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Original Paper

Characteristics of Eye Movements during Musical Expression in Early Childhood by Tonality: Through Quantitative Analysis by Eye Tracking

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Abstract

Early childhood children frequently use body movements while singing songs accompanied to the music. When trying to express the recognition of musical elements by body movement, the child in early childhood creates his own musical expression by thinking and judging while looking at the surrounding children and the accompaniment teacher. This study aims to quantitatively analyze changes in eye movements during musical expression. 3-year-old, 4-year-old, and 5-year-old children at two nursery schools in 2020 and two kindergartens in 2021 (n=118) participated in eye tracking during singing a song using an eye tracker (Tobii3). Quantitative analysis by three-way ANOVA was mainly conducted on the calculated data. As a result, the increase in data such as number of saccade occurrences and size, and the moving average velocity of saccade, showed that saccades during musical expression in early childhood tended to be larger in major key than in minor key. From the calculated data on saccade, which is the eye movement during musical expression, it was predicted that effective feature quantities of eye movement during musical expression for machine learning could be derived in the same way as feature quantities depended on the results of quantitative analysis of body movement during musical expression.

Keywords

saccade during musical expression in early childhood, ANOVA, tonality, nursery rhyme, the moving average velocity of saccade, feature quantity of movement

1. Introduction

The author has used a 3D motion capture system (MVN) to analyze the movement in musical expression of early childhood children and clarify the close relationship between the recognition of musical elements and body movements in early childhood (Sano, 2018). In particular, as the practical process of the step-by-step activity deepened the recognition of the musical elements of the children, the increase in the moving average acceleration of the hands and pelvis by the analysis of movement showed characteristic changes with age and differences among child facilities. The author used motion capture technology to extract the developmental characteristics of musical expressions in early childhood, and devised a method for evaluating the developmental process of musical expression in early childhood applying machine learning technique (Fernandez-Delgado et al., 2014; Sano, 2019; 2020).

In the research report that used 3D motion capture in the field of education, some discussions were presented on the results of specific analysis of movement in traditional Japanese dance and sawing, mainly for adults, and the development of learning support methods (Ando et al., 2012; Sato et al., 2010). In addition, research on music and movement showed the reaction to adult sounds (Burger, 2013), viewing experiments and video analysis on the relationship between the movement and expression of the performer (Dahl & Friberg, 2007; Thompson & Luck, 2012). However, these researchers did not capture the musical expressions that occurred in the process of continuous musical practice for young children. Regarding machine learning methods, it is also used in educational fields such as behavior recognition and individual recognition methods in daily life (Kodama et al., 2015; Takada et al., 2012), and learning support of movement such as upturning of elementary school students (Matsumoto et al., 2014). But, there have been no research reports that have used machine learning for musical expression in early childhood. The author has conducted machine learning using feature quantities of movement that have caused characteristic changes in the practical process of musical expression in early childhood. As a result, a certain level of classification accuracy was obtained by several classifiers, and derived a discriminant model for the musical expression in early childhood (Sano, 2019; 2020).

The author focused on the eye movements of early childhood children during musical expression because of the need for additional feature quantities of movement based on the results of these studies. The participant children in the activity of musical expression often watched around other children or a teacher’s accompaniment. The children participating in the activity of musical expression often watched around other children or a teacher’s accompaniment in my investigation by the motion capture technique. The author thought the eye movement during musical expression affected the body movement in musical expression by the participant child.

Previous studies on eye movements have shown quantitative analysis of eye movements and eye movements related to character recognition, and how eye movements affect judgment by cognitive function (Higuchi, 2019; Watanabe et al., 2019; Kusunoki et al., 2017; Mpofu, 2016; Seong-un Kim, 2016; Moreno-Estevaa et al., 2018; Lin et al., 2018； Reumont, 2020; Valtakari et al., 2021). An analysis

of the line of sight of a craftsman during forging work using a camera has also be conducted (Kitajima et al., 2017). For research using eye trackers in the field of music, eye movements during rhythm hearing and reading (Plöchl et al., 2017; Lörch et al., 2017; Fusase, 2017), gaze behavior of musical instrument players (Bishopa et al., 2019; Vandemoortele et al., 2018), eye-hand synchronization during instrumental performance (Marandola, 2017), differences in reading and listening to melody between music experts and non-music experts (Drai-Zerbib & Baccino, 2018; Puutinen, 2018) etc. are presented, but the attention was mainly paid to the participant's line of sight looking at the display. Studies such as eye contact on the possibility of enhancing music conducting skills through a virtual reality learning environment have also been shown (Orman et al., 2017; Orman, 2016). There is a study (Burger et al., 2017) that attempted to analyze the response to music by combining eye tracking and motion capture, but the subject of the study was adults (Fink et al., 2019).

The author considered using a glasses-type as a wearable system of eye tracker to capture changes in eye movements during musical expression in early childhood children. The eye movements captured by the eye tracker are mainly divided into saccade (rapid eye movement) and fixation. The movement of the eyeball can be quantified by the moving velocity (angular velocity) and the moving distance (magnitude of the angle). To that end, the author thought to focus on saccades during musical expression and find effective feature quantities of eye movement.

2. Purpose of This Study

This study aims to quantitatively analyze the eye movements of early childhood children during musical expression using an eye tracker, and to find effective feature quantities of eye movement in the same method the feature quantities of movement depended on the results of analysis of movement in musical expression. In this paper, the author focuses on changes related to saccade when a child singing a song, and extract characteristic differences depended on tonality, songs, and age.

3. Method

In order to quantitatively capture the saccade that occurs when an early childhood child is singing, the following research method is used.

3.1 Eye Tracking of Children in Early Childhood When Singing a Song

Children in early childhood are singing songs and watching the accompaniment of the teachers and the children around them. In my past studies, it was confirmed by video analysis when observing the behavior of children in early childhood, but it was not possible to quantitatively capture the actual aspect of eye movements. Therefore, in this study, the author tried to quantify the eye movements of children in early childhood during singing by using an eye tracker (Tobii Glass 3). Tobii Glass 3 is a glasses-type eye tracker. Each participant child wears it in the same way as glasses, is calibrated while being fixed with a

strap, starts singing with a signal, and eye-tracks until the end of the singing. It is a 1/50 second time frame at 50Hz, and audio and video are recorded at the same time.

3.2 The Participant Children of Eye Tracking, Inspection Contents and Inspection Schedule

Table 1 below shows the number of children who participated in eye tracking in 2020 and 2021 and the data acquisition dates for each song in major and minor.

Table 1. Songs by Children Participating in Eye Tracking and The Date Acquiring Data in 2020 and 2021

		U nursery school (n=28)	M nursery school (n=30)	Y kindergarten (n=30)	N kindergarten (n=30)
Major key	"Kaerunouta" Lyrics: Toshiaki Okamoto, Composer: German Folk Song		August 19, 2020 14: 30-16: 00	June 21, 2021 9: 30-11: 00	July 6, 2021 9: 30-11: 00
	"Umi" (G major,) Lyrics: Ryuha Hayashi, Composer: Takeshi Inoue	August 18, 2020 9: 30-11: 00			
	"Musundehiraite" Lyrics: Unknown, Composition: Rousseau			May 31, 2021 9: 30-11: 00	
	"Tewotatakimasho" Lyrics: Junichi Kobayashi, Composer: Spanish Folk Song			June 7, 2021 9: 30-11: 00	June 29, 2021 9: 30-11: 00
	"Shiawasenaratewotatakou" Lyrics: Kimura Rihito Composer: American folk song				June 8, 2021 9: 30-11: 00
minor key	"Ureshiihinamatsuri" Lyrics: Hachirou Satou, Composer: Koyo Kawamura	August 18, 2020 9: 30-11: 00			
	"Darumasan" Nursery rhyme in Japan			June 7, 2021 9: 30-11: 00	
	"Hotarukoi" Nursery rhyme in Japan				June 8, 2021 9: 30-11: 00
	"Teruterubouzu" Lyrics: Asahara Kagamimura Composer: Shinpei Nakayama		August 19, 2020 14: 30-16: 00		June 29, 2021 9: 30-11: 00
	"Genkotsuyamanotanuki" Lyrics: Yoshiko Kayama Composer: Akihiro Komori			June 21, 2021 9: 30-11: 00	

In 2020, it was difficult to adjust multiple survey schedules due to COVID-19. In Osaka prefecture, at U nursery school from 9:30 to 11:00 on August 18 and 14:30 to 16:00 on August 19 at M nursery school, Only one measurement was taken. Since the situation was similar in 2021, the author decided to conduct only a short-term inspection schedule, and eye tracking when singing 5 songs each at 2 kindergartens in Shizuoka prefecture according to the schedule shown in Table 1. Data at Y kindergarten was acquired in

9:30-11:00 on May 31, June 7, and June 21st. Data at N kindergarten was acquired in 9:30-11:00 on June 8, June 29, and July 6th.

In 2020, the number of subjects was 8 for 3-year-old children, 10 for 4-year-old children, and 10 for 5-year-old children at U nursery school. At M nursery school, there were 9 of 3-year-olds, 9 of 4-year-olds, and 12 of 5-year-olds. In 2021, the participant number of children was 10 each for 3-year-old children, 4-year-old children, and 5-year-old children in Y kindergarten and N kindergarten.

These investigations have been approved by the research ethics committee to which the author belongs, as well as permission by the person in charge of the kindergarden that cooperates in the research, the parents of the participant children, and the submission of consent forms.

Here, out of the songs experienced by the participants in the four child facilities during their everyday life, one song was sung in major key and another one in minor key. The songs are as follows.

In 2020, at U nursery school, the song in major key is “Umi” (G major, lyrics: Hayashi Yanaginami, composition: Takeshi Inoue), and the song in minor key is “Ureshii Hina Matsuri” (a minor, lyrics: Sato Hachiro, composition: Mitsuyo Kawamura). The participant children sung, while in M nursery school, the song in major key was “Kaeru nouta” (C major, lyrics: Toshiaki Okamoto, composition: German folk song), and the song in minor key was “Teruterubozu” (a minor, Written by Kagamimura Asahara, composed by Shinpei Nakayama) was sung.

In 2021, in Y kindergarten, the songs in major key are “Musundehiraitte” (lyrics: unknown, composition: Rousseau), “Tewotatakimashou” (lyrics: Junichi Kobayashi, composition: Spanish folk song), “Kaerunouta” (lyrics: Toshiaki Okamoto, composition: German folk song) is sung, and “Darumasan” (Nursery rhyme=warabeuta) and “GenkotsuyamanoTanuki” (lyrics: Miko Kayama, composition: Akihiro Komori) are sung in minor key. In N kindergarten, the songs as “Shiawasenaratewotatakou” (lyrics: translation: Kimura Rihito, composition: American folk song), “Tewotatakimashou” (lyrics: Junichi Kobayashi, composition: Spanish folk song), “Kaerunouta” (lyrics: Toshiaki Okamoto, composition: German folk song) are sung in major key, and the songs are “Hotarukoi” (warabeuta) and “Teruterubozu” (lyrics: Kagamimura Asahara, composition: Shinpei Nakayama) are sung in minor key.

The measurement time per person was 20 seconds for songs in major key and 20 seconds for songs in minor key.

3.3 Quantitative Analysis of Data Acquired by Eye Tracking

In this study, in order to capture eye movements, the author conducted a saccade-specific quantitative analysis from fixation to next fixation. Therefore, the author quantitatively analyzed the number of occurrences of saccade, the moving average velocity (angular velocity), the average value of the size of movement (total angle), the average of moving distance (total angle), the angular velocity of the moving average of the first saccade (rapid eye movement), and the magnitude (angle) of the first saccade. It was inspected whether these data differed by early childhood facility, age, and major key/minor key.

4. Result

In this paper, among the calculated data, an example of individual calculation data of eye movement analyzed by analysis software (Tobii Pro analyzer) and a part of the result of quantitative analysis on the data items presented by methodology are shown. Regarding the occurrence of saccade, the analysis results of "Tewotatakimashou" (major key) "Kaeru no Uta" (major key), "Darumasan" (minor key), and "Teruterubouzu" (minor key), an individual example is shown by age such as 3-year-old, 4-year-old, and 5-year-old.

Firstly, an example of individual calculation data for eye movement are shown for a song in major key by age.

4.1 Movement of the Line of Sight When Singing "Tewotatakimashou" (major key)

4.1.1 Analysis Results of a 3-year-old Child When Singing "Tewotatakimashou"

The following Figure 1 shows the order of eye movements of a 3-year-old child when singing "Tewotatakimashou" and Figure 2 shows the heat map.

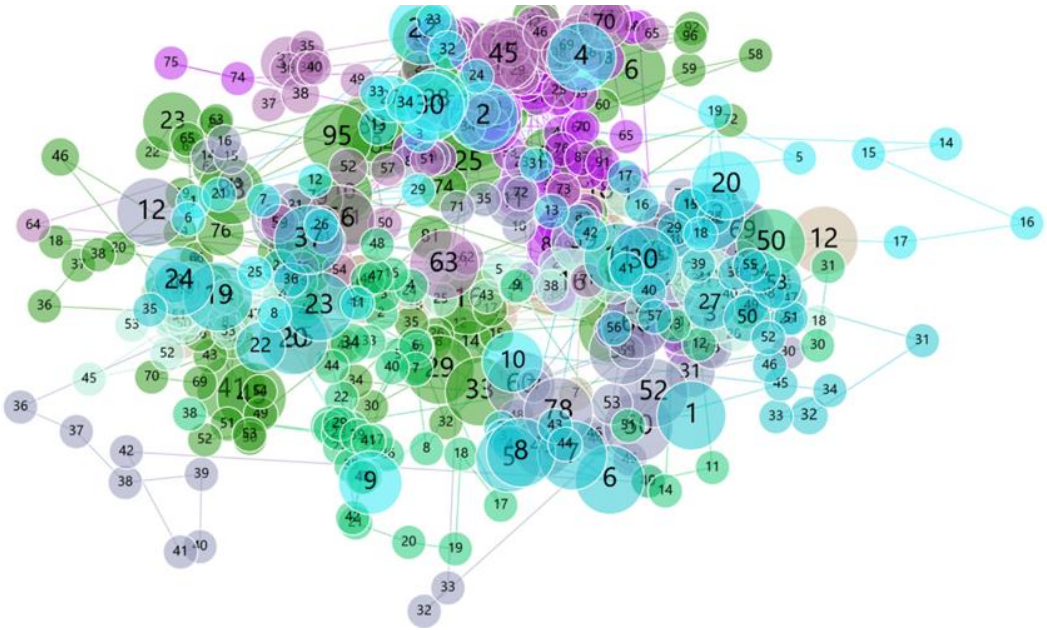

Figure 1. Gaze Plot When A 3-Year-Old Child Sings "Tewotatakimashou"

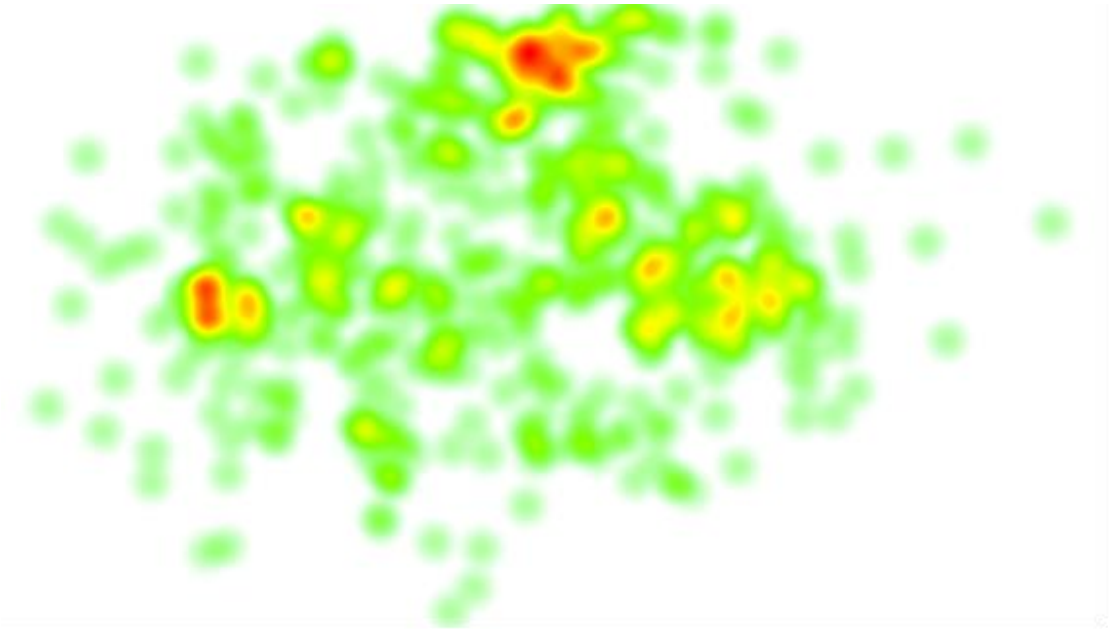

Figure 2. Heat Map When A 3-Year-Old Child Sings "Tewotatakimashou"

4.1.2 Analysis Results When a 4-year-old Child Sings "Tewotatakimashou"

The following Figure 3 shows the order of eye movements of a 4-year-old child when singing "Tewotatakimashou" and Figure 4 shows the heat map.

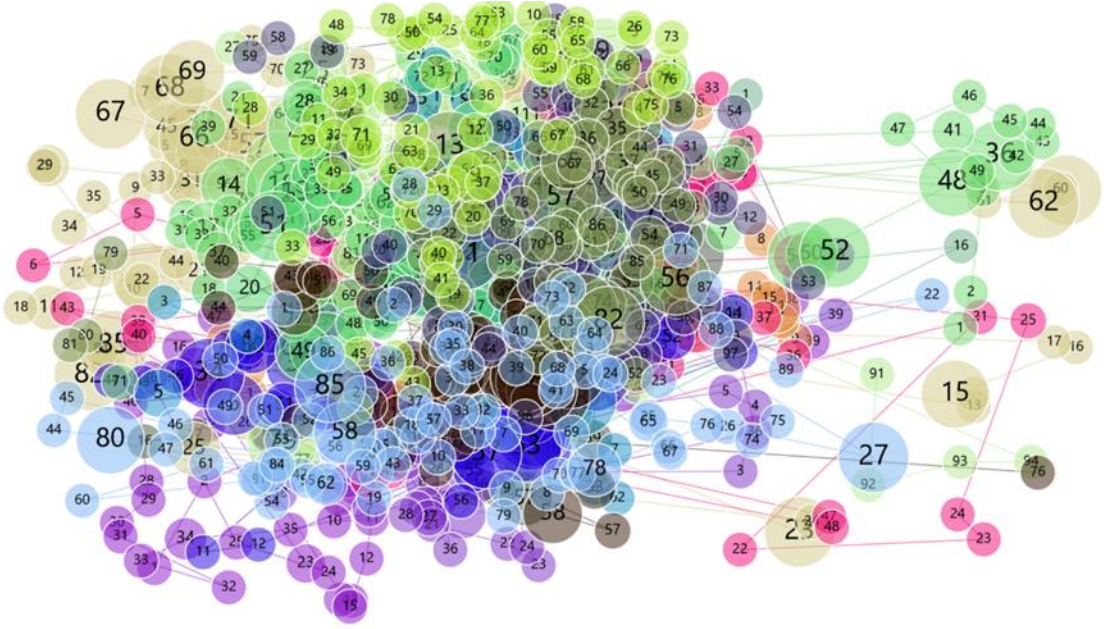

Figure 3. Gaze Plot When A 4-Year-Old Child Sings "Tewotatakimashou"

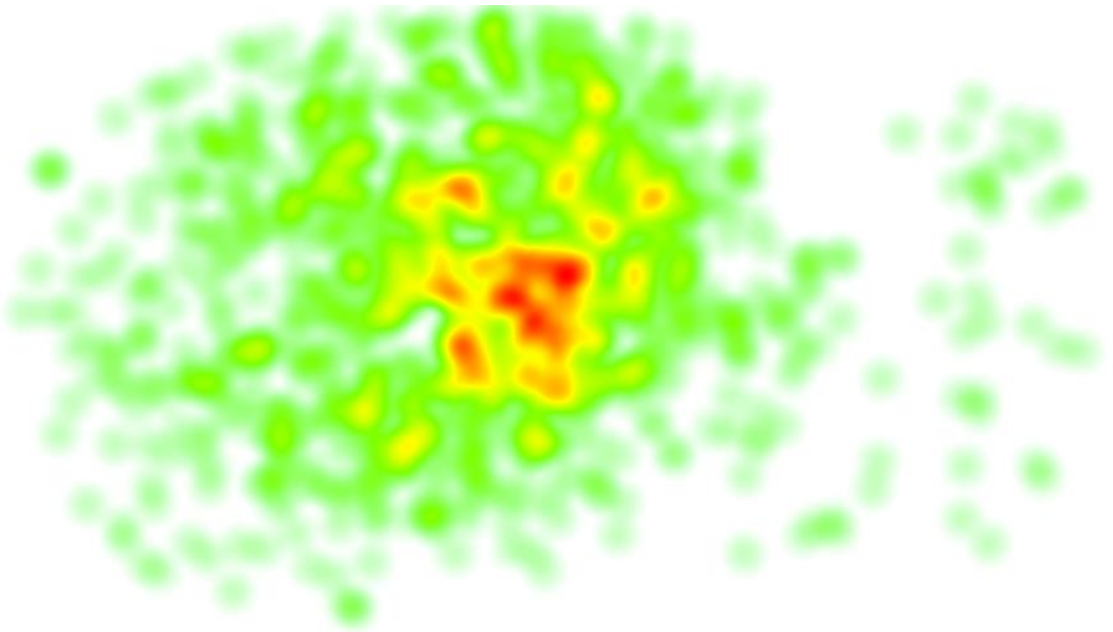

Figure 4. Heat Map When A 4-Year-Old Child Sings "Tewotatakimashou"

4.1.3 Analysis Results When a 5-year-old Child Sings "Tewotatakimashou"

The following Figure 5 shows the order of eye movements of a 5-year-old child when singing "Tewotatakimashou" and Figure 6 shows the heat map.

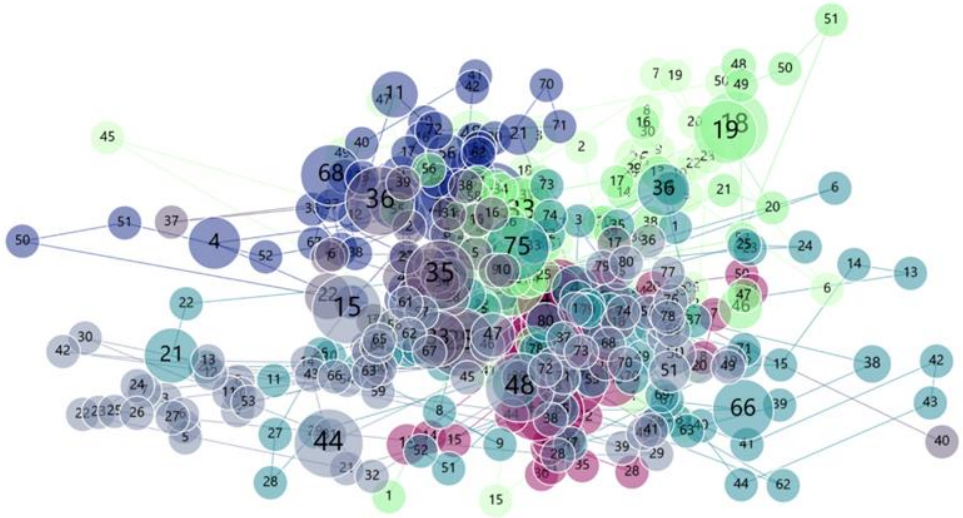

Figure 5. Gaze Plot When A 5-Year-Old Child Sings "Tewotatakimashou"

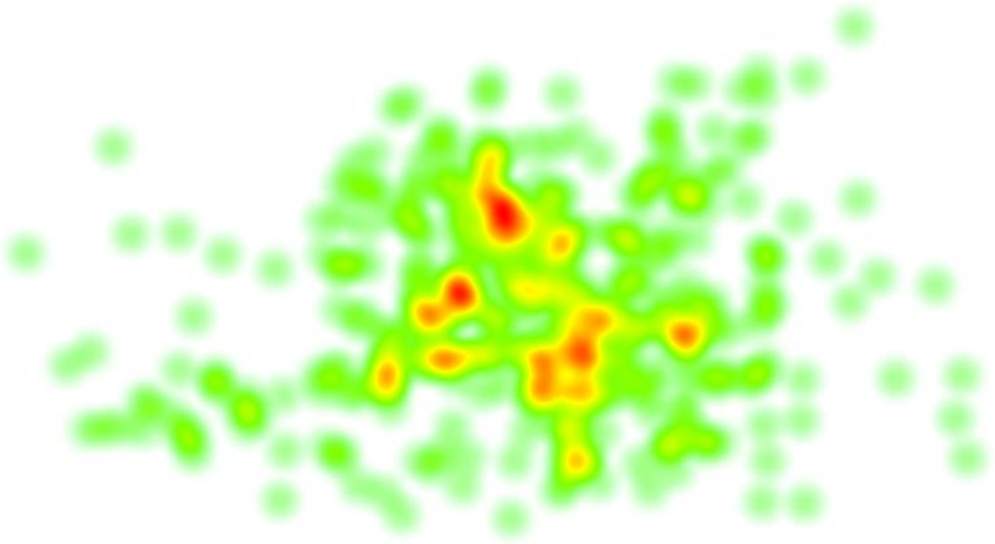

Figure 6. Heat Map When A 5-Year-Old Child Sings "Tewotatakimashou"

The above figures regarding an individual case are examples of visualization of the movement of the line of sight. The gaze plot shows the order of movement of the line of sight, and the size of circle indicates the relative length of time that the line of sight stayed there and the participant child was gazing at that part. The heat map shows that the time spent watching in the order of red, yellow, and yellow-green was relatively long. All of the participant children performed their own singing and accompanying movements while paying close attention to the teachers and other children nearby. Regarding songs in major key with body movements such as "Tewotatakimashou" and "Kaeru no Uta", the 3-year-old saccade tended to alternate between the teacher on the right side and the other children on the left side, and finally the other children each other. However, 4-year-olds and 5-year-olds tended to look at the center of the place where the participant child could see the teacher and other children at the same time. Regarding songs in minor key such as "Darumasan", participant children tended to sing with facing forward without moving their eyes too much. Regarding "Teruterubozu" in minor key, the eyes of the participating children were relatively moving because singing was accompanied by their own spontaneous movements with watching around other children at the same time.

Next, in order to clarify whether there is a statistically significant difference or not in characteristic differences between major key and minor key from these eye tracking results, the author conducted a three-way ANOVA (non-repeated tonality factors: 2 levels, non-repeated early childhood facility factors: 4 levels, non-repeated age factors: 3 levels).

4.2 Characteristic Differences in Saccade between Major Key and Minor Key

Regarding the data acquired by eye tracking, the author focused the change of saccade as calculated data. The following results were obtained as a result of a three-way ANOVA (non-repeated factors as 2 levels in major key/minor key, non-repeated factors as 4 levels in U nursery school, M nursery school, Y kindergarten, N kindergarten, non-repeated factors as 3 levels in 3-year-old, 4-year-old, 5-year-old).

4.2.1 The Number of Occurrences of Saccade

Table 2 below shows the average number of saccade occurrences by major key/minor key and child facility.

Table 2. The Number of Occurrences of Saccade

Major/minor key	Child facility	Age	Average	SD	N
Major key	U nursery school	3-year-old	19.875	9.26495	8
		4-year-old	18	10.50926	10
		5-year-old	14.9	8.33267	10
	M nursery school	3-year-old	14.7778	7.01388	9
		4-year-old	11	8.80656	10
		5-year-old	16	6.45262	12
	Y kindergarten	3-year-old	26.4483	14.49036	29
		4-year-old	26.1	18.75311	30
		5-year-old	30.3333	16.75654	30
	N kindergarten	3-year-old	16.8966	15.13592	29
		4-year-old	18.7	14.72308	30
		5-year-old	15.1071	12.32985	28
minor key	U nursery school	3-year-old	21.125	5.66789	8
		4-year-old	18.1	9.46866	10
		5-year-old	24.2	12.14542	10
	M nursery school	3-year-old	4.8889	1.83333	9
		4-year-old	6.5556	4.50309	9
		5-year-old	8.5833	3.75278	12
	Y kindergarten	3-year-old	12	4.45814	17
		4-year-old	12.1111	4.25495	18
		5-year-old	15.35	6.45857	20
	N kindergarten	3-year-old	19	11.49534	15
		4-year-old	21.5	13.54719	20
		5-year-old	13.3	10.60834	20

As a result of three-way ANOVA for these acquired data, a main effect/interaction between subjects of the test showed a statistically significant difference (major/minor factor ($F(1, 379)=9.953$, $p<.005$, child facility factor ($F(3, 379)=9.922$, $p<.005$), major/minor factor * child facility factor ($F(3, 379) =11.938$, $p<.005$)). Therefore, a simple main effect test and a multiple comparison test by Bonferroni's method

were conducted. Concerning major/minor factor/ child facility factor* major/minor factor * age factor, the simple main effect was statistically significant for 3-year-old children ($F(1, 379)=15.036$, $p<.005$), 4-year-old ($F(1, 379)=14.796$, $p<.005$), and 5-year-old ($F(1, 379)=18.106$, $p<.005$) in Y kindergarten. As a result of multiple comparison, in Y kindergarten, major key was larger than minor key. Concerning child facility factor/child facility factor* major/minor factor * age factor, the simple main effect was statistically significant for major key (4-year-old: ($F(3, 379)=4.486$, $p<.005$), 5-year-old: ($F(3, 379)=9.537$, $p<.005$)). As a result of multiple comparison, 3-year-old and 5-year-old showed a statistically significance in Y kindergarten, larger than 3 other facilities regarding major key. 4-year-old in Y kindergarten was significantly larger than M nursery school in major key. Regarding minor key, 3-year-old children in U nursery school and N kindergarten were larger than M nursery school, 4-year-old children in N nursery school were larger than M nursery school, and 5-year-old children in U nursery school were larger than M nursery school.

A statistically significant difference was not observed by age, but it was found that the average number of occurrences was significantly larger in major than in minor.

4.2.2 The Moving Average Velocity (angular velocity) of Saccade (degrees/second)

Table 3. The Moving Average Velocity of Saccade

Major/ minor key	Child facility	Age	Average	SD	N
Major key	U nursery school	3-year-old	225.815	66.5225	8
		4-year-old	224.392	37.61292	10
		5-year-old	254.645	63.00146	10
	M nursery school	3-year-old	238.0011	45.50136	9
		4-year-old	218.273	47.78794	10
		5-year-old	253.1667	63.9497	12
	Y kindergarten	3-year-old	191.97	97.63757	29
		4-year-old	221.4853	89.85153	30
		5-year-old	349.7953	531.74638	30
	N kindergarten	3-year-old	187.5766	33.10906	29
		4-year-old	216.9787	55.67087	30
		5-year-old	205.26	41.1883	28
minor key	U nursery school	3-year-old	231.2688	47.18051	8
		4-year-old	246.329	66.13405	10
		5-year-old	226.766	37.44762	10
	M nursery school	3-year-old	186.3311	44.71741	9
		4-year-old	220.0822	56.74914	9
		5-year-old	259.2358	61.12917	12
	Y kindergarten	3-year-old	215.8435	40.8591	17
		4-year-old	213.5211	54.991	18
		5-year-old	221.8145	40.48186	20

	3-year-old	208.7093	33.18712	15
N kindergarten	4-year-old	195.1075	39.5047	20
	5-year-old	198.2135	34.7814	20

Similarly, for the calculation data of the moving average velocity of saccade, a three-way ANOVA was conducted based on the major/minor factor, child facility factor, and the age factor. As a result of the test of the effect between the subjects, a statistically significant difference was not observed, but for songs in major key, 5-year-olds were larger than 3-year-olds and 4-year-olds in Y kindergarten.

4.2.3 Average Size of Saccade

Similarly for the calculation data of the average value of the size of saccade, a three-way ANOVA was conducted based on major/minor factors, child facility factors, and age factors.

As a result of the test of the effect between subjects, the main effect/interaction showed a statistically significant difference (major/minor factor: F (1, 379)=8.499, p<.005, child facility factor: F(3, 379) =12.407, p<.005, major/minor factors * child facility factor: F (3, 379)=12.308, p<.005). Therefore, a simple main effect test and a multiple comparison test by Bonferroni's method were conducted.

Concerning the major/minor factor/major/minor * child facility * age factor, a simple main effect was statistically significant in Y kindergarten (3-year-old child: F (1, 379)=15.076, p<.005, 4-year-old child: F (3, 379)=18.671, p<.005, 5-year-old child: F (3, 379)=24.166, p<.005). As a result of multiple comparisons, 3-year-old, 4-year-old, and 5-year-old in Y kindergarten showed larger in major key than minor key.

Concerning the child facility factor/major/minor factor * child facility factor * age factor, a simple main effect was statistically significant in major (3-year-old child: F(3, 379)=8.518, p<.005, 4-year-old: F(3, 379)=10.357, p<.005, 5-year-old child: F(3, 379)=12.585, p<.005). As a result of multiple comparisons, 3-year-old, 4-year-old, and 5-year-old children in Y kindergarten were significantly larger than other three facilities in major key.

4.2.4 The Average Value of the Total Moving Distance of Saccade

Similarly, for the calculation data of the total moving distance of saccade, a three-way ANOVA was conducted based on the factors of major/minor factor, child facility factor, and age factor.

Table 4. Average Total Moving Distance of Saccade (Degrees)

Major/ minor key	Child facility	Age	Average	SD	N
Major key	U nursery school	3-year-old	177.3925	87.82232	8
		4-year-old	166.643	106.03598	10
		5-year-old	126.014	84.17718	10
	M nursery school	3-year-old	148.9222	99.34946	9
		4-year-old	117.874	114.52879	10
		5-year-old	165.0575	96.21823	12
	Y kindergarten	3-year-old	190.5079	132.80593	29
		4-year-old	184.7997	141.44637	30
		5-year-old	204.1963	103.82075	30
	N kindergarten	3-year-old	114.8897	127.50648	29
		4-year-old	138.708	121.25421	30
		5-year-old	111.4611	105.18776	28
minor key	U nursery school	3-year-old	204.5575	83.86732	8
		4-year-old	175.55	106.52629	10
		5-year-old	235.001	148.61351	10
	M nursery school	3-year-old	40.8122	30.54065	9
		4-year-old	55.8367	48.28457	9
		5-year-old	96.085	56.75702	12
	Y kindergarten	3-year-old	103.5582	54.15056	17
		4-year-old	92.6878	40.46515	18
		5-year-old	123.2695	59.87629	20
	N kindergarten	3-year-old	139.6707	102.94324	15
		4-year-old	143.3985	105.13491	20
		5-year-old	97.488	89.47006	20

As a result of the test of the effect between subjects, the main effect/interaction was statistically significant (child facility factor: F (3, 379)=6.539, p<.005, major/minor factor * child facility factor: F (3, 379)=8.23, p<.005). Therefore, a simple main effect test and a multiple comparison test by Bonferroni's method were conducted.

Concerning the major/minor factor/child facility factor * major/minor factor * age factor, a simple main effect was statistically significant in Y kindergarten (4-year-old: F (1, 379)=8.718, p<.005)) regarding major key. As a result of multiple comparisons, 5-year-old in minor key was larger than major key in U nursery school, 3-year-old in major was larger than minor key in M nursery school. 3-year-old, 4-year-old, and 5-year-old in major key was larger than minor key in Y kindergarten.

Concerning the child facility factor/major/minor factor * child facility factor * age factors, a simple main effect was statistically significant in minor key (5-year-old: F (3, 379)=4.438, p<.005). As a result of multiple comparison, in major key, 3-year-old and 5-year-old in Y kindergarten were larger than N

kindergarten. Regarding minor key, 3-year-old in U nursery school was significantly larger than M nursery school and 5-year-old in U nursery school was significantly than other three facilities.

Figure 7 shows the total moving distance of saccade in M nursery school, and Figure 8 shows the total moving distance of saccade in Y kindergarten.

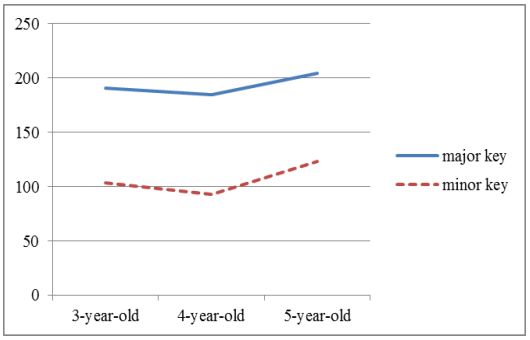

Figure 7. The Total Moving Distance of Saccade M nursery School

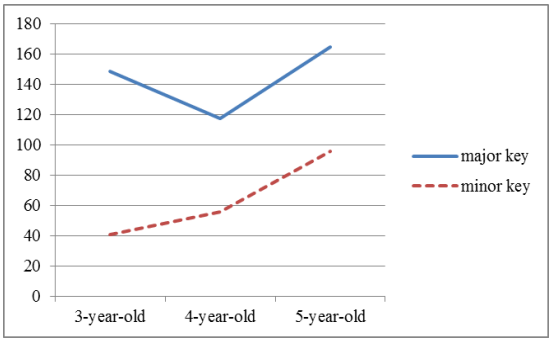

Figure 8. The Total Moving Distance of Saccade Y Kindergarten

As shown in Figure 7 and Figure 8, the total moving distance of saccade tended to be larger in major key than in minor key, which was remarkable in M nursery school and Y kindergarten.

4.2.5 The Size of the First Saccade

Similarly, for the calculation data regarding the size of the first saccade, a three-way ANOVA was conducted based on major / minor factor, child facility factor, and age factor.

Table 5. First Saccade Size (Degrees)

Major/ minor key	Child facility	Age	Average	SD	N
Major key	U nursery school	3-year-old	10.24	5.26771	8
		4-year-old	6.64	3.65792	10
		5-year-old	6.061	2.17636	10
	M nursery school	3-year-old	12.4633	9.17476	9
		4-year-old	11.579	8.34354	10
		5-year-old	13.4	7.1227	12
	Y kindergarten	3-year-old	76.2845	129.89091	29
		4-year-old	71.2517	105.14894	30
		5-year-old	64.698	93.78386	30
	N kindergarten	3-year-old	6.7159	5.66665	29
		4-year-old	7.0097	4.80204	30
		5-year-old	6.7146	5.00763	28
minor key	U nursery school	3-year-old	8.2925	6.50261	8
		4-year-old	8.67	5.047	10
		5-year-old	12.444	8.62215	10
	M nursery school	3-year-old	4.9422	3.86937	9
		4-year-old	8.84	5.01415	9
		5-year-old	10.0992	7.26828	12
	Y kindergarten	3-year-old	8.5282	4.7698	17
		4-year-old	7.1517	3.98349	18
		5-year-old	8.9725	5.78889	20
	N kindergarten	3-year-old	7.3647	7.30578	15
		4-year-old	6.7825	4.90401	20
		5-year-old	8.723	9.07599	20

As a result of the test of the effect between subjects, the main effect/interaction was statistically significant (child facility factor: F (3, 379)=10.239, p<.005, major/minor factor * child facility factor: F (3, 379)=10.222, p<.005). Therefore, a simple main effect test and a multiple comparison test by Bonferroni's method were conducted.

Concerning the major/minor factor/major/minor factor * child facility factor * age factor, the simple main effect was statistically significant in major key (3-year-old child (F (3, 379)=17.614, p<.005), 4-year-old child (F (3, 379)=16.548, p<.005) and 5-year-old children (F (3, 379)=13.34, p<.005). As a result of multiple comparison, in songs of major key, Y kindergartens for 3-year-olds, 4-year-olds, and 5-year-olds were larger than U kindergarten, M kindergarten, and N kindergarten.

Concerning the child facility factor/major/minor factor * child facility factor * age factor, the simple main effect was statistically significant in major key (3-year-old (F(3, 379)=9.796, p<.005), 4-year-old (F(3, 379)=9.015, p<.005), 5-year-old (F(1, 394)=7.196, p<.005)) in Y kindergarten. As a result of

multiple comparison, 3-year-old, 4-year-old, and 5-year-old children in Y kindergarten showed larger magnitude in major key than other three facilities.

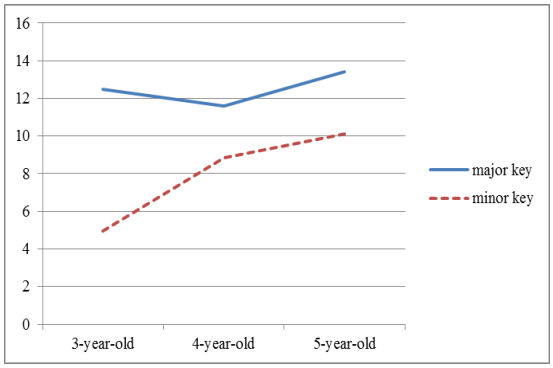

Figure 9. First Saccade Size in M Nursery School

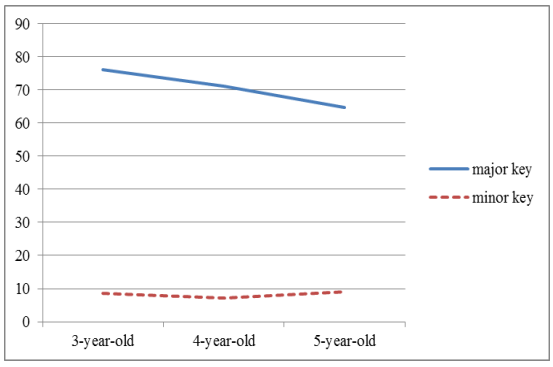

Figure 10. First Saccade Size in Y Kindergarten

As shown in Figure 9 and Figure 10, the size of the saccade that occurred at the first time tended to be larger in major key than in minor key, which was remarkable in M nursery school and Y kindergarten.

4.3 The Characteristics of Saccade by Songs

Next, in order to inspect whether a statistically significant difference was observed or not in the calculated data regarding saccade for all 10 specific songs, a two-way ANOVA was carried out (non-repeated song factor as 10 levels and non-repeated age factor as 3 levels).

4.3.1 The Number of Occurrences of Saccade by Songs

Table 6 shows the average data regarding number of occurrences of saccade by song.

Table 6. Number of Occurrences of Saccade by Song

Song	Age	Average	SD	N
Kaerunouta	3-year-old	15.4138	8.65001	29
	4-year-old	16.4	10.54252	30
	5-year-old	17.7097	10.31243	31
Umi	3-year-old	19.875	9.26495	8
	4-year-old	18	10.50926	10
	5-year-old	14.9	8.33267	10
Musundehiraite	3-year-old	22.1111	14.47795	9
	4-year-old	23.4	21.22472	10
	5-year-old	29.7	17.21143	10
Tewotatakimashou	3-year-old	31.5789	18.7626	19
	4-year-old	29.1	21.06356	20
	5-year-old	29.1053	19.24374	19
Shiawasenara Tewotatakou	3-year-old	14.4	9.41866	10
	4-year-old	16.2	12.85647	10
	5-year-old	12.6	10.65833	10
Ureshii Hinamasturi	3-year-old	21.125	5.66789	8
	4-year-old	18.1	9.46866	10
	5-year-old	24.2	12.14542	10
Darumasan	3-year-old	9.75	3.05894	8
	4-year-old	11.4444	5.17472	9
	5-year-old	11.5	4.74342	10
Hotarukoi	3-year-old	16.125	10.66955	8
	4-year-old	16	10.79094	10
	5-year-old	10.3	6.11101	10
Teruterubouzu	3-year-old	12.7222	11.88576	18
	4-year-old	17.3158	14.86253	19
	5-year-old	12.0909	10.00433	22
Genkostuyamano Tanuki	3-year-old	14	4.69042	9
	4-year-old	12.7778	3.27024	9
	5-year-old	19.2	5.71159	10

As a result of the test of the effect between subjects, the main effect was statistically significant with the music factor (F (9, 375)=9.64, p<.005). As a result of multiple comparison, the 3-year-old child's "Tewotatakimashou" was significantly larger than "Kaerunouta", "Shiawasenaratewotatakou", "Darumasan", "Teruterubouzu", and "Genkotsuyamanotanuki". 4-year-old child's "Tewotatakimashou" was significantly larger than "Kaerunouta" and "Darumasan". Regarding 5-year-old, "Musundehiraite" was significantly larger than "Hotarukoi" and "Teruterubouzu", "Tewotatakimashou" was significantly larger than "Darumasan", "Hotarukoi", and "Teruterubouzu".

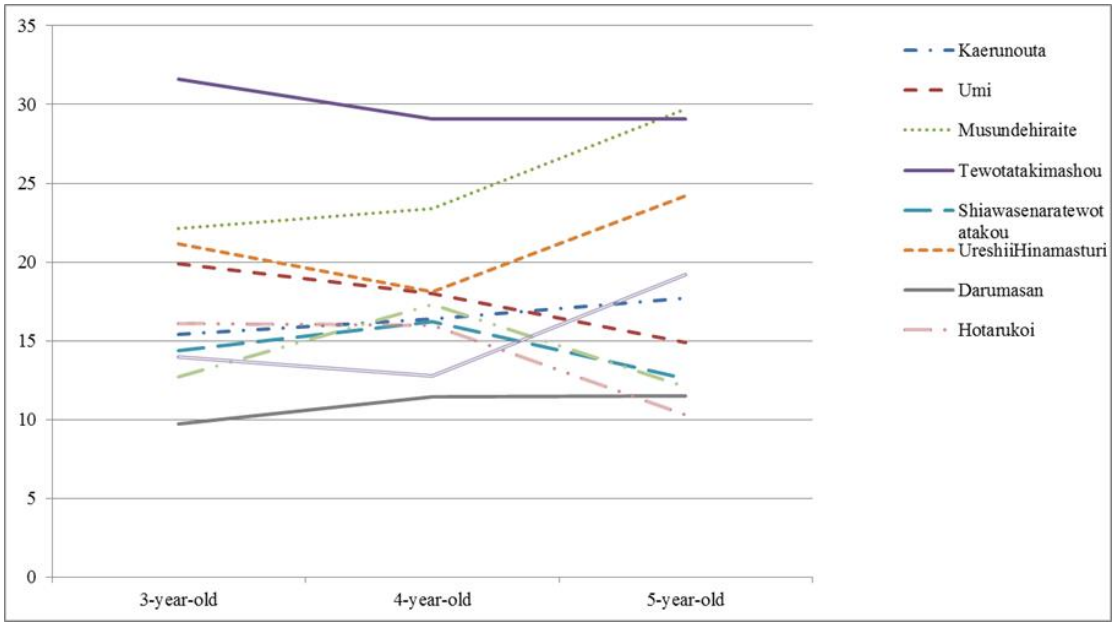

Figure 11. Age-Specific Changes in The Number of Saccades That Occur Depending on The Song

As shown in Figure 11, even among the songs in major key, the number of occurrences in "Tewotatakimashou" and "Musundehiraite" were remarkable.

4.3.2 The Moving Average Velocity of Saccade

In order to inspect whether a statistically significant difference was observed or not in the calculated data of the moving average velocity of saccade, a two-way ANOVA was conducted by the song factor (10 levels) and the age factor (3 levels).

Table 7. The Moving Average Velocity of Saccade (Degrees/Second)

Song	Age	Average	SD	N
Kaerunouta	3-year-old	198.4259	47.81486	29
	4-year-old	215.969	51.89155	30
	5-year-old	222.711	54.63452	31
Umi	3-year-old	225.815	66.5225	8
	4-year-old	224.392	37.61292	10
	5-year-old	254.645	63.00146	10
Musundehiraite	3-year-old	202.4444	175.4381	9
	4-year-old	222.4	140.10567	10
	5-year-old	643.1	875.51286	10
Tewotatakimashou	3-year-old	190.6111	27.01139	19
	4-year-old	204.255	53.5489	20
	5-year-old	202.4784	22.30516	19
Shiawasenara	3-year-old	195.09	30.01467	10
	4-year-old	219.518	64.88319	10

Tewotatakou	5-year-old	209.701	48.17227	10
	3-year-old	231.2688	47.18051	8
Ureshii	4-year-old	246.329	66.13405	10
Hinamasturi	5-year-old	226.766	37.44762	10
	3-year-old	211.405	36.22365	8
Darumasan	4-year-old	197.7244	23.98627	9
	5-year-old	216.874	53.97441	10
	3-year-old	212.2813	24.66576	8
Hotarukoi	4-year-old	210.799	36.65742	10
	5-year-old	195.801	41.2738	10
	3-year-old	192.9467	44.82111	18
Teruterubouzu	4-year-old	198.6789	50.6791	19
	5-year-old	232.595	56.64364	22
	3-year-old	219.7889	46.40676	9
Genkostuyamano	4-year-old	229.3178	72.72708	9
Tanuki	5-year-old	226.755	22.18492	10

As a result of the test of the effect between subjects, the main effect/interaction was statistically significant (song factor: F (9, 375)=3.054, p<.005, song factor * age factor: F (18, 375)=2.803, p<.005). Therefore, a simple main effect test and a multiple comparison test by Bonferroni's method were conducted.

Concerning the song factor/song factor * age factor, a simple main effect was statistically significant in 5-year-old (F(9, 375)=8.641, p<.005). As a result of multiple comparison, 5-year-old children showed significantly larger data in "Musundehiraite" than in other nine songs.

Concerning the age factor/song factor * age factor, age factor, a simple main effect was statistically significant in "Musundehiraite" (F(2, 375)=28.012, p<.005). As a result of multiple comparison, 5-year-old children showed significantly larger data in "Musundehiraite" than 3-year-old and 4-year-old children.

4.3.3 Average Size Data of Saccade

In order to inspect whether a statistically significant difference was observed or not in the calculated data of the size of Saccade, a two-way ANOVA was conducted by the song factor (10 levels) and the age factor (3 levels).

Table 8. Average Size Data of Saccade (Degrees)

Song	Age	Average	SD	N
Kaerunouta	3-year-old	7.5052	2.85719	29
	4-year-old	8.6037	2.96961	30
	5-year-old	8.4171	3.48662	31
Umi	3-year-old	9.1463	2.63067	8
	4-year-old	8.805	2.01257	10
	5-year-old	7.839	3.1224	10
Musundehiraite	3-year-old	400.9067	173.44916	9
	4-year-old	401.422	120.26263	10
	5-year-old	442.11	181.74859	10
Tewotatakimashou	3-year-old	6.6184	1.22373	19
	4-year-old	6.748	2.26008	20
	5-year-old	7.3774	1.79441	19
Shiawasenara Tewotatakou	3-year-old	6.266	1.81167	10
	4-year-old	6.916	1.92473	10
	5-year-old	6.937	2.29484	10
Ureshii Hinamasturi	3-year-old	9.4875	1.90246	8
	4-year-old	9.721	3.46217	10
	5-year-old	9.339	2.53537	10
Darumasan	3-year-old	8.88	2.02932	8
	4-year-old	8.1267	3.01173	9
	5-year-old	7.616	2.90651	10
Hotarukoi	3-year-old	6.71	2.10036	8
	4-year-old	6.932	2.33268	10
	5-year-old	7.118	3.12936	10
Teruterubouzu	3-year-old	7.3222	2.98825	18
	4-year-old	6.7268	2.44988	19
	5-year-old	9.1723	4.32873	22
Genkostuyamano Tanuki	3-year-old	8.3289	2.94255	9
	4-year-old	7.53	2.19371	9
	5-year-old	8.293	2.59907	10

As a result of the test of the effect between subjects, the main effect was statistically significant in the song factor (F (9, 375)=276.291, p<.005). According to multiple comparisons, 3-year-old, 4-year-old and 5-year-old showed significantly larger data in “Musundehiraite” than other nine songs.

4.3.4 The Total Moving Distance of Saccade

In order to inspect whether a statistically significant difference was observed or not in the calculated data of the total moving distance of saccade, a two-way ANOVA was conducted by the song factor (10 levels) and the age factor (3 levels).

Table 9. The Average of Total Moving Distance of Saccade

Song	Age	Average	SD	N
Kaerunouta	3-year-old	126.8666	102.49737	29
	4-year-old	141.7307	107.32831	30
	5-year-old	147.6052	92.5503	31
Umi	3-year-old	177.3925	87.82232	8
	4-year-old	166.643	106.03598	10
	5-year-old	126.014	84.17718	10
Musundehiraite	3-year-old	150.9378	152.44822	9
	4-year-old	135.103	112.99221	10
	5-year-old	168.456	79.01437	10
Tewotatakimashou	3-year-old	218.5353	152.32141	19
	4-year-old	217.206	178.77244	20
	5-year-old	213.4763	140.28595	19
Shiawasenara Tewotatakou	3-year-old	100.709	96.94952	10
	4-year-old	123.663	116.54486	10
	5-year-old	91.112	83.91147	10
Ureshii Hinamatsuri	3-year-old	204.5575	83.86732	8
	4-year-old	175.55	106.52629	10
	5-year-old	235.001	148.61351	10
Darumasan	3-year-old	86.0938	32.70565	8
	4-year-old	88.7289	46.00924	9
	5-year-old	92.945	56.501	10
Hotarukoi	3-year-old	113.3513	98.03137	8
	4-year-old	114.315	93.43521	10
	5-year-old	77.22	53.50204	10
Teruterubouzu	3-year-old	97.6444	96.73537	18
	4-year-old	117.2289	104.78197	19
	5-year-old	105.9355	86.21995	22
Genkostuyamano tanuki	3-year-old	119.0822	65.97339	9
	4-year-old	96.6467	36.43381	9
	5-year-old	153.594	48.29937	10

As a result of the test of the effect between subjects, the main effect was statistically significant in the song factor (F (9, 375)=6.67, p<.005). As a result of multiple comparison, in 3-year-old child children's data regarding the average of total moving distance of saccade, "Tewotatakimashou" was larger than "Teruterubouzu". 5-year-old children's data of "Ureshiihinamatsuri" was larger than "Hotarukoi".

4.3.5 The First Saccade

In order to inspect whether a statistically significant difference was observed or not in the calculation data of the size of the saccade that occurred the first time, a two-way ANOVA with the song factor (10 levels) and the age factor (3 levels) was conducted. Table 10 shows the first size of saccade (degrees).

Table 10. The First Size of Saccade (Degrees)

Song	Age	Average	SD	N
Kaerunouta	3-year-old	7.7986	6.61434	29
	4-year-old	8.8443	6.67036	30
	5-year-old	9.0384	5.91631	31
Umi	3-year-old	10.24	5.26771	8
	4-year-old	6.64	3.65792	10
	5-year-old	6.061	2.17636	10
Musundehiraite	3-year-old	232.0822	139.33696	9
	4-year-old	199.29	90.89385	10
	5-year-old	181.769	74.0519	10
Tewotatakimashou	3-year-old	6.2274	3.9628	19
	4-year-old	6.876	4.68213	20
	5-year-old	7.1658	5.81135	19
Shiawasenara Tewotatakou	3-year-old	8.596	8.30099	10
	4-year-old	5.776	3.10534	10
	5-year-old	5.572	2.68285	10
Ureshii Hinamasturi	3-year-old	8.2925	6.50261	8
	4-year-old	8.67	5.047	10
	5-year-old	12.444	8.62215	10
Darumasan	3-year-old	9.7813	4.37451	8
	4-year-old	8.3511	4.33887	9
	5-year-old	8.852	6.24701	10
Hotarukoi	3-year-old	6.0675	4.87504	8
	4-year-old	6.014	4.76115	10
	5-year-old	10.701	11.69227	10
Teruterubouzu	3-year-old	6.5317	6.71919	18
	4-year-old	8.1616	5.00062	19
	5-year-old	8.5745	6.54268	22
Genkostuyamano Tanuki	3-year-old	7.4144	5.0786	9
	4-year-old	5.9522	3.41426	9
	5-year-old	9.093	5.62926	10

As a result of the test of the effect between subjects, the main effect was statistically significant in the song factor (F (9, 375)=148.385, p<.005). As a result of multiple comparison, 3-year-old's data of "Musundehiraite" was significantly larger than the other 9 songs in 4-year-olds and 5-year-olds.

5. Discussion

In this article, the author inspected whether a characteristic difference was observed in eye movements during singing by early childhood children depending on whether the song is in major key or minor key. Firstly, regarding the acquired data by eye tracking, the author specified in saccade and conducted a three-way ANOVA based on major key/minor key (2 levels), child facility (4 levels), and age (3 levels). As a result of the analysis, it was found that saccades occurred more frequently in major key than in

minor key. Regarding the moving average velocity of saccade, the data of 5-year-old children at Y kindergarten was larger than 3-year-old and 4-year-old in major key. Regarding the size of saccade, the data in major key was significantly larger than the data in minor key regarding 3-year-old, 4-year-old, and 5-year-old children in Y kindergarten. The total moving distance of saccade tended to be larger in major key than in minor key, which was more remarkable in Y kindergarten. On the other hand, for 5-year-old children in U nursery school, the total moving distance of saccade was larger in minor key than in major key, but the data of 3-year-old children in M nursery school in major key was larger than the data in minor key. The size of the first saccade that occurred was remarkable in Y kindergarten. The size of the first saccade occurred in Y kindergarten and M nursery school were clearly characterized by being larger in major key than in minor key.

Secondly, in order to inspect whether a statistically significant difference was observed in the calculated data regarding saccade for all 10 specific songs, a two-way ANOVA was carried out (non-repeated song factor (10 levels), non-repeated age factor (3 levels)). As a result, regarding the number of occurrences of saccade, the number of occurrences of “Tewotatakimashou” and “Musundehiraite” were remarkable in the songs of major key. As for the average moving velocity of saccade, “Musundehiraite” was remarkable for 5-year-old children, and “Musundehiraite” was also large for the size of saccade. Regarding the total moving distance of saccade, the data of “Tewotatakimashou” for 3-year-old children were large. It was found that the size of saccade occurred in “Musundehiraite” for the first time was large in all ages of 3-year-old children, 4-year-old children, and 5-year-old children.

In this way, as a result of quantitative analysis by song, the number of occurrences of saccade was large in “Tewotatakimashou” for 3-year-old children. The moving average velocity and size of saccade in “Musundehiraite” for 5-year-old children were remarkable. Regarding the size of the saccade occurred for the first time, “Musundehiraite” was large for all ages of 3-year-old children, 4-year-old children, and 5-year-old children. Those results showed that participant children involved in a spontaneous body movement accompanied to singing a nursery rhyme from the beginning of singing “Musundehiraite” during every-day life in early childhood facility. In the singing, the participant children, looking at the teacher, other children nearby, and their own hands, put their hands forward and shake them up and down accompanied to the beat. “Tewotatakimashou” is also a Japanese lyrics that encourages the movement while singing “Te-wo-ta-ta-ki-ma-sho”, and the children sung to link with the movement, it was naturally that the moving average velocity and size of saccade especially increased in 5-year-old children. The change in the numerical value of eye movement verified that as the recognition of musical elements progresses, the early childhood child consciously thinks to express his or her recognition of musical elements by the spontaneous body movement accompanied to singing.

6. Conclusion

As a result of those above quantitatively analysis, it was found that the saccade in the musical expression in early childhood tended to be larger in major key than in minor key, which was remarkable in Y kindergarten, depended on the increase in the acquired data for two years. These results of this study made it possible to clarify the characteristics extracted the above quantitative analysis based on the result of analysis in 2020 depending more added data by eye-tracking. According to a result of quantitative analysis in 2020, some differences were found out depended on the two childcare forms between play-centered childcare form and a childcare form of following the Montessori method. In the results of eye-tracking in 2020, participant children involved in Montessori method tended to express the recognition of regularity and tonality regarding musical elements although participant children taking a play-centered childcare form tended to express the recognition of Japanese lyrics (Sano, 2021). By increasing more added data in 2021 regarding the number of songs and participant children, those results showed more clearly that the children tended to show characteristic change of eye movement depending on tonality and songs.

From the calculated data on saccade, which was the eye movement during musical expression of early childhood children, it was verified that effective feature quantities of eye movement for machine learning could be derived in the same way as feature quantities of movement based on the results of quantitative analysis during musical expression in early childhood. In order to extract another effective feature quantity from body movement included in musical expression, simultaneous analysis of musical expression in early childhood using motion capture with eye tracker is the next research subject.

Acknowledgement

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