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FUNCTION OF THE PROXIMAL PHALANX IN EARLY CHILDHOOD CHILDREN'S FINGERS: THROUGH MOVEMENT ANALYSIS OF MUSICAL EXPRESSION

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ABSTACT

This study aims to clarify the effect of movement regarding the proximal phalanx of finger during musical expression in early childhood. 3-year-old, 4-year-old, and 5-year-old children (n=86) from three facilities participated in an analysis of hand and finger movements during musical expression in early childhood using the Meta gloves system connected to the MVN system (3D motion capture). Regarding the 19 types of data calculated from the movement analysis, a quantitative analysis was conducted on the proximal phalanges of each of the five fingers, focusing on a three-way non-repeated analysis of variance with factors of facility (three levels), melody (two levels), and age (three levels). As a result, the total moving distance and the moving average acceleration showed a statistically significant difference in the melody (bright), just as in the analysis of the movement of the entire hand, whereas the moving average velocity and the moving smoothness showed that movements following the beat and rhythm induced by both the melody (bright) and the melody (dark). The moving smoothness was remarkable large in the melody (dark), but it was found that the third proximal phalanx showed the characteristic movement of expressing the recognition of the beat while feeling the melody.

Keywords: finger movement, proximal phalanges, Meta gloves, musical expression in early childhood, three-way analysis of variance

1.0 INTRODUCTION

The author has quantitatively analyzed the results of movement analysis and improved the classification accuracy of machine learning using extracted feature quantities in order to find objective indicators of the developmental process of musical expression in early childhood (Sano, 2018; 2019). It was also focused on the gaze movements during musical expression from the state of their behavior during the measurement, and analyzed their eye movements (Sano, 2021). In 2022 and 2023, machine learning was conducted using new feature quantities based on quantitative analysis of the results of simultaneous analysis of body movement and eye movement during musical expression, and the accuracy of discrimination has been further improved using multiple classifiers such as SVM and MLP-NN (Sano, 2023;2024). By presenting objective indicators to capture the developmental process of musical expression in early childhood, it will contribute to devise the next musical experience provided to each individual child. The author thought that a more detailed analysis of finger movements was necessary, based on the results of the quantitative analysis regarding noticeable hand movements.

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In the previous researches, movement analysis focusing on hand and finger movements in related fields has tended to capture the relationship between the hand and finger movements of experts in specific techniques and the gaze movements associated with hand and finger movements. Movement analysis focusing on hand and finger movements has included classification and pattern analysis of hand movement functions (Liu et al., 2021; Braido & Zhang, 2004), toothbrush gripping method (Yu et al., 2014), a method for modeling the range of movement of the hand from joint angle data in various postures (Shimizu et al., 2012), analysis of the tendon fixation action of the hand and fingers during movement and movement analysis of the upper limbs and fingers (Ito et al., 2021; Mihara et al., 2016), educational use of motion capture systems for hand and finger movements, data analysis of cooking movements, quantitative analysis of catching movements in ball games, and evaluation of grip strength (Aoki & Kurebayashi, 2020; Akiyama & Yamanaka, 2016; Kaplan, 2016; Nara et al., 2011).

In the field of music, these include the relationship between the movements of pianist's fingers and upper body and their performance proficiency, movement analysis of pianist's finger movements (Nishimori et al., 2016; Goebl & Palmer, 2013), upper limb movement control due to changes in volume when striking keys (Kobayashi et al., 2017), hand movements and movement parameters when playing musical instruments (Albrecht, 2014; Miura, 2022), changes in the coordination of overall joint movement during expert piano playing under psychological stress (Kotani & Furuya, 2018), and the impact of a conductor's hand and body movements on the quality of music performance (Çoşkunsoy & Güdek, 2019). With regard to learning support, researches have examined the effects of gaze movements and finger use on learning (Park et al., 2023), a quantitative analysis of 6-year-old children's finger movements in response to tasks (Bonafede & van der Merwe, 2023), and the effects of music on improving the learning of fine hand movements and the synchronization of hand movements and music (Khoran et al., 2012; Bayed et al., 2022). Other examples include research into the effects of musical training on hand-eye coordination, the moving velocity and bimanual coordination in elementary school children's fine motor skills (Martins et al., 2018), and on conditions that promote visual interaction during duet performances (Bishop et al., 2019).

However, no research report was observed in quantitative analysis based on the movement analysis during musical expression in early childhood. Therefore, the author conducted a movement analysis and quantitative analysis focusing on the finger movements during musical expression in early childhood (Sano, 2025). Based on the relationship between the third metacarpal bone and the second proximal phalanx in the acquired data, the author tried to conduct a quantitative analysis focusing on the movement of the proximal phalanxes of all five fingers.

2.0 PURPOSE OF THIS STUDY

This study aims to clarify, through quantitative analysis, the effect of the movement of the proximal phalanx, which is closest to the metacarpal bone, among the movements of the five fingers during musical expression in early childhood. To achieve this, using the Meta gloves system, which analyzes finger movements in detail. Next, the author will show how to analyze the movements and quantitatively analyze them.

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3.0 METHOD OF THIS STUDY

3.1 Method of analyzing finger movements

In this study, the Meta gloves system will be connected to a 3D motion capture system (MVN) to analyze finger movements during musical expression in early childhood. To operate Meta gloves, the MVN system and the Meta gloves system are started, and both systems are put on, calibrated, and prepared. For each child participating, it is necessary to start up, calibrate, and prepare both systems for each measurement, and each measurement takes 5 to 6 minutes. The procedure is as follows:

(1) Connection between the MVN system and the Meta gloves system

The MVN system and the Meta gloves system are started on one PC. The participating child is asked to wear the MVN system's motion sensors at 11 of the 17 designated measurement points on the upper body. The time frame is 1/60 seconds.

(2) Wearing and Calibrating Meta Gloves

Each child wears Meta gloves, a pair of gloves for early childhood children that the author created and equipped with sensors. Following the instructions on the Meta gloves system, each child participates in calibration using three types of movements.

(3) Calibration and preparation of the MVN system

According to the indications of the MVN system, the author inputs and adjusts the necessary physical information for each child and prepares for the measurements.

(4) Analysis of finger movements in musical expression

Each child performs body movements while singing nursery rhymes and finger-play songs, and the author analyzes and records the movements in real time.

3.2 Method for quantitative analysis of finger movement in musical expression

Movement analysis involves quantitative analysis using data acquired from 11 measurement points on the upper body and 19 measurement points on the fingers. In particular, data on finger movements are required for the following 19 parts: the first finger (first metacarpal, first proximal phalange, first distal phalange), the second finger (second metacarpal, second proximal phalange, second middle phalange, second distal phalange), the third finger (third metacarpal, third proximal phalange, third middle phalange, third distal phalange), the fourth finger (fourth metacarpal, fourth proximal phalange, fourth middle phalange, fourth distal phalange), and the fifth finger (fifth metacarpal, fifth proximal phalange, fifth middle phalange, fifth distal phalange).

In this study, using the data calculated in the total moving distance, the moving average velocity, the moving average acceleration, and the moving smoothness of each proximal phalange of all five fingers, a quantitative analysis centered on a three-way non-repeated analysis of variance with the factors of facility (3 levels), melody (2 levels), and age (3 levels)

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was conducted to investigate whether there were any statistically significant differences in the average values. In this article, the melodies are divided into bright and dark, with songs in major keys being labeled as melody (bright), and traditional Japanese nursery rhymes and songs in minor keys being labeled as melody (dark).

3.3 Survey dates, facility and number of participants,

The survey dates, facility and number of participants in 2024 were as follows.

Approximately 10 children aged 3-year-old, 4-year-old, and 5-year-old from each of T facility (n=29), W facility (n=28), and Y facility (n=29) participated in this survey. The measurement dates for T facility were June 4th, June 11th, June 18th, and June 25th, for 1-2 hours each; the measurement dates for W facility were July 2nd, July 5th, July 9th, July 12th, July 23rd, and July 24th, for 1 hour each; and the measurement dates for Y facility were September 13th and September 27th, for 2.5 hours each. The songs included were 11 songs: "Guchokipadenanitsukurou", (French folk songs), "Tontontonhigejiisan", (Lyrics: Unknown, Music: Tamayama Hidemitsu), "Panyasnniokaimono", (Lyrics: Tomoko Sakura, Music: Tatsuyuki Ozawa), "Yamanoongakuka", (Lyrics: Shisen Mizuta, Music: German folk song), "Tokeinouta", (Lyrics: Keisuke Tsutsui, Music: Taro Murakami), "Kaerunouta", (Lyrics: Toshiaki Okamoto, Music: German folk song), "Agarimesagarime", (Lyrics: Masaru Mizutani, Music: Shinpei Nakayama), "Nabenabesokonuke", (Japanese nursery rhymes), "Genkotsuyamanotanuki", (Lyrics: Yoshiko Kayama, Music: Akihiro Komori), "Usagi", “Japanese nursery rhymes,”and "Hotarukoi"(Lyrics and composition: Tomekichi Mikami).

This study was reviewed and approved by the research ethics committee of the author’s affiliation, and informed consent was obtained through the submission of consent forms by the cooperating nurseries, the parents of the participant children, and the person in charge of the facilities.

4.0 RESULTS

4.1 The moving trace of the proximal phalanx

The following figure 1 shows an example of the moving trace of the third proximal phalanx of the third finger when measuring the musical expression of a five-year-old child playing the song "Guchokipadenanitsukurou". The moving trace was not significantly different for the proximal phalanxes of the other fingers.

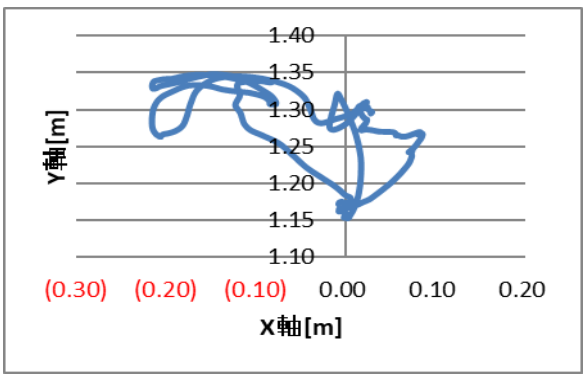

Figure 1: Example of the moving trace of the right third phalange (PP) in a 5-year-old child

4.2 The moving distance by the proximal phalanx of the fingers

Table 1 below shows the moving average distance of each proximal phalanx of the finger.

Table 1. Average moving distance of each proximal phalanx of the five fingers

facility	melody	Age	First proximal phalanx		Second proximal phalanx		Third proximal phalanx		Fourthth proximal phalanx		Fifth proximal phalanx	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
		3-year-old	3.402332	1.481313	4.118616	1.784887	4.607788	1.923268	4.607788	1.923268	4.769222	1.934741
	bright	4-year-old	4.408145	2.079973	5.315923	2.427813	5.871205	2.561501	5.871205	2.561501	6.058186	2.600241
T facility		5-year-old	4.548514	1.596418	5.440716	1.848205	6.008002	1.96237	6.008002	1.96237	6.167522	2.019374
		3-year-old	1.987101	1.338383	2.440349	1.690898	2.665271	1.751088	2.665271	1.751088	2.814424	1.83692
	dark	4-year-old	1.836327	1.316639	2.239173	1.650351	2.396077	1.734042	2.396077	1.734042	2.394914	1.718726
		5-year-old	3.491997	2.691559	4.238526	3.399842	4.48918	3.511406	4.48918	3.511406	4.53769	3.494271
		3-year-old	4.487906	2.195293	5.407433	2.640166	5.968794	2.818272	5.968794	2.818272	6.146882	2.84221
	bright	4-year-old	3.718004	1.279456	4.486988	1.439565	5.071658	1.648748	5.071658	1.648748	5.004055	1.577745
W facility		5-year-old	4.258071	2.340628	5.022022	2.60294	6.020905	3.01319	6.020905	3.01319	5.669689	2.840198
		3-year-old	1.883104	1.23317	2.278923	1.478223	2.443495	1.546858	2.443495	1.546858	2.530393	1.604847
	dark	4-year-old	1.831549	1.179032	2.172231	1.377804	2.428378	1.470065	2.428378	1.470065	2.372171	1.419674
		5-year-old	2.658353	1.792912	3.184088	2.052487	3.597867	2.299351	3.597867	2.299351	3.479174	2.250499
		3-year-old	5.634812	2.695561	6.313015	2.788335	6.801322	2.984322	6.801322	2.984322	7.002597	3.058316
	bright	4-year-old	6.306837	3.044325	6.97541	3.201725	7.418	3.33691	7.418	3.33691	7.443831	3.366724
Y facility		5-year-old	6.983369	2.662839	7.765443	2.745234	8.322602	2.799248	8.322602	2.799248	8.549917	2.931989
		3-year-old	3.115122	1.592813	3.592751	1.698168	4.022516	1.825394	4.022516	1.825394	4.135855	1.856141
	dark	4-year-old	3.419814	2.028698	3.838327	2.209036	4.269733	2.348844	4.269733	2.348844	4.323489	2.369931
		5-year-old	3.910349	1.207184	4.341221	1.181047	4.970059	1.316086	4.970059	1.316086	5.234265	1.417394

(1) Analysis of the moving distance of the first proximal phalanx

A three-way non-repeated ANOVA was conducted on the first proximal phalanx for the total moving distance, the average values as shown in Table 1. The result of between-subject effects test showed that the main effects were statistically significant in the facility factor (F (2, 402)=29.636, p<.05), melody factor (F(1,402) =125.133, p<.05), and age factor (F(2, 402)=8.212, p<.05). As a result of multiple comparison test by Bonferroni method, the data was larger in Y facility than T facility, and 4-year-old and 5-year-old were larger in Y facility than T facility and W facility. 4-year-old was larger in Y facility than T facility and W facility by the melody (dark). 3-year-old and 4-year-old were larger in melody (bright) than melody (dark) in T facility. 3-year-old, 4-year-old and 5-year-old were larger in melody (bright) than melody (dark). 5-year-old was larger than 3-year-old in melody (bright), 5-year-old was larger than 4-year-old in melody (dark).

(2) Analysis of the moving distance of the second proximal phalanx

A three-way non-repeated ANOVA was conducted on the moving average distance by the second proximal phalanx. The results of between-subject effects test showed that the main effects were observed in the facility factor (F(2,402) =21.177, p<.05), melody factor (F(1, 402)=128.146, p<.05), and age factor (F(2,402)=7.900, p<.05)). As a result of multiple

comparison test, 3-year-old was larger in Y facility than T facility by melody (bright), 4-year-old and 5-year-old were larger in Y facility than T facility and W facility. 4-year-old was larger in Y facility than W facility by melody (dark). 3-year-old and 4-year-old were larger in melody (bright) than melody (dark), 3-year-old, 4-year-old, and 5-year-old were larger in melody (bright) than melody (dark) in W facility and Y facility. 5-year-old was larger than 3-year-old by melody (bright), 5-year-old was larger than 3-year-old and 4-year-old by melody (dark) in T facility.

(3) Analysis of the moving distance of the third proximal phalanx

A three-way ANOVA was conducted on the mean values of the third proximal phalanx, and the results of between-subject effects test showed that the main effects were statistically significant in the facility factor ($F(2,402)=19.542$, $p<.05$), melody factor ($F(1,402)=135.099$, $p<.05$), and age factor ($F(2,402)=9.692$, $p<.05$). As a result of multiple comparison test, 3-year-old was larger in Y facility than T facility, 4-year-old was larger in Y facility than W facility, and 5-year-old was larger in Y facility than T facility and W facility, in melody (bright). 4-year-old was larger in Y facility than T facility and W facility by melody (dark). 3-year-old, 4-year-old, and 5-year-old were larger in melody (bright) than melody (dark) in 3-year-old, 4-year-old, and 5-year-old. 5-year-old was larger than 3-year-old in melody (bright), and 5-year-old was larger than 4-year-old in melody (dark).

(4) Analysis of the movement of the fourth proximal phalanx

A three-way non-repeated ANOVA on the moving average distance by the fourth proximal phalanx, and the results of between-subject effects test showed that the main effects were observed in the facility factor ($F(2,402) =22.684$, $p<.05$), melody factor ($F(1,402)=136.570$, $p<.05$), and age factor ($F(2,402) =8.765$, $p<.05$). As a result of multiple comparison test, 3-year-old was larger in Y facility than T facility, 4-year-old was larger in Y facility than W facility, and 5-year-old was larger in Y facility than T facility and W facility, in melody (bright). 3-year-old, 4-year-old, and 5-year-old was larger in melody (bright) than melody (dark) in T facility, W facility and Y facility. 5-year-old was larger than 3-year-old in melody (bright), and 5-year-old was larger than 4-year-old in melody (dark) in T facility.

(5) Analysis of the movement of the fifth proximal phalanx

A three-way non-repeated ANOVA was conducted on the moving average distance by the fifth proximal phalanx and the results of between-subject effects test showed that the main effects were statistically significant in the facility factor ($F(2,402) =24.445$, $p<.05$), melody factor ($F(1,402) =140.656$, $p<.05$), and age factor ($F(2,402) =9.023$, $p<.05$). As a result of multiple comparison test, 3-year-old was larger in Y facility than T facility, 4-year-old was larger in Y facility than W facility, 5-year-old was larger in Y facility than T facility and W facility in melody (bright). 4-year-old was larger in Y facility than T facility and W facility, and 5-year-old was larger in Y facility than W facility in melody (dark). 3-year-old, 4-year-old, and 5-year-old were larger in melody (bright) than melody (dark) in T facility, W facility, and Y facility. 5-year-old was larger than 3-year-old in melody (bright), and 5-year-old was larger than 4-year-old in melody (dark), in T facility.

4.3 The moving average velocity of the proximal phalanx in the fingers

(1) Analysis of the moving average velocity of the first proximal phalanx

A three-way non-repeated ANOVA was conducted on the moving average velocity of the first proximal phalanx, and the results of between-subject effects test showed that the main effects and interactions were statistically significant (the facility factor: (F(2,402)=7.433, p<.05), melody factor: (F(1,402)=6.081, p<.05), age factor: (F(2,402)=10.714, p<.05), and the facility * melody factor: (F(2,402)=17.542, p<.05)).

Concerning the facility factor/ the facility * melody * age factor, the simple main effects were observed in the melody (bright) (3-year-old: (F(2,402) =6.949, p<.05), 4-year-old: (F(2,402) =5.484, p<.05), 5-year-old: (F(2,402)= 8.990, p<.05)) and the melody (dark) (5-year-old: (F(2,402)=6.924, p<.05)). As a result of

Multiple comparison test, 3-year-old, 4-year-old, and 5-year-old were larger in Y facility than T facility and W facility in melody (bright), and 5-year-old was larger in T facility than W facility and Y facility.

Concerning the melody factor/ the facility * melody * age factor, the simple main effects were observed (5-year-old in T facility: (F(1,402)=13.987, p<.05), and Y facility (3-year-old: (F(1,402)=10.492, p<.05), 4-year-old: (F(1,402)=8.214, p<.05), 5-year-old: (F(1,402)=12.763, p<.05)). As a result of the multiple comparison test, 5-year-old in T facility and 3-year-old, 4-year-old, and 5-year-old in Y facility were larger in melody (bright) than melody (dark).

Concerning the age factor/ the facility * melody * age factor, the simple main effects were observed in T facility (melody(dark): (F(2,402) =9.020, p<.05)), and W facility (melody (dark): (F(2,402) =4.084, p<.05)). As a result of multiple comparison test, 5-year-old was larger than 3-year-old and 4-year-old in T facility by melody (dark), and 5-year-old was larger than 4-year-old in W facility by melody (dark).

(2) Analysis of the moving average velocity of the second proximal phalanx

A three-way non-repeated ANOVA was conducted on the moving average velocity of the second proximal phalanx, and the results of between-subject effects test showed that the main effects and interactions were statistically significant in the facility factor (F(2,402)=4.965, p<.05), melody factor (F(1,402)=4.435, p<.05), age factor (F(2,402)=10.340, p<.05), and the facility * melody factor (F(2,402)=16.755, p<.05).

Concerning the facility factor/ the facility * melody * age factor, the simple main effects were observed in the melody (bright) (3-year-old: (F(2,402)=5.197, p<.05), 4-year-old: (F(2,402)=3.663, p<.05), 5-year-old: (F(2,402)=6.322, p<.05), and the melody (dark) (5-year-old: (F(2,402)=9.045, p<.05)). As a result of multiple comparison test, 3-year-old was larger in y facility than T facility, 4-year-old was larger in Y facility than W facility, and 5-year-old was larger in Y facility than T facility and W facility in the melody (bright). 5-year-old was larger in T facility than W facility and Y facility in the melody (dark).

Concerning the melody factor/ the facility * melody * age factor, the simple main effects were observed in T facility (5-year-old: (F(1,402)=15.809, p<.05)), and Y facility (3-year-old: (F(1,402)=9.048, p<.05), 4-year-old: (F(1,402)=7.230, p<.05), 5-year-old: (F(1, 402)=11.493, p<.05)). As a result of multiple comparison test, 5-year-old was larger in melody (dark) than melody (bright) in T facility, and 3-year-old, 4-year-old, and 5-year-old were larger in melody (bright) than melody (dark) in Y facility.

Concerning the age factor/ the facility * melody * age factor, the simple main effects were observed in T facility (the melody (dark): (F(2,402) =9.557, p<.05)), and W facility (the melody (dark): (F(2,402) =4.596, p<.05)). As a result of multiple comparison test, 5-year-old was larger than 3-year-old and 4-year-old in T facility and W facility by the melody (dark).

(3) Analysis of the moving average velocity of the third proximal phalanx

A three-way non-repeated ANOVA was conducted on the moving average velocity of the third proximal phalanx, and the results of between-subject effects test showed that the main effects and interactions were statistically significant in the facility factor (F(2, 402)=4.176, p<.05), the melody factor (F(1,402)=5.158, p<.05), age factor (F(2, 402)=12.382, p<.05), and the facility * melody factor (F(2,402)=14.580, p<.05).

Concerning the facility factor/ the facility * melody * age factor, the simple main effects were observed in the melody (bright) (3-year-old: (F(2,402)=4.882, p<.05), 4-year-old: (F(2, 402)=3.219, p<.05), 5-year-old: (F(2,402)=5.100, p<.05)) and the melody (dark) (F(2, 402)=7.531, p<.05). As a result of multiple comparison test, 3-year-old was larger in Y facility than t facility, 4-year-old was larger in Y facility and W facility, and 5-year-old was larger in Y facility than T facility and W facility in melody (bright). 5-year-old was larger in T facility than W facility and Y facility in melody (dark).

Concerning the melody factor/ the facility * melody * age factor, the simple main effects were observed in T facility (5-year-old: F(1,402)=14.247, p<.05), and Y facility (3-year-old: (F(1,402) =8.755, p<.05), 4-year-old: (F(1,402)=6.693, p<.05), 5-year-old: (F(1,402)=9.604, p<.05)). As a result of multiple comparison test, 5-year-old was larger in melody (dark) than melody (bright) in T facility, and 3-year-old, 4-year-old, and 5-year-old were larger in melody (bright) than melody (dark) in Y facility.

Concerning the age factor/ the facility * melody * age factor, the simple main effects were observed in T facility (the melody (dark): (F(2,402) =9.422, p<.05)), and W facility (the melody (dark): F(2,402) =5.709, p<.05). As a result of multiple comparison test, 5-year-old was larger than 3-year-old and 4-year-old in T facility and W facility by melody (dark).

(4) Analysis of the moving average velocity of the fourth proximal phalanx

A three-way non-repeated ANOVA was conducted on the moving average velocity of the fourth proximal phalanx, and the results of between-subject effects test showed that the main effects and interactions were statistically significant in the facility factor (F(2,402)=5.766, p<.05), melody factor (F(1,402)=5.009, p<.05), age factor (F(2,402)=11.064, p<.05), the facility * melody factor (F(2,402)=13.849, p<.05), and the melody *age factor (F(2,402) =3.325, p<.05).

Concerning the facility factor/ the facility * melody * age factor, the simple main effects were observed in the melody (bright) (3-year-old: (F(2,402)=4.824, p<.05), 4-year-old: (F(2,402) =3.126, p<.05), 5-year-old: (F(2,402) =6.005, p<.05)), and the melody (dark) (5-year-old: (F(2,402) =7.048, p<.05). As a result of multiple comparison test, 3year-old was larger in Y facility than T facility, 4-year-old was larger in Y facility than W facility, and 5-year-old was larger in Y facility than T facility and W facility in melody (bright). 5-year-old was larger in T facility than W facility and Y facility in melody (dark).

Concerning the melody factor/ the facility * melody * age factor, the simple main effects were observed in T facility (5-year-old: (F(1,402) =13.199, p<.05)), and Y facility (3-year-old: (F(1,402) =8.823, p<.05), 4-year-old: (F(1,402) =6.229, p<.05), 5-year-old: (F(1,402) =8.805, p<.05)). As a result of multiple comparison test, 5-year-old was larger in melody (dark) than melody (bright) in T facility, and 3-year-old, 4-year-old, and 5-year-old were larger in melody (bright) than melody (dark) in Y facility.

Concerning the age factor/ the facility * melody * age factor, the simple main effects were observed in T facility (the melody (dark): (F(2,402) =8.968, p<.05)) and W facility (the melody (dark): (F(2,402) =4.547, p<.05)). As a result of multiple comparison test, 5-year-old was larger than 3-year-old and 4-year-old in T facility and W facility in melody (dark).

(5) Analysis of the moving average velocity of the fifth proximal phalanx

A three-way non-repeated ANOVA was conducted on the moving average velocity of the fifth proximal phalanx, and the results of between-subject effects test showed that the main effects and interactions were observed in the facility factor (F(2,402)=6.229, p<.05), melody factor (F(1,402) =6.179, p<.05), age factor (F(2,402) =11.266, p<.05), the facility * melody factor (F(2,402) =14.206, p<.05), and melody *age factor (F(2,402) =3.370, p<.05).

Concerning the facility factor/ the facility * melody * age factor, the simple main effects were observed in the melody (bright) (3-year-old: (F(2,402)=4.834, p<.05), 4-year-old: (F(2,402) =3.720, p<.05), 5-year-old: (F(2,402) =6.328, p<.05)), and the melody (dark) (5-year-old: (F(2,402)=6.540, p<.05). As a result of multiple comparison test, 3-year-old was larger in Y facility than T facility, 4-year-old was larger in Y facility than W facility, and 5-year-old was larger in Y facility than T facility and W facility in melody (bright). 5-year-old was larger in T facility than W facility and Y facility in melody (dark).

Concerning the melody factor/ the facility * melody * age factor, the simple main effects were observed in T facility (5-year-old: (F(1,402)=12.024, p<.05)), and Y facility (3-year-old: (F(1,402) =9.547, p<.05), 4-year-old: (F(1,402) =6.929, p<.05), 5-year-old: (F(1,402) =9.515, p<.05)). As a result of multiple comparison test, 5-year-old was larger in melody (dark) than melody (bright), and 3-year-old, 4-year-old, and 5-year-old were larger in melody (bright) than melody (dark) in T facility.

Concerning the age factor/ the facility * melody * age factor, the simple main effects were observed in T facility (the melody (dark): (F(2,402) =8.848, p<.05), and W facility (the melody (dark): (F(2,402) =5.139, p<.05)). As a result of multiple comparison test, 5-year-old was larger than 3-year-old and T facility and W facility in melody (dark). The following Figures 2-1 to 2-

10 show the age-related changes in the moving average velocity for the first, second, third, fourth and fifth proximal phalanges, divided by melody (bright) and (dark).

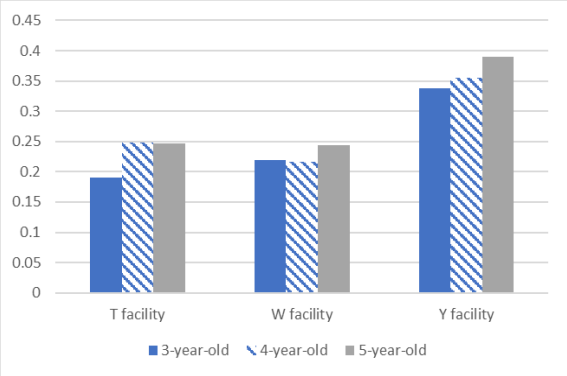

Figure 2-1. The moving average velocity of the first proximal phalanx: melody (bright)

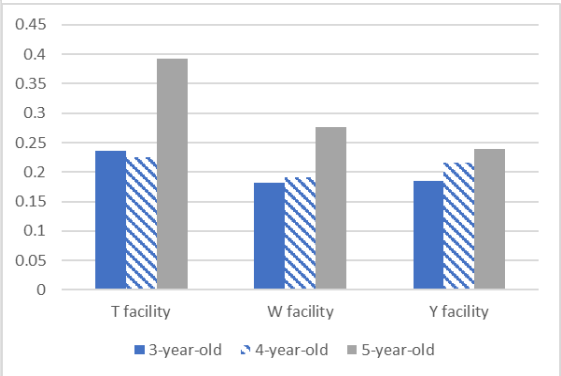

Figure 2-2. The moving average velocity of the first proximal phalanx: melody (dark)

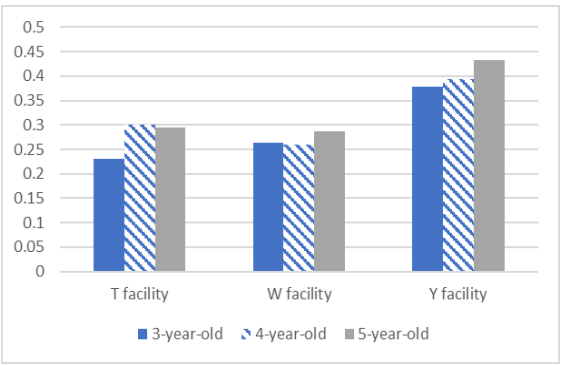

Figure 2-3. The moving average velocity of the second proximal phalanx: melody (bright)

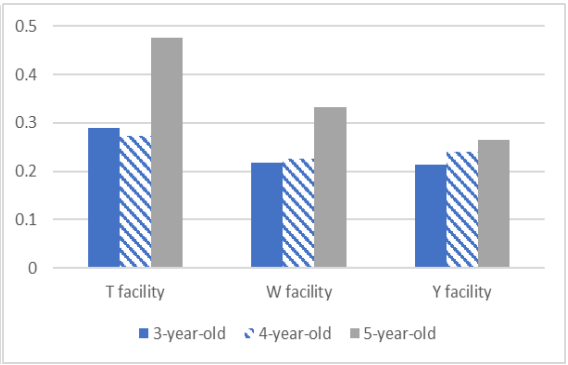

Figure 2-4. The moving average velocity of the second proximal phalanx: melody (dark)

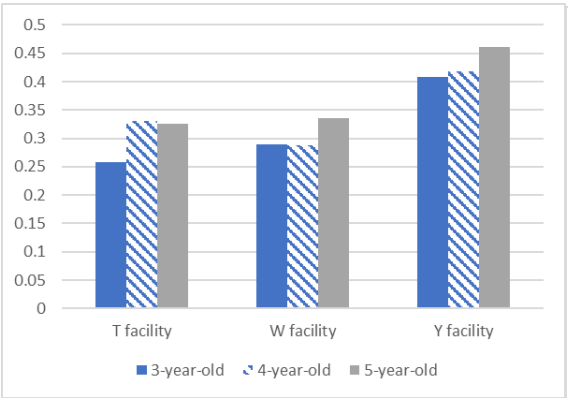

Figure 2-5. The moving average velocity of the third proximal phalanx: melody (bright)

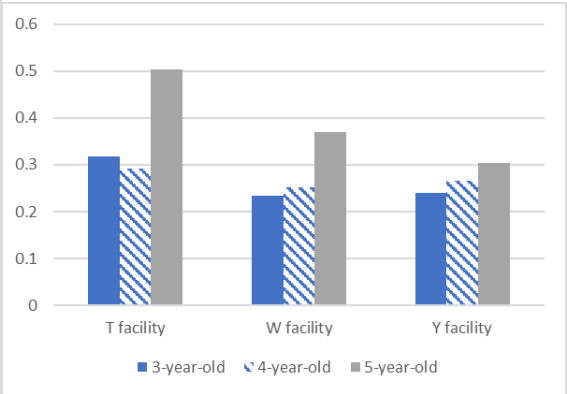

Figure 2-6. The moving average velocity of the third proximal phalanx: melody (dark)

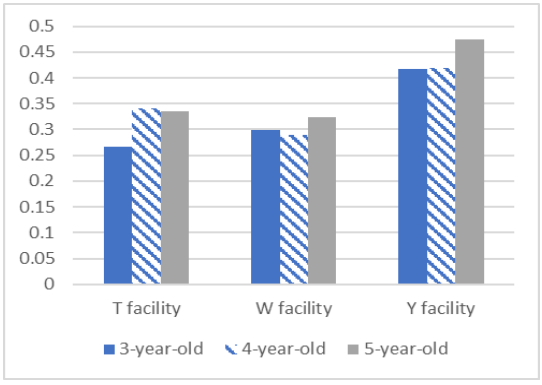

Figure 2-7. The moving average velocity of the fourth proximal phalanx: melody (bright)

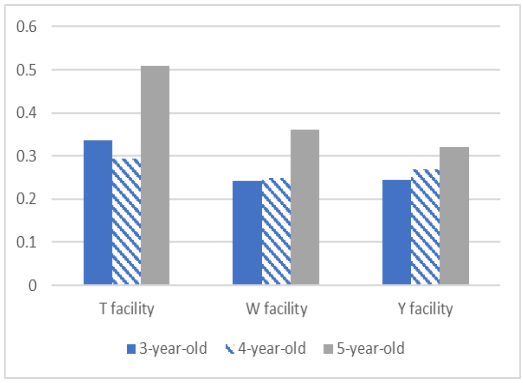

Figure 2-8. The moving average velocity of the fourth proximal phalanx: melody (dark)

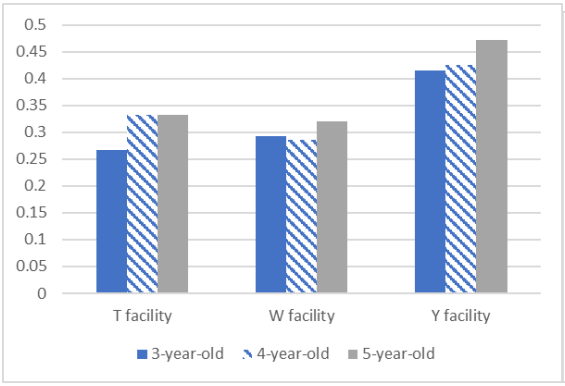

Figure 2-9. The moving average velocity of the fifth proximal phalanx: melody (bright)

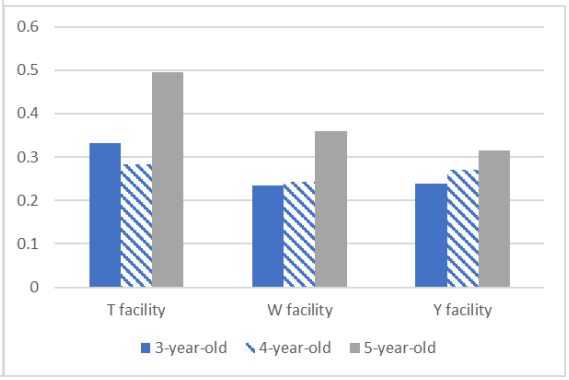

Figure 2-10. The moving average velocity of the fifth proximal phalanx: melody (dark)

From Figures 2-1 to 2-10 and the results of the quantitative analysis, 3-year-old, 4-year-old, and 5-year-old were remarkable large in Y facility by melody (bright), and 5-year-old was remarkable large in T facility by melody (dark).

4.4 The moving average acceleration of the proximal phalanx in five fingers

(1) Analysis results of the moving average acceleration of the first proximal phalanx

A three-way non-repeated ANOVA was conducted on the moving average acceleration of the first proximal phalanx, and the results of between-subject effects test showed that the main effects and interactions were statistically significant in the melody factor ($F(1,402) = 27.033$, $p<.05$), age factor ($F(2,402) = 6.184$, $p<.05$), and the facility * melody factor ($F(2, 402) = 7.356$, $p<.05$).

Concerning the facility factor/ the facility * melody * age factor, the simple main effects were observed in the melody (bright) (3-year-old: ($F(2,402) = 3.807$, $p<.05$), 5-year-old: ($F(2,402) = 4.253$, $p<.05$)). As a result of multiple comparison test, 3-year-old and 5-year-old were larger in Y facility than T facility in melody (bright).

Concerning the melody factor/ the facility * melody * age factor, the simple main effects were observed in Y facility (3-year-old: ($F(1,402) = 5.285$, $p<.05$), 4-year-old: ($F(1,402) = 11.370$,

p<.05), 5-year-old: (F(1,402) =14.625, p<.05)). As a result of multiple comparison test, 3-year-old, 4-year-old, and 5-year-old were larger in melody (bright) than melody (dark) in Y facility.

Concerning the age factor/ the facility * melody * age factor, the simple main effects were observed in T facility (the melody (dark): (F(2,402) =3.613, p<.05)). As a result of multiple comparison test, 5-year-old was larger than 4-year-old in melody (dark).

(2) Analysis results of the moving average acceleration of the second proximal phalanx

A three-way non-repeated ANOVA was conducted on the moving average acceleration of the second proximal phalanx, and the results of between-subject effects test showed that the main effects and interactions were statistically significant in the melody factor (F(1,402) =26.831, p<.05), age factor (F(2,402) =6.347, p<.05), and the facility * melody factor (F(2,402) =5.952, p<.05).

Concerning the melody factor/ the facility * melody * age factor, the simple main effects were observed in Y facility (3-year-old: (F(1,402) =5.091, p<.05), 4-year-old: (F(1,402) =9.732, p<.05), 5-year-old: (F(1,402) =13.089, p<.05)). As a result of multiple comparison test, 3-year-old, 4-year-old, and 5-year-old were larger in melody (bright) than melody (dark) in Y facility.

Concerning the age factor/ the facility * melody * age factor, the simple main effects were observed in T facility (melody (dark): (F(2,402) =4.212, p<.05)). As a result of multiple comparison test, 5-year-old was larger than 4-year-old in T facility by melody (dark).

(3) Analysis results of the moving average acceleration of the third proximal phalanx

A three-way non-repeated ANOVA was conducted on the moving average acceleration of the third phalanx, and the results of between-subject effects test showed that the main effects were statistically significant in the melody factor (F(1,402) =10.247, p<.05) and age factor (F(2,402) =7.086, p<.05). As a result of multiple comparison test, 5-year-old was larger in W facility than T facility in the melody (bright). In W facility, 5-year-old was larger than 3-year-old and 4-year-old in melody (bright), and 5-year-old was larger than 3-year-old in melody (dark).

(4) Analysis results of moving average acceleration of the fourth proximal phalanx

A three-way analysis non-repeated was conducted on the moving average acceleration of the fourth phalanx, and the results of between-subject effects showed that the main effects were statistically significant in the melody factor (F(1,402) =11.985, p<.05) and age factor (F(2,402) =3.815, p<.05). As a result of multiple comparison test, 4-year-old was larger in the melody (bright) than the melody (dark) in T facility.

(5) Analysis results of the moving average acceleration of the fifth proximal phalanx

A three-way non-repeated ANOVA was conducted on the moving average acceleration of the fifth phalanx, and the results of between-subject effects showed that the main effects were statistically significant in the melody factor (F(1,402) =13.167, p<.05) and the age factor (F(2,402) =3.058, p<.05). As a result of multiple comparison test, 4-year-old was larger in the

melody (bright) than the melody (dark) in T facility. 3-year-old was larger than 4-year-old by the melody (dark) in T facility.

4.5 The moving smoothness of the proximal phalanges of the five fingers

(1) Analysis results of the moving smoothness of the first proximal phalanges

A three-way non-repeated ANOVA was conducted on the moving average smoothness of the first phalanx, and the results of between-subject effects test showed that the main effects and interactions were statistically significant in the melody factor (F(1, 402) =72.682, p<.05), age factor (F(2,402) =3.714, p<.05), the facility * melody factor (F(2, 402) =6.772, p<.05), and melody * age factor (F(2,402) =3.834, p<.05).

Concerning the facility factor/ the facility * melody * age factor, the simple main effects were observed in the melody (dark) (4-year-old: (F(2,402) =7.128, p<.05), 5-year-old: (F(2,402) =4.111, p<.05)). As a result of multiple comparison test, 4-year-old was larger in Y facility than W facility, and 5-year-old was larger in Y facility than T facility in melody (dark).

Concerning the melody factor/ the facility * melody * age factor, the simple main effects were observed in T facility (4-year-old: (F(1,402) =11.227, p<.05), W facility ((3-year-old: (F(1,402) =8.356, p<.05), 4-year-old: (F(1,402) =11.027, p<.05), 5-year-old: (F(1,402) =14.202, p<.05)), and Y facility ((3-year-old: (F(1,402) =6.191, p<.05), 4-year-old: (F(1,402) =30.183, p<.05), 5-year-old: (F(1,402) =11.026, p<.05)). As a result of multiple comparison test, 4-year-old in T facility, and 3-year-old, 4-year-old, and 5-year-old in W facility and Y facility were larger in the melody (dark) than the melody (bright).

Concerning the age factor/ the facility * melody * age factor, the simple main effects were observed in T facility (the melody (dark): (F(2,402) =4.960, p<.05)), and Y facility (the melody (dark): F(2,402) =5.371, p<.05). As a result of multiple comparison test, 4-year-old was larger 5-year-old in T facility and Y facility by melody (dark).

(2) Analysis results of the moving smoothness of the second proximal phalanx

A three-way non-repeated ANOVA was conducted on the moving smoothness of the second proximal phalanx, and the results of between-subject effects test showed that the main effects and interactions were statistically significant in the facility factor (F(2,402) =6.676, p<.05), melody factor (F(1,402) =70.274, p<.05), and the facility * melody factor (F(2,402) =6.322, p<.05).

Concerning the facility factor/ the facility * melody * age factor, the simple main effects were observed in Y facility (the melody (dark): (F(2,402) = 5.882, p<.05)). As a result of multiple comparison test, 4-year-old was larger than 3-year-old and 5-year-old by melody (dark) in Y facility.

Concerning the melody factor/ the facility * melody * age factor, the simple main effects were observed in W facility (3-year-old: (F(1,402) =9.869, p<.05), 4-year-old: (F(1,402) = 9.346, p<.05), 5-year-old: (F(1,402) =18.848, p<.05), and Y facility (3-year-old: (F(1,402) = 4.973, p<.05), 4-year-old: (F(1,402) =28.888, p<.05), 5-year-old: (F(1,402) = 8.737, p<.05)). As a

result of multiple comparison test, 3-year-old, 4-year-old, and 5-year-old were larger in the melody (dark) than the melody (bright) in W facility and Y facility.

Concerning the age factor/ the facility * melody * age factor, the simple main effects were observed in Y facility (the melody (dark): (F(2,402) = 5.882, p<.05)). As a result of multiple comparison test, 4-year-old was larger than 3-year-old and 5-year-old by the melody (dark) in Y facility.

(3) Analysis results of the moving smoothness of the third proximal phalanx

A three-way non-repeated ANOVA was conducted on the third proximal phalanx smoothness, and the results of between-subject effects test showed that the main effects and interactions were statistically significant in the facility factor (F(2,402) =6.728, p<.05), melody factor (F(1,402) =19.427, p<.05), the facility * age factor (F(4,402) =2.680, p<.05), and the facility * melody * age factor (F(4,402) =2.654, p<.05).

Concerning the facility factor/ the facility * melody * age factor, the simple main effects were observed in the melody factor (bright) (5-year-old: (F(2,402) = 5.755, p<.05), the melody factor (dark) (4-year-old: (F(2,402) = 9.467, p<.05). As a result of multiple comparison test, 5-year-old was larger in T facility and Y facility than W facility in the melody (bright), and 4-year-old was larger in Y facility than T facility and W facility in the melody (dark).

Concerning the melody factor/ the facility * melody * age factor, the simple main effects were observed in T facility (5-year-old: (F(1,402)=4.238, p<.05)), W facility (3-year-old: (F(1,402) =3.964, p<.05), 5-year-old: (F(1,402) =15.146, p<.05), and Y facility (4-year-old: (F(1,402) =8.446, p<.05). As a result of multiple comparison test, 5-year-old was larger in melody (dark) than melody (bright), 3-year-old and 5-year-old were larger in melody (dark) than melody (bright) in W facility, and 4-year-old was larger in melody (dark) than melody (bright) in Y facility.

Concerning the age factor/ the facility * melody * age factor, the simple main effects were observed in Y facility (the melody (dark): (F(2,402) =5.788, p<.05)). As a result of multiple comparison test, 4-year-old was larger than 3-year-old and 5-year-old by melody (dark) in Y facility.

(4) Analysis of the moving smoothness of the fourth proximal phalanx

A three-way non-repeated ANOVA was conducted on the moving smoothness of the fourth proximal phalanx, and the results of between-subject effects test showed that the main effects and interactions were statistically significant in the facility factor (F(2, 402)=3.152, p<.05), the melody factor (F(1,402) =16.381, p<.05), and the facility * age factor (F(4,402) =3.335, p<.05).

Concerning the facility factor/ the facility * melody * age factor, the simple main effects were observed in the melody (dark) (4-year-old: (F(2,402) =7.273, p<.05)). As a result of multiple comparison test, 4-year-old in melody (dark) was larger in Y facility than W facility.

Concerning the melody factor/ the facility * melody * age factor, the simple main effects were observed in W facility (3-year-old: (F(1,402) = 5.885, p<.05), 5-year-old: (F(1,402) = 10.275, p<.05)), and Y facility (4-year-old: (F(1,402) =5.567, p<.05)). As a result of multiple comparison test, 3-year-old and 5-year-old in W facility and 4-year-old in Y facility were larger in melody (dark) than melody (bright).

Concerning the age factor/ the facility * melody * age factor, the simple main effects were observed in Y facility (the melody (dark): (F(2,402) =8.412, p<.05)). As a result of multiple comparison test, 5-year-old was larger than 4-year-old by the melody (dark) in W facility, and 4-year-old was larger then 3-year-old and 5-year-old by melody (dark) in Y facility.

(5) Analysis results of the moving smoothness of the fifth proximal phalanx

A three-way non-repeated ANOVA was conducted on the moving smoothness of the fifth proximal phalanx, and the results of between-subject effects test showed that the main effect was statistically significant in the melody factor (F(1,402) =14.602, p<.05). As a result of multiple comparison test, 4-year-old in melody (dark) was larger in Y facility than W facility. 4-year-old was larger in melody (dark) than melody (bright) in W facility and Y facility. 4-year-old was larger than 3-year-old and 5-year-old by melody (dark) in Y facility.

4.6 Analysis results regarding the function of the proximal phalanx of the fingers

Principal component analysis and cluster analysis were conducted on the data for each proximal phalange in the five fingers mentioned above. The following figure 3 is a dendrogram showing the results of the cluster analysis. As the cluster analysis results show, the bones are roughly divided into the first and second proximal phalanges, and the third, fourth and fifth proximal phalanges. The distances between the first and second proximal phalanges, and between the fourth and fifth proximal phalanges, are the closest, respectively. The correlation matrix showed that the second proximal phalange was highly correlated with the first (.788), fourth (.706), and fifth (.739) proximal phalanges, and the fourth proximal phalange was highly correlated with the third (.753) and fifth (.837) proximal phalanges.

Furthermore, the results of the principal component analysis showed that the total explained variance had an explanatory power of 93.443% up to the third principal component. The principal component score coefficient matrix showed that the factor loadings of the first principal component were positive for the proximal phalanges of all five fingers, and thus these were estimated to work together to represent "the ability to express musical sensitivity." In the second principal component, the first proximal phalanx had the largest positive factor loading (.942), and the second proximal phalanx also had a positive factor loading, while the third, fourth, and fifth proximal phalanx had negative factor loadings. Therefore, it was estimated to represent the ability to form an image of the events in a song while keeping the rhythm, "the ability to recognize rhythm and form an image." For the third principal component, the third proximal phalanx had the largest positive factor loading, while the fourth (-.752) and fifth (-.776) proximal phalanxes were negative, suggesting that this represents "the ability to evoke the perception of rhythm and the expression of images." From this, it was suggested that the third proximal phalanx, while linking with the first and second proximal phalanxes, independently stimulates and maintains the minute movements of the fourth and fifth proximal phalanxes.

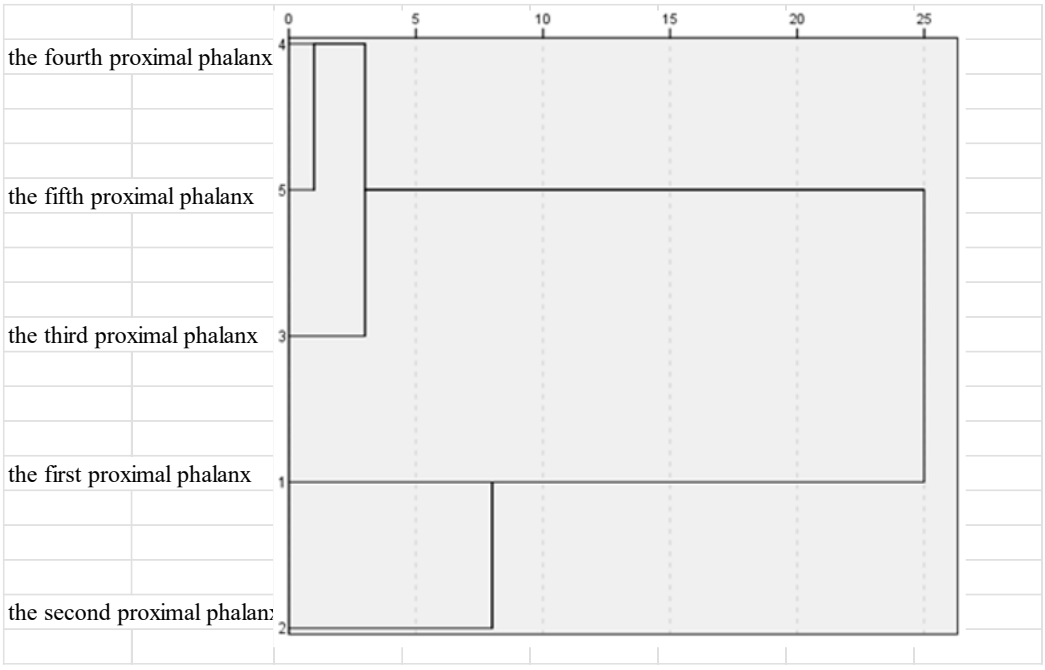

Figure 3. A result of cluster analysis

5.0 DISCUSSION

In this study, based on calculated data on the total moving distance, the moving average velocity, the moving average acceleration, and the moving smoothness for each proximal phalanx of the five fingers in finger movements during musical expression, the author conducted a three-way non-repeated ANOVA with factors of facility, melody, and age.

As a result, statistically significant differences were observed, mainly in the melody factor, and the total moving distance was larger in melody (bright) than in melody (dark), with this tendency being remarkable in Y facility. Regarding the moving average velocity, the data in melody (bright) was larger in Y facility, while the data in melody (dark) was larger in T facility due to age factors, and a similar tendency was observed in the moving average acceleration of the second proximal phalanx. However, the moving average acceleration in the melody (bright) was significantly larger than in the melody (dark) in the first, third, fourth and fifth proximal phalanges. Regarding the moving smoothness, the data in melody (dark) was significantly larger than melody (bright) in the first, second, fourth and fifth proximal phalanges, and was characteristic in Y facility, while, in the third proximal phalange, 5-year-old was large in melody (bright) as well as melody (dark).

While the total moving distance and the moving average acceleration were significantly larger for the melody (bright), the moving average velocity showed a response to the characteristic rhythm of the song while being sensitive to the melodies (bright) (dark). While the moving smoothness was significantly larger for the melody (dark), it was found that the third proximal phalanx showed the movement characteristic of sensing the melodies (bright) (dark) during recognizing the beat at the same time. As a result, it was found that it is broadly divided into the first and second proximal phalanges, and the third, fourth, fifth proximal phalanges. The second proximal phalange was strongly correlated with the first, fourth, and fifth proximal

phalanges, and the results of principal component analysis indicated that the first principal component was "the ability to indicate sensitivity to music," the second principal component was "the ability to recognize rhythm and form images," and the third principal component was "the ability to evoke sensitivity to rhythm and the expression of images."

6.0 CONCLUSION

In this way, the results of the author's quantitative analysis of the movement of the hand as a whole showed that the remarkable movement was characteristic for the melody (bright), but focusing the movement of each proximal phalanx of all five fingers, it was found that the characteristics of the action of each finger could be found in the moving average velocity and the moving smoothness. In my future task, the author would explore new effective feature quantities based on specifically quantitative analysis of each calculated data regarding minute movements of each finger during musical expression in early childhood.

Acknowledgement

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REFERENCES

1. Akiyama, K., & Yamanaka, K. (2016). The relationship between skill and knife handling in peeling apples, *Abstracts of the Research Presentations at the Japan Society of Food Science and Technology Conference*, 28 (0), 58.
2. Albrecht, S., Janssen, D., Quarz, E., Newell, K., Schöllh orn,W. (2014). Individuality of movements in music: Finger and body movements during playing of the flute, *Human Movement Science*, 35, 131-144.
3. Aoki, R., & Kurebayashi, S. (2020). Study on the educational use of a simple hand movement analysis system, *Journal of Curriculum Development Studies*, 8, 83-92.
4. Bayed, H., Guyot, P., Bardy, B., & Slangen, P.(2022) Automatic scoring of synchronization from fingers motion capture and music beats*, ISHAPE 2022 - 1st Int. Workshop on Intelligent Systems in Human and Artificial Perception*, May 2022, Lecce, Italy. pp.235-245, ff10.1007/978-3-031-13321-3_21ff. ffhal-03682819
5. Bishopa,L., Cancino-Chacón, C., & Goebl, W. (2019). Eye gaze as a means of giving and seeking information during musical interaction, *Consciousness and Cognition*, 68, 73-96. https://doi.org/10.1016/j.concog.2019.01.002
6. Bonafede, C., & van der Merwe, E. (2023). Normal Ranges for Proprioceptive Tasks in 6-Year-Old Children in Mangaung, *South African Journal of Childhood Education*, 13(1), Article 1243.
7. Braido, P., & Zhang, X. (2004). Quantitative analysis of finger motion coordination in hand manipulative and gestic acts, *Human Movement Science*, 22 (6), 661-678. https://doi.org/10.1016/j.humov.2003.10.001
8. Çoşkunsoy, B., & Güdek, B. (2019). The Impact of Body Language Use of a Conductor on Musical Quality, *Journal of Education and Training Studies*, 7(9), 39-47. doi:10.11114/jets.v7i9.4271
9. Goebl, W., & Palmer, C. (2013). Temporal Control and Hand Movement Efficiency in Skilled Music Performance, *PLoS One*, 8(1): e50901. https://doi.org/10.1371/journal.pone.0050901

10. Ito, T., Yoshida, M., Funakoshi, I., & Kokubu, T. (2021). Tendon fixation and muscle activity of the hand and fingers during successive keystrokes during typing, *40th Kanto Koshinetsu Block Physical Therapist Conference*, 115, O21-5.
11. Kaplan, D. (2016). Evaluating The Relation Between Dominant and Non-Dominant Hand Perimeters and Handgrip Strength of Basketball, Volleyball, Badminton and Handball Athletes, International *Journal of Environmental & Science Education*, 11(10), 3297-3309.
12. Khoran, H., Alibakhshi, E., & Khoran, Z. (2012). Effect of music on learning of hand fine movement skills in mental retarded children, *Procedia - Social and Behavioral Sciences*, 12, 324–327.
13. Kobayashi, A., Kokubu, T., Muraki, T., & Kanemura, T. (2017). Effects of changes in volume during typing on trunk and upper limb motor control, *Abstracts of the 52nd Japanese Physical Therapy Conference*, Vol.44 Suppl. No.2, P-KS-15-1.
14. Kotani, S., & Furuya, S. (2018). State anxiety disorganizes finger movements during musical performance, *Journal of Neurophysiology*, 120 (2), 439-451. https://doi.org/10.1152/jn.00813.2017
15. Liu, Y., Jiang, Li., Liu, H., & Ming, D. (2021). A Systematic Analysis of Hand Movement Functionality: Qualitative Classification and Quantitative Investigation of Hand Grasp Behavior, *Frontiers in Neurorobotics*, 15. https://doi.org/10.3389/fnbot.2021.658075
16. Martins, M., Neves, L., Rodrigues, P., Vasconcelos, O., & Castro,S. (2018). Orff-Based Music Training Enhances Children's Manual Dexterity and Bimanual Coordination, *Front. Psychol*., 9, 1-12. https://doi.org/10.3389/fpsyg.2018.02616
17. Mihara, N., Nakao, K., & Ota, M. (2016). Analysis of upper limb and finger movements when placing and releasing an object, *Kyushu Physical Therapist and Occupational Therapist Joint Conference 2016,* p.155, P1-C01.
18. Miura, M. (2022). Acquiring movement parameters to support musical instrument practice using a motion capture system: In the case of finger positioning in piano playing, *Research Bulletin*, 56, 331-333.
19. Nara, T., Mamizuka, N., Kawamura, T., Tago, S., & Shimada, K. (2011). Quantitative analysis of finger and limb positions in a glove during baseball catching movements, *Kanazawa Seiryo University Human Science Research*, 4(2), 55-58.
20. Nishimori, Y., Yamaguchi, S., & Miura, M. (2016). The relationship between the movements of the hands and upper body of piano players and their performance proficiency, *Materials from the Music Acoustics Research Society*, 35 (4), 47-52.
21. Park, B., Korbach, A., Ginns, P., & Brünken, R. (2023). How Learners Use Their Hands for Learning: An Eye-Tracking Study, *Educational Psychology Review*, 35 (4), Article 116.
22. Sano, M. (2018). Statistical Analysis of Elements of Movement in Musical Expression in Early Childhood Using 3D Motion Capture and Evaluation of Musical Development Degrees Through Machine Learning, *World Journal of Education*, Sciedu Press 8(3) 118-130. doi: 10.5430/wje.v8n3p118
23. Sano, M. (2019). Predicting developmental degrees of music expression in early childhood by machine learning classifiers with 3D motion captured body movement data, *Journal of Educational Research and Reviews (International),* 7(7) 155-168. doi: 10.33495/jerr_v7i7.19.128

24. Sano, M. (2021). Quantitative Analysis of Eye Movements during Singing of Early Childhood Children, *Research Journal of Education*, 7(3) 125-140. doi: 10.32861/rje.73.156.1
25. Sano, M. (2023). An exploration of prediction accuracy of developmental degrees of music expression in early childhood based on a simultaneous analysis of both eye movement and full-body movement, *Transactions on Engineering and Computing Sciences*, 11(3) 10-25. Doi:10.14738/tecs.113.14
26. Sano, M. (2024). Advancement of discrimination accuracy of musical development degree utilizing machine learning with optimized feature quantities extracted from simultaneous analysis of both eye movement and body movement during musical expression in early childhood, *Advances in Social Sciences and Management*, HeadStart Network for Education and Research, UK. 2(10) 53-69.
27. Sano, M. (2025). Chapter 3, Investigating Musical Expression through Body Movement in Early Childhood: A Device-based Quantitative Approach to Extract Various Feature Quantities, *New Horizons of Science, Technology and Culture*, Khalid Mujasam Batoo (Eds.), BP International Publisher, Vol.1, 34-58.
28. Shimizu, H., Miyata, N., Maeda, Y. (2012). Modeling of finger movement area based on measurements, *Proceedings of the JSPE Annual Meeting*, 2012S (0), 849-850.
29. Yu, Y., Kodama, M., Inada, E., Saitoh, I., Tomiyama,D., Takemoto, Y., Murakami, D., Morizono, K., Simotahira, T., Fukushige, M., Kitaue, M., & Yamasaki, Y. (2014). Analysis of Toothbrushing Motion with High Precision Motion Capture－Fourth Report : Analysis and Comparison of Arm Movement between Dominant and Non-dominant Hand, *The Japanese Journal of Pediatric Dentistry*, 53(3), 389.

