results of rater A, the Kruskal-Wallis test showed significant intergroup differences in average velocity of the arms, MUs of the arms, kurtosis of acceleration of the arms, and mean curvature of the legs (all P values $< .025$). The post hoc comparison revealed that the average velocity of the arms in the continual FMs group was significantly higher than that in the sporadic FMs group (df = 113; $t = 3.64$; $P < .01$), the number of MUs of arms in the continual FMs group was significantly higher than that in the sporadic FMs group ($t = 3.79$; $P < .01$), and the number of MUs of arms in the intermittent FMs group was significantly higher than that in the sporadic FMs group (df = 113; $t = 2.74$; $P < .05$). Kurtosis of the acceleration of arms in the continual FMs group was significantly lower than that in the intermittent FMs group (df = 113; $t = 3.11$; $P < .01$) and the sporadic FMs group (df = 113; $t = 4.07$; $P < .01$). The average curvature of legs in the continual FMs group was significantly higher than that in the sporadic FMs group (df = 113; $t = 3.30$; $P < .05$). In the results of rater

Table 2.
Characteristics of Participants[a]

Rater	Characteristic	Result for Participants With:			
		Continual FMs	Intermittent FMs	Sporadic FMs	Other GMs
A (locally trained)	No. of males/females[b]	13/12	26/27	22/16	6/6
	Median gestational age (range)[c]	39 wk 4 d (35 wk 6 d to 41 wk 1 d)	39 wk 1 d (37 wk 0 d to 42 wk 3 d)	39 wk 4 d (36 wk 3 d to 41 wk 2 d)	39 wk 5 d (35 wk 6 d to 41 wk 4 d)
	Mean [SD] birth weight,[d] g	2980.5 [303]	3050 [326.5]	3032.9 [425.3]	2923.7 [369]
	Median age (range) at recording of spontaneous movements,[c] d	95 (81–110)	85 (75–109)	85 (80–110)	95 (81–109)
B (certified)	No. of males/females[b]	12/8	42/42	11/9	2/2
	Median gestational age (range)[c]	39 wk 4 d (37 wk 5 d to 41 wk 1 d)	39 wk 4 d (35 wk 6 d to 41 wk 4 d)	38 wk 5 d (35 wk 6 d to 42 wk 3 d)	38 wk 2 d (36 wk 3 d to 39 wk 5 d)
	Mean [SD] birth weight,[d,e] g	3056.2 [328.7]	3072.8 [347]	2823.1 [377.7]	2698.5 [142.9]
	Median age (range) at recording of spontaneous movements,[c] d	83 (80–109)	86 (75–110)	87 (81–109)	84 (81–89)
C (locally trained)	No. of males/females[b]	20/14	24/27	21/17	2/3
	Median gestational age (range)[c]	39 wk 3 d (35 wk 6 d to 41 wk 2 d)	39 wk 5 d (35 wk 6 d to 42 wk 3 d)	39 wk 3 d (35 wk 6 d to 41 wk 0 d)	38 wk 0 d (36 wk 6 d to 40 wk 5 d)
	Mean [SD] birth weight,[d] g	3130 [342.1]	2998.4 [375.0]	2990.4 [332.8]	2704.8 [256.7]
	Median age (range) at recording of spontaneous movements,[c] d	85 (80–110)	86 (75–107)	88 (80–110)	87 (84–102)

[a]FMs = fidgety movements; GMs = general movements. *P* values for comparison of 3 groups (continual FMs, intermittent FMs, and sporadic FMs) were not significant unless otherwise noted.
[b]χ^2 test.
[c]Kruskal-Wallis test.
[d]1-way analysis of variance.
[e]Tukey honestly significant difference test (intermittent FMs >sporadic FMs; $P < .05$).

B, the Kruskal-Wallis test showed significant intergroup differences in average curvature of the arms ($P < .025$), whereas the post hoc comparison revealed that the average curvature of the arms in the continual FMs group was significantly higher than that in the sporadic FMs group (df = 121; $t = 2.57$; $P < .05$). In the results of rater C, the Kruskal-Wallis test showed significant intergroup differences in average curvature of the legs ($P < .025$), whereas the post hoc comparison revealed that the average curvature of the arms in the intermittent FMs group was significantly higher than that in the sporadic FMs group (df = 120; $t = 2.80$; $P < .05$).

Figure 4 shows the results of mixed ANOVA and multiple comparisons of *z*-transformed correlations among limb velocities. In the results of all raters, there were no significant main effects of group but a significant main effect of the combination of the *z*-transformed correlations among limb velocities (df = 5; $F = 198.9$; $P < .01$ for rater A; df = 5; $F = 134.6$; $P < .01$ for rater B; and df = 5; $F = 209.8$; $P < .01$ for rater C). The Ryan procedure for post hoc comparisons revealed that the correlation for the RL to LL was significantly stronger than that for all other combinations of limbs (all *P* values < .01), whereas the correlation for RA and LA was significantly stronger than that for other combinations of limbs (all *P* values < .01) for each rater.

Discussion

In the present study, interrater agreement about the presence of FMs ranged from 86.7% to 93.0%. A number of previous studies have shown sufficient interobserver agreement for the assessment of GMs.[2] For example, Einspieler et al reported that the interrater agreement between 51 raters of GMs of 30 infants was 84% to 88%.[26] Cioni et al reported that interrater agreement between 2

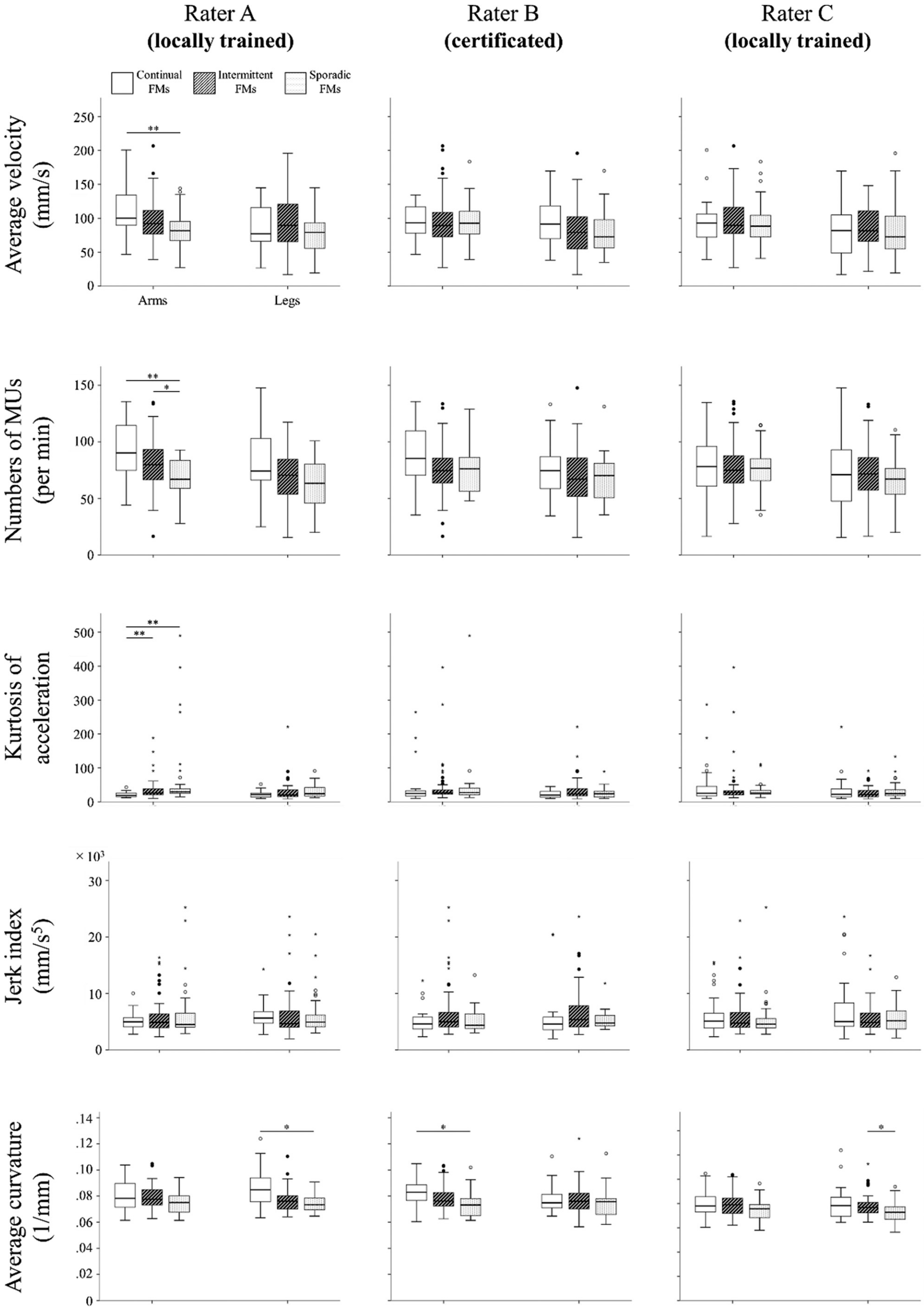

Figure 3.
The indices of limb movements in each group for each rater: average velocities of limb movements for each group; the number of movement units for each group; the kurtosis of acceleration for each group; the jerk index for each group; and the average curvature for each group. Median (line in the box), 25th and 75th percentiles (upper and lower edges of the box), and range (upper and lower bards of the box) are shown in each case. FMs = fidgety movements; MUs = movement units. $*P < .05$; $**P < .01$.

raters of GMs of 66 infants was 91%.[27] Similarly, Guzzetta et al reported interrater agreement between 3 raters of GMs of 22 infants of 92% to 100%.[28] Although the interrater agreement of the present study is comparable with those of the previous studies, the characteristics of the participants in the present study differ in that the 128 infants subjected to the analysis did not include high-risk infants. This contrasts with most of the previous studies,

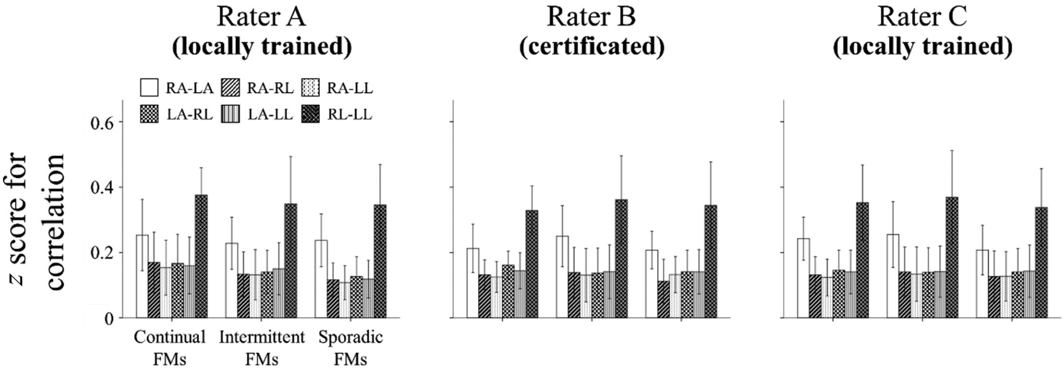

Figure 4.
The *z*-transformed correlations between limb velocities in each group for each rater. Means and 95% CIs are shown. FMs = fidgety movements; LA = left arm; LL = left leg; RA = right arm; RL = right leg.

which analyzed high-risk infants (eg, preterm, low birth weight, with brain injury) and included similar numbers of normal and abnormal patterns of GMs. Furthermore, the present study showed that the interrater agreement between the subtypes of FMs (continual, intermittent, or sporadic FMs) was 30.5% to 43.0%, suggesting low reliability. To the best of our knowledge, no study has reported the interrater reliability of ratings between the subtypes of FMs. Studies on the relation between some subtypes of FMs (ie, sporadic) and neurodevelopmental outcome have been reported.[6] However, discussions about the reliability of evaluation of subtypes of FMs are necessary for future research.

We aimed to examine the correlations between the FM ratings based on the GMA and movement characteristics of limbs based on 3D motion analysis. We examined whether 6 indices of limb movements showed differences among the subtypes of FMs assigned by each rater. A major finding was the difference in the values of average curvature among the subtypes of FMs according to each rater. The value of curvature in this study is the amount by which a trajectory deviates from being straight and is expressed as the reciprocal of the radius of the curvature. Therefore, high values of average curvature are consistent with the definition of FMs: “an ongoing stream of small and circular movements of limbs.”[3] The high values of average curvature in the continuous FMs and low values in the sporadic FMs suggest that the 3 raters captured the spatial geometric features of the infant limb movements, and the differences in the temporal organization of FMs were reflected in ratings of the GMA. Furthermore, the finding that the differences in the average curvature among the various features of the limb movement reflected the rating suggests that the results are associated with the basic mechanism of human visual perception of movement. A number of psychophysics studies have shown that the human visual system is sensitive to differences in curvature.[29–31] It should be also noted that traditional psychophysics studies use a method of repeatedly conducting stimulation and rating on a single participant and reveal universal mechanisms by the consistency among a small number of participants.[29–31] Although the present study used only 3 raters, they were provided with 2D video images of 128 infants (total recording time: 23.3 hours). In this regard, the study design is similar to that used in psychophysics. Thus, the commonality among the 3 raters should suggest general mechanisms underlying Gestalt perception of FMs.

Another important finding was that the analysis revealed individual differences in the visual Gestalt perception of FMs. Rater A’s ratings were associated with the differences in average curvature of the lower limbs and those in average velocity, numbers of MUs, and kurtosis of acceleration of the upper limbs. Rater B’s and C’s ratings were associated with the differences in the average curvature of the upper and lower limbs, respectively. These results showed that there were differences in limbs of interest for ratings in each rater. Despite such differences, their ratings were consistently based on the spatial characteristics of distal movements of the limbs represented by the average curvature. This suggests that the subtypes of FMs were consistently rated by each rater based on the temporal organization of the occurrence of FMs. However, the low interrater agreements between subtypes of FMs suggest that the boundaries between subtypes were ambiguous. The approach in our study gives important suggestions on how to interpret the results when analyzing data with a low interrater reliability. A further study would focus on the finding that the rating by the certified rater was associated with the difference in curvature of the upper limb, whereas the rating of the locally trained raters was associated with the difference in curvature of the lower limb.

Recent progress on computer-based assessments of spontaneous movements of infants of similar ages has provided detailed information about their movement properties. Gima et al evaluated the complexity of movements using acceleration time series data of spontaneous movements of the lower extremities by an accelerometer and reported that the indicator of complexity (maximum Lyapunov exponent) shows an increasing trend at 3 to 4 months of age.[15] Ohmura et al measured knee-ankle coordination using multiple attitude sensors and showed that 3-month-old infants moved their ankle joints more independently of knee motions than 2-month-old infants.[17] The results of these studies were thought to reflect changes in the characteristics of spontaneous movements of the limbs in this period, but the correlation between each result and the subtypes of FMs based on the GMA has not been clarified. Karch et al recorded the spontaneous movements of infants between term and 3 months of age using an electromagnetic tracking system and showed the difference in the movement characteristics between normal and abnormal GMs.[18] However, few studies have directly examined which properties of movements are perceived by the GMA. Adde et al studied the difference between FMs and absent FMs using motiongrams and reported that the variability in displacement of a spatial center of active pixels in the image (centroid of motion SD) had the highest sensitivity and specificity for classifying FMs.[19] Furthermore, they showed high prediction accuracy of cerebral palsy using the same index.[20] However, differences in the rating, for example of continual, intermittent, or sporadic FMs, were not evaluated in these studies. In the present study, we analyzed the kinematic details of the distal movements of the limbs in 3 dimensions and found that the average curvature was a sensitive index to reflect the differences in the subtypes of FMs classified by the raters.

The limitations of this study must be considered. First, it focused only on the characteristics of distal movements of the limbs and did not cover those of the whole body including the neck and trunk. We recently reported that differences in spontaneous head movements of younger infants were associated with the development of autism spectrum disorder.[32] Thus, the computer-based analysis of FMs should be integrated to include both proximal and distal movements of the whole body in future studies. Second, it is difficult to generalize the results of this study to GMA by physical therapists with various levels of expertise and backgrounds. Further, in this study, 1 of the raters had the GMA basic course certification, but 2 of the raters were locally trained. In order to clarify this issue, future studies should take a different approach using a feasible number of infants' GMs for rating by a large number of raters who have GMA advanced course certification.

In conclusion, we conducted a study to match the GMA based on Gestalt perception of infants' movements with the analysis of 3D limb movements of the observed infants. Our findings suggest that the curvature information can be used for the assessment of FMs. Furthermore, this study gives a new perspective on evaluating the commonality and individuality of video assessment of movements by physical therapists.

Author Contributions and Acknowledgments

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Fund procurement: H. Gima, G. Taga
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Ethics Approval

The Life Science Research Ethics and Safety Committee of The University of Tokyo, and the local ethics committee of the Faculty of Regional Sciences, Tottori University, approved the study. All participants were recruited via the local Basic Resident Register. All parents signed an informed consent form before the measurements were taken.

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Disclosures

The authors completed the ICJME Form for Disclosure of Potential Conflicts of Interest and reported no conflicts of interest.

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