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Abstract

Interacting through understanding others' roles based on perspective taking is important for achieving a group goal. However, complex and dynamic interactions, such as group non-verbal behaviors with three or more members, have not been fully examined. Our theoretical contribution expands the range of the theory applied to problem solving and learning in cognitive science to group non-verbal behavior with three members. In this study, participant triads repeatedly engaged in a coordinated drawing task, operating reels to adjust the thread tensions and moving a pen connected to the three threads to draw an equilateral triangle. We measured the pen positions and tensions. Analyzing group behavior quantitatively, the results showed that the role of stretching the thread a little significantly contributed to improved performance for drawing quickly. It suggests that maintaining overall balance through individuals' understanding others' roles based on perspective taking, is key to coordination.

Keywords: coordination; group behavior; interaction; perspective taking; role

Introduction

Sociality is the tendency to spontaneously involve oneself with others (DeJaegher, DiPaolo, & Gallagher, 2010). Humans often try to achieve a group goal based on sociality, and the planned coordination (Knoblich, Butterfill, & Sebanz, 2011) is a foundation for living our lives. Investigating mechanisms of coordination is therefore a meaningful subject in cognitive science. Since teamwork in sports and orchestras are representative examples (Sebanz, Bekkering, & Knoblich, 2006), researchers need to study such complex and dynamic non-verbal interactions among three or more members to understand cognition related to coordination. However, these interactions have not been fully considered. We hence focused on group non-verbal behavior with three members and investigated individuals' understanding others' roles based on perspective taking.

Previous psychology studies have shown that it is important to represent roles, monitor and anticipate others' behaviors for coordination, and such elements are needed for various group activities (e.g., Sebanz et al., 2006; Sebanz & Knoblich, 2009; Sebanz, Knoblich, & Prinz, 2003). Cognitive science studies of problem solving and learning have analyzed dialogue when implementing a task with others and found that the interaction structure is key for achieving a group goal and facilitating a positive learning effect. These studies have indicated that each member should interact and share roles by taking others' perspectives (e.g., Hayashi, Miwa, & Morita, 2006; Lombrozo, 2006). Increasing the number of members does not necessarily facilitate problem solving and a positive learning effect (e.g., Laughlin, Bonner, & Miner, 2002; Stasson, Kameda, Parks, Zimmerman, & Davis, 1991). The findings are consistent with the distributed cognition theory (Hutchins, 1995), which indicates that an overall group function works through interactions based on relationships among subsystems, where each subsystem is regarded as a role. The sports science study (Fujii et al., 2016) has found that cooperated and defensive group behavior in a basketball game involves switching and overlapping hierarchical roles depending on the emergency level.

According to these previous findings, interacting through understanding others' roles based on perspective taking is important to achieve a group goal. However, these studies (e.g., Hayashi et al., 2006; Sebanz et al., 2006) have not observed complex and dynamic coordination, such as group non-verbal behaviors with three or more members. As complexity, it is more difficult to model and interpret interactions among three members than those among two members (Yokoyama & Yamamoto, 2011). Dynamic coordination involves a time-varying characteristic, such as continuous body movement (Braun, Ortega, & Wolpert, 2009). Relative static movements were hence not included in the present study, such as posture, gesture, or pressing a button for a presented stimulus used in the Simon task (Sebanz et al., 2006). Some problem solving and learning studies have investigated verbal interactions among three or more members in a school setting (e.g., Engle, 2006; Saito & Miyake, 2011), but none have examined group non-verbal behaviors. Biology and sports science researchers have employed quantitative analysis using position data to investigate characteristics and mechanisms of animal group behaviors and teamwork in sports with three or more individuals (e.g., Bialek et al., 2012; Fujii et al., 2016; Yokoyama & Yamamoto, 2011). However, these studies have not fully investigated cognition related to complex and dynamic group behaviors. The novelty of this study was to quantitatively analyze group non-verbal behavior with three members and examine the relationship between coordinated group behavior and understanding others' roles based on perspective taking.

The purpose of this study is to investigate understanding

Table 1: Three roles in the coordinated drawing task that correspond to Figure 1.

Side	Operator		
	[1]	[2]	[3]
<1>	Loosen	Stretch	Stretch a little
<2>	Stretch a little	Loosen	Stretch
<3>	Stretch	Stretch a little	Loosen

others' roles based on perspective taking through quantitative analysis of group non-verbal behavior. We observed the process of improved task performance in a triad, analyzed group behavior, and related coordinated group behavior to the cognition. Our theoretical contribution expands the range of the theory applied to problem solving and learning (e.g., Hayashi et al., 2006; Lombrozo, 2006) to group non-verbal behavior with three members. It is similar to the study by Braun et al. (Braun et al., 2009), which expands the range of classical game theory by two players in decision making to continuous body movement. We focused on the role of balancing overall coordination, which requires to understand others' roles based on perspective taking, regardless of the type of group activities. Identifying the importance of this role may influence theories in other research fields, such as sports science. This study further hypothesized that maintaining overall balance contributes to achieving a group goal.

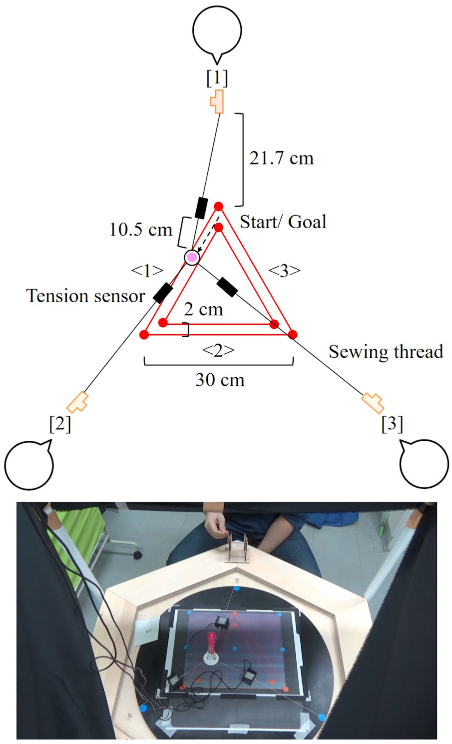

Figure 1: Coordinated drawing task showing the pattern diagram (upper) and the experiment image (lower). The length and width of each triangle side are 30 cm and 2 cm, respectively.

Method

Coordinated drawing task

This study used a coordinated drawing task (Maruno, 1991), where each operator in a triad adjusts the thread tension using a reel, which moves a pen connected to the three threads to draw an equilateral triangle. The length and width of each triangle side are 30 cm and 2 cm, respectively (Figure 1). The thread stretches or loosens as the operator turns a reel inward or outward. The group goal is to draw the triangle directly without deviating from the side specifications.

During this task, the triad should share three roles: "stretching", "loosening", and "stretching a little", and should switch these roles counterclockwise when a drawn side changes. The stretching and loosening roles serve to move the pen as if an operator pulls it closer to his or her hand and to keep with the pen moving smoothly, respectively. The stretching a little role balances overall coordination without deviating from the length and width or increasing the time it takes to complete the drawing. Table 1 presents the roles that correspond to Figure 1.

The task allows observation of controlled group behavior because the group goal and roles are clear. In addition, it allows us to quantitatively evaluate the roles by measuring the thread tensions. Understanding others' roles based on perspective taking is key to improving the required performance. The perspective taking is reflected by simulating the pen position as seen by others and their reel operations. Such cognitive processing is important for the stretching a little role of balancing overall coordination.

Participants

Eight triads by 24 participants (four male and four female triads) engaged in the coordinated drawing task. All participants were right-handed, knew and often talked with each other prior to their participation. Two triads (one male and one female) were excluded from the analysis because they did not engage in the task according to the experimenter's instructions. The average age of the remaining six triads was 20.78 years ($SD = 1.31$).

Each participant's perspective taking ability was measured before the task by a subscale of the Japanese version of the Interpersonal Reactivity Index (IRI) (Himichi et al., 2017) because it might influence interactions and task performance as an intra-individual factor. The average score across a group was 15.72 of 28 ($SD = 0.97$), and no triads recorded an average score outside the $\pm 2SD$ range.

We explained to participants how we would video-record and collect data, and obtained written informed consent from all participants. This study was approved by the ethics and safety committee of Kanagawa University.

Procedure and environment

The experimenter instructed participants that the group goal was to move a pen by operating each reel and to draw an equilateral triangle directly without deviating from each side's length and width. Participants were instructed on how to use the reel to stretch or loosen the thread by turning inward or outward, but were not instructed on the details of the three roles. Time limit to draw three sides was 90 seconds per trial. The rules; the pen's start and goal positions and the direction to draw counterclockwise, were the same across all trials (Figure 1). A practice trial was conducted without the time limit. After the practice, each triad repeated the task for 20 minutes per session. Three sessions were conducted with a five-minute break between sessions. Conversation and gesture were prohibited during the task.

Figure 2 shows the experimental environment. Each thread tension was recorded on a personal computer (Panasonic, Let's note CF-SX3) at 100 Hz using three sensors (Tokushukeisoku Co., Ltd., TK-A-30N), amplifier equipment (KYOWA Co., Ltd., PCD-300B), and dedicated software (KYOWA Co., Ltd., DCS-100A ver. 04.43). A positive value (N) was recorded in response to tension when a reel was turned inward; the tension decreased when it was turned outward. Black curtains were placed in front of participants so that they could not see each other's facial expression and make eye contact. The task activities each trial were recorded from a bird's-eye view using a video camera (Sony, HDR-CX680) (Figure 1). The video images (W 1280 px * H 720 px) were automatically digitized by motion analysis software (DITECT Co., Ltd., DIPP-Motion V/2D ver. 1.1.31) to capture the pen positions in two dimensions at 20 Hz.

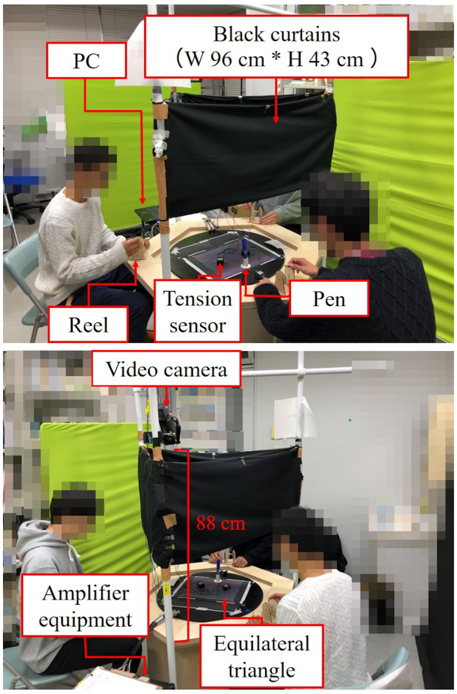

Figure 2: Experimental environment.

Analysis

Performance We analyzed two performance indices; the degree of deviation on a side (cm) and the time to draw a side (sec). The former index, which represented the average degree of pen deviation from each side's width, was calculated using the following equations:

$$Dev_{(f_i)} = \frac{1}{\|\boldsymbol{P}_{ver_{(i+1)}} - \boldsymbol{P}_{ver_{(i)}}\|} \begin{vmatrix} \boldsymbol{P}_{ver_{(i+1)}} - \boldsymbol{P}_{ver_{(i)}} \\ \boldsymbol{P}_{pen_{(f)}} - \boldsymbol{P}_{ver_{(i)}} \end{vmatrix}, \quad (1)$$

$$Dev_{(f)} = min(Dev_{(f_i)}), \quad (2)$$

$$\overline{Dev} = \frac{1}{F}\sum_{f=1}^{F} Dev_{(f)}. \quad (3)$$

The fixed positions directly beneath each vertex of the triangle were $\boldsymbol{P}_{ver_{(i)}} = (x_{P_{ver_{(i)}}}, y_{P_{ver_{(i)}}})$ and $\boldsymbol{P}_{ver_{(i+1)}} = (x_{P_{ver_{(i+1)}}}, y_{P_{ver_{(i+1)}}})$, with the range $1 \leqq i \leqq 3$. If $i = 3$, then $\boldsymbol{P}_{ver_{(i+1)}}$ indicates coming back to $\boldsymbol{P}_{ver_{(1)}}$. The lines connecting these points represented the median lines of width. $\boldsymbol{P}_{pen_{(f)}} = (x_{P_{pen_{(f)}}}, y_{P_{pen_{(f)}}})$ and F represented the pen position in the current time frame f and the number of time frames for each side, respectively. We calculated the distances between the pen position and each median line, and regarded the minimum value $Dev_{(f)}$ as the degree of deviation (cm) on a side in the current time frame f. The index of the time to draw a side represented the time to change the combination of i and $i+1$ when calculating $Dev_{(f)}$. For example, in Figure 1, the combination to calculate $Dev_{(f)}$ changed from $i = 1$ and $i+1 = 2$ to $i = 2$ and $i+1 = 3$ when a drawn side switched from $< 1 >$ to $< 2 >$.

Smaller values of both indices indicated faster drawing time without deviating from each side's width.

Role We analyzed two indices for the stretching and stretching a little roles, considering the sensor specifications. The former index was the match between a participant who recorded a maximum peak of the three tensions and an operator who should play the stretching role on each side (match: 1, mismatch: 0). The latter index was the frequency of tension peaks by a participant who should play the stretching a little role on each side.

A low-pass filter was applied to the tension data at 0.5 Hz to remove high-frequency noise. In addition, a threshold value of 0.2 N was applied to extract at least one tension peak in each sensor. With the index for the stretching role, we investigated a participant who recorded a maximum peak of the three tensions on each side. If an operator played the stretching role, the pen was pulled closer to his or her hand and the tension was relatively large. When the operators who recorded maximum peaks were [2], [3], and [1] on each side (Table 1), it indicated that the stretching role was properly switched. Meanwhile, the operators who should to

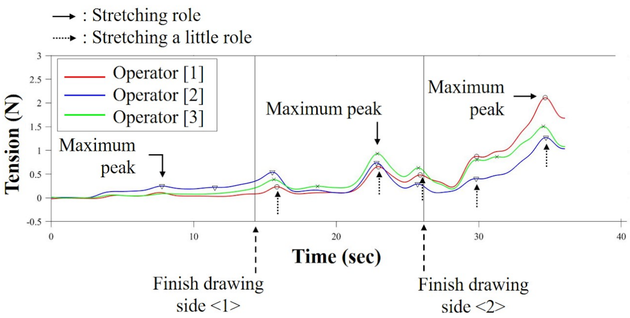

Figure 3: Analysis procedures pattern diagram of the roles that correspond to Figure 1 and Table 1.

play the stretching a little role were [3], [1], and [2] on each side (Table 1). This role was required to balance overall coordination without deviating from each side's width or causing time loss during the task. When participants who should play the stretching a little role recorded tension peaks, this suggested handling and breakthroughs against others' or their own misses. Conversely, if the frequencies of tension peaks were low, it suggested that participants understood others' roles based on perspective taking and prevented the problems mentioned above to maintain overall balance.

Figure 3 presents the pattern diagram of these analysis procedures that correspond to Figure 1 and Table 1. All analysis including performance were conducted using MATLAB R2016b. Two trials in one group and three trials in another were missing data due to measurement problems, such as thread breaking.

Statistical modeling We investigated whether performance was improved through trials, then evaluated the relationship between improved performance and the roles. Regression analysis were conducted using a linear mixed model to investigate the relationship between performance and trial or roles, considering the variabilities between triads or sides.

In the first regression, performance index; the degree of deviation on a side or the time to draw a side, was regarded as the dependent variable, respectively. Trial was a fixed effect of the independent variable, and six triads and three sides were regarded as random effects. If the fixed effect gradient of trial was significant at the 5% level, the second regression was conducted, where an index, which would indicate a significant gradient, was regarded as the dependent variable. Here, two indices for the stretching and stretching a little roles were fixed effects of the independent variables, and six triads and three sides were regarded as random effects. Moreover, in both regressions, we calculated Akaike Information Criterion (AIC) values to determine whether random effects should be set in the gradient, intercept, or both elements. In the second regression, the AIC values were also used to determine whether an interaction between the independent variables should be included.

Before the first regression, Augmented Dickey-Fuller (ADF), Point Optimal (PO), and Durbin-Watson tests were conducted on the time series data of performance through trials at the 5% level to investigate pseudo correlations between the dependent and independent variables. All statistical analysis were conducted with R-3.6.1 using the lme4, lmerTest, tseries, urca, and lmtest packages.

Results

Triads engaged in the task for the average 24.5 trials ($SD = 2.06$). There were 18 time series data of each performance index through trials based on a combination of six triads and three sides. All time series data for the index of the degree of deviation on a side and 15 data for the index of the time to draw a side were significantly unit root and cointegration, or neither unit root nor autocorrelation of residuals. These results indicated that pseudo correlations between the dependent and independent variables were not present in most of the limited amount of experimental data, as confirmed ADF, PO, and Durbin-Watson tests. We therefore conducted the first regression using all the time series data.

We reported the overall characteristics for the relationship between performance and trial or roles. In the first regression for both indices, the models were selected, where random effects were set in both gradient and intercept. For the index of the degree of deviation on a side, AIC values in the models were 138.153, 4.564, and 2.304, respectively, where random effects were set in the gradient, intercept, and both elements. For the index of the time to draw a side, those in the same models were 2498.9, 2475.8, and 2463.7, respectively. Table 2 presents the result details. The fixed effect gradient of trial was significant only for the index of the time to draw a side (coefficient: -0.395, $SE = 0.086, p = 0.005$). The first regression indicated that triads significantly drew the triangle quickly through trials while maintaining a certain amount of pen deviation. In the second regression, the model was selected, where random effects were set in both gradient and intercept, but an interaction between the independent variables was not included. AIC values in the models were 2566.9, 2579.9, and 2566.4, respectively, where random effects were set in the gradient, intercept, and both elements, but an interaction between the independent variables was not included. The values in the models were 2568.7, 2580.2, and 2567.4, respectively, where random effects were set in the gradient, intercept, and both elements, and an interaction between the independent variables was included. Table 3 presents the result details. The fixed effect gradient of the index for the stretching a little role was a significant trend (coefficient: 1.062, $SE = 0.475, p = 0.074$). Figure 4 shows the scatter plot, in which the vertical and horizontal axes are the indices of the time to draw a side and the frequency of tension peaks in the stretching a little role. This regression indicated that lower frequency of tension peaks in the stretching a little role was significantly related to faster drawing on a side. It suggested that the tension was adjusted

Table 2: Relationship between performance and trial considering the variabilities between participant triads and sides.

Dependent variable	Fixed effect						Random effects			
							Group		Side	
	Gradient			Intercept			Gradient	Intercept	Gradient	Intercept
	Coefficient	*SE*	*p*-value	Coefficient	*SE*	*p*-value	Variance	Variance	Variance	Variance
Deviation	-0.001	0.004	0.848	0.705	0.208	0.065	0.000	0.014	0.000	0.121
Time	**-0.395**	**0.086**	**0.005**	24.041	1.921	0.001	0.025	5.305	0.007	7.909

Note. Independent variable is trial. *Deviation* is the degree of deviation on a side (cm); *Time* is the time to draw a side (sec).

Table 3: Relationship between performance and the roles considering the variabilities between participant triads and sides.

Independent variables	Fixed effects						Random effects			
							Group		Side	
	Gradient			Intercept			Gradient	Intercept	Gradient	Intercept
	Coefficient	*SE*	*p*-value	Coefficient	*SE*	*p*-value	Variance	Variance	Variance	Variance
Match	-0.724	0.590	0.232	17.728	1.347	0.000	0.169	3.607	0.000	0.000
Frequency	**1.062**	**0.475**	**0.074**				1.160	0.210	0.008	2.481

Note. Dependent variable is the time to draw a side (sec). *Match* is the match between a participant who records a maximum peak of the three tensions and an operator who should play the stretching role (match: 1, mismatch: 0); *Frequency* is the frequency of tension peaks in the stretching a little role.

to prevent time loss during the task.

Those results supported the hypothesis that the role of maintaining overall balance through individuals' understanding others' roles based on perspective taking contributed to improved performance.

Discussion

The results confirmed that the stretching a little role of maintaining overall balance significantly contributed to improved performance. Tension peaks recorded in the role suggested the occurrence of others' and their own mishandling. For example, the pen did not move when drawing side <1> because operator [1] played the stretching role by mistake (Table 1). In such a conflict situation, operator [3] might inform operator [1] of the tension relationship among three members by thread stretching. This behavior would induce operator [1] to correct the wrong role. Here, the tension relationship among three members indicated that operators [2] and [3], who positioned opposite from operator [1], needed to increase the tensions relatively. Conversely, low frequency of tension peaks in the stretching a little role suggested that the tension was adjusted to prevent the problems mentioned above. It was be related to understanding others' roles based on perspective taking, indicating that participants simulated the pen position as seen by others and their reel operations. The role of balancing overall coordination is also required in teamwork in sports and debate. Previous sports science studies (e.g., Yokoyama, Shima, Fujii, Tabuchi, & Yamamoto, 2018; Yokoyama & Yamamoto, 2011) have investigated characteristics and mechanisms of group behaviors comparing between expert and novice players. In this study, we observed significantly improved performance in novice participants. Triads might therefore acquire skills related to the role through trials. Our findings may influence theories in other research fields, such as sports science.

This study did not confirm the significant relationship between performance and the stretching role (Table 3). We found that the role of maintaining overall balance contributed more to improved performance than that of mainly moving the pen. Previous studies (e.g., Hayashi et al., 2006; Lombrozo, 2006) have analyzed dialogue to identify the importance of taking others' perspectives for coordination. Our findings suggest that the theory for problem solving and learning in cognitive science can be applied to more complex and dynamic interactions, such as group non-verbal behaviors with three members. Although we did not explain the role of maintaining overall balance to participants, they spontaneously played the role. As a basis for understanding others' roles based on perspective taking, they might represent roles, and monitor and anticipate others' reel operations (e.g., Sebanz et al., 2006; Sebanz & Knoblich, 2009; Sebanz et al., 2003). Meanwhile, the role might work bahavioral dimensional compression and reciprocal compensation in coordination explained by Riley et al. (Riley, Richardson, & Shockley, 2011). In future works, our results will be also needed to discuss in term of the dynamical systems approach (Warren, 2006).

There is a still room to discuss cognition, which contributes to coordination. In this study, it was difficult to investigate what behaviors in others should be anticipated and when participants should anticipate their behaviors. Multi-agent simulation methodology is effective in solving this problem. In our future work, we plan to focus on the stretching a little role, model the cognition of anticipating others' behaviors,

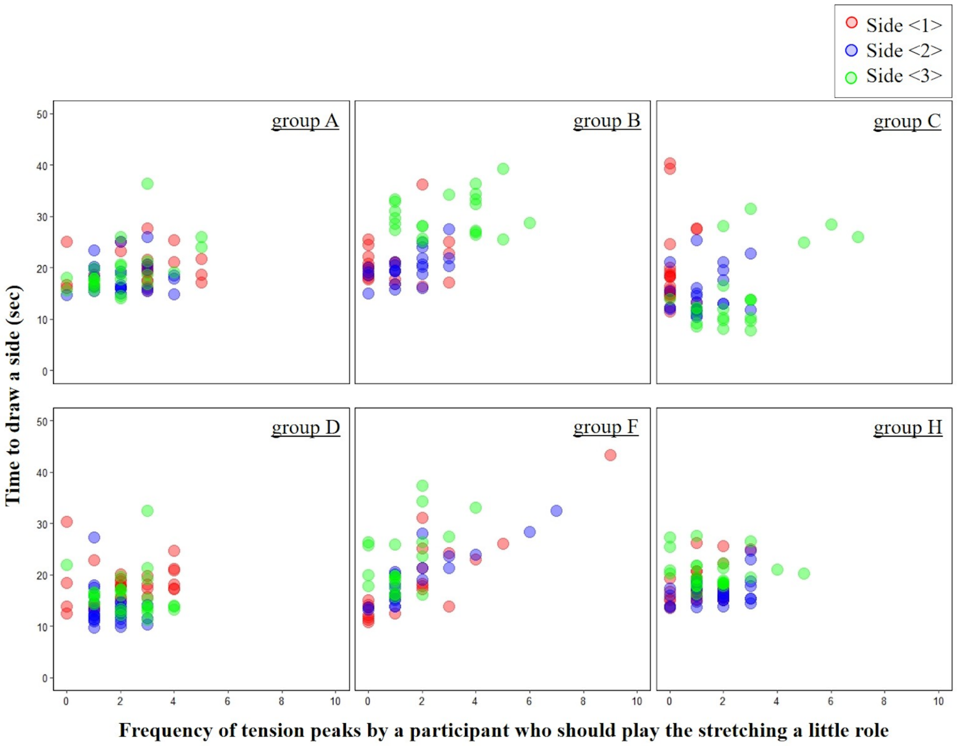

Figure 4: Scatter plot between the time to draw a side (sec) and the frequency of tension peaks by a participant who should play the stretching a little role. Two trials in group C and three trials in group F were missing data due to measurement problems, such as thread breaking.

and investigate how performance is affected by changing parameters related to anticipation of others' behaviors. We will attempt to understand the cognition that underlies the role of balancing overall coordination, by establishing cognitive model and comparing the results of this study and simulation.

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