

# Multi-modal Conversational Dominance Modelling in the Weight Task Dataset

The final report for the project “Multi-scale Dynamics of Multi-modal Communication” at ILLC

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June 2024

## 1. Introduction

Dominance plays an important role in the analysis of conversations. Importantly, an understanding of conversations as multi-modal communication allows for a holistic characterisation of conversational dominance. Therefore, previous research has sought to define conversational dominance in terms of verbal and non-verbal communication and provides some computational approaches to quantify dominance in terms of these. Based on these conceptual findings, the aim of this paper is, firstly, to provide a methodology to computationally determine three dimensions of dominance (participatory, quantitative and sequential dominance) and to illustrate possible insights with respect to the data provided by Khebour et al. (2023). Secondly, we illustrate the explanatory power of the provided quantifiable determination of the three dimensions of conversational dominance by analysing the relationship between conversational dominance and success with respect to the data provided by Khebour et al. (2023).

## 2. Background

### 2.1. *Conversational Dominance*

According to Burgoon et al. (2021), conversational dominance is characterised by an imbalance in the interaction. Intuitively, this imbalance is characterised by the fact that the dominant interlocutor in some way determines the conversation. Itakura (2001) distinguishes three dimensions of conversational dominance: Sequential, Participatory and Quantitative Dominance. The first refers to a successful initiation of conversational patterns. In contrast, participatory dominance illustrates an interlocutor’s tendency to restrict the participatory rights of other interlocutors. Finally, quantitative dominance illustrates whether a speaker is over-represented during the conversation. Furthermore, Manusov and Patterson (2006) and Burgoon et al. (2021) illustrate that sequential conversational dominance is determined by the initiation of movements and the corresponding reciprocation and non-reciprocation. Consequently, these findings on the relationship to conversational dominance are transferable to Itakura’s analysis of sequential dominance as they highlight nonverbal conversational patterns. In addition, Jayagopi et al. (2009) argue that a relatively higher level of activity with respect to body movements indicates dominance, whereby this analysis can be linked to quantitative dominance. Lastly, Rienks and Heylen (2005) and Rienks et al. (2006) determine conversational dominance by several quantitative measures such as interruptions and floor grabbing, which are related to participatory dominance.

### 2.2. *Group dynamics and group performance*

The relationship between group dynamics and group performance has been discussed from various perspectives. Licorish et al. (2024) investigated the ranking of the significance of group dynamic themes among university students participating in software development projects, where “useful

feedback”, “listening” and “taking initiative” are a few mentioned in conversational group interactions. Lehmann-Willenbrock and Chiu (2018) claims that content disagreements between group members are essentially more helpful than convergent off-task behaviors viewing from the perspective of task completion. Another research by Lehmann-Willenbrock et al. (2017) focused on linguistic expressions of “positivity” and concluded that positive expressions present in the last 100 utterances of a conversation bear a significant positive link with group performance.

From the particular angle regarding “dominance”, Klug and Bagrow (2016) provides interesting insights. The study investigated group dynamics in 150,000 real-world project teams on GitHub and their relationship with team success, which is measured by the number of “stargazers” of their published projects. They proposed the notion of “effective team size” defined by the extent of workload concentration on a smaller number of members within the team. Interestingly, they found that this value bears a significant negative relationship with the team’s success. Furthermore, they also defined “dominance” in their context as a situation where the lead member contributed more work than all other members combined. It’s observed that highly successful “top” teams (in the top 10% of the success distribution) were significantly more likely to be “dominated” than average teams. On the other hand, the research also discussed the scenario of “collective leadership”, as the greater number of team members who are “dominators” of some other projects in a team also correlates with a higher success level.

### *2.3. Turn Taking and Social Asymmetry*

Another important part of the project was to understand the relationship between turn taking behaviour and power dynamics within conversations. In addition, we sought to find out how unbalanced levels of mimicry between participants (hereafter referred to as “social asymmetry”) also plays a role in characterising group power dynamics. With regards to the latter, Richardson et al. (2019) demonstrated via a series of three experiments that lower power participants demonstrated greater language matching than higher power participants. It is reasonable to hypothesise that the same correlation would be present for movement matching. This conclusion is supported by Patrick Bourgeois (2008), which showed that facial mimicry is sensitive to social group membership, and Rick van Baaren and Dijksterhuis (2009), which concludes that movement mimicry is a socially moderated behaviour. Dindar et al. (2022) were able to show that analysis of facial mimicry can accurately identify leaders and social dynamics within group learning activities. This research supports the notion of sequential dominance as a useful measure of dominance in conversation.

Shazia Akbar Ghilzai (2016) highlighted the complexity of turn-taking and its interaction with gender stereotypes. It found that women are more likely to take turns in conversation, meaning that they more often allow their interlocutor to interject, rather than continuing to speak. The authors attribute this tendency to interpersonal sensitivity, suggesting that participants who are more socially aware of the others in their group will take more, shorter, turns, rather than speaking for long periods without allowing interruption. This demonstrates that while quantitative dominance will be a useful measure of power in a conversation, it is equally important to understand the nature of turn transitions (as with participatory dominance).

### 3. Methodology

This section outlines the methods employed to transform the insights gleaned from the background information into actionable steps using Python.

#### 3.1. Sequential dominance

To determine sequential dominance, we analyse interlocutors’ body movements and check whether body movements are imitated by other interlocutors which makes it a sequentially dominant action. Based on the annotations of body movements, a Python script determines imitated actions by iterating through all actions of a certain type and checking if another interlocutor performs the same action within 10 seconds.<sup>1</sup> Furthermore, it is essential to order the actions in time and to mark movements that are analyzed as imitations of another movement. This ensures that two movements of different interlocutors, which are imitations of the same movement and occur one after the other, are only sequentially dominant actions of the imitated interlocutor.

#### 3.2. Participatory dominance

The participatory dominance is modeled from 2 perspectives of “interruptions” and “unsuccessful overlaps”. The former is defined as a participant’s action to successfully grab the conversational stage from another participant and establish participatory dominance during her following unit of utterance; while the latter is defined as a participant’s effective defense of the conversational stage, where another participant intends to take it over by cutting in with an utterance and form a period of overlapping, but then gives up. As a result, the original participant secures her conversational stage despite the challenge from another participant, revealing her participatory dominance during her unit of utterance.

Based on oracle transcripts of each group in the dataset, a Python script iterates over every utterance in each group and all utterances following it to extract utterance pairs involving “interruptions” and “unsuccessful overlaps” and stores them in respective files for manual reference. Standards used for extractions are as follows:

- **Interruption**

- (i) 2 different participants are involved and the organizer (Participant 4) is excluded (based on the “Participant” column of original oracle files);
- (ii) The interrupting utterance should start after the interrupted utterance (based on the “Start” column of original oracle files);
- (iii) The interrupting utterance should start before when the interrupted utterance is ended (based on the “Start” and “End” columns of original oracle files);
- (iv) The interrupting utterance should end later than the interrupted utterance (based on the “End” column of original oracle files);
- (v) The interrupting utterance should be longer than a threshold (here specified as 10) to rule out pure filler utterances like “yes”, “yeah”, etc.

Interrupting utterances extracted are regarded as revealing participatory dominance.

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<sup>1</sup>The literature on movement alignment in conversation seems to suggest a time frame of up to 10 seconds. For example, Dale et al. (2020) suggests that body movements are aligned within a 10 second time frame. Hale et al. (2020) suggests that an alignment of head movements is established within 600ms. Similarly, Paggio (2016) suggests that these movements are aligned within 1 second.

- **Unsuccessful overlaps<sup>2</sup>**

- (i) 2 different participants are involved and the organizer (Participant 4) is excluded (based on the “Participant” column of original oracle files);
- (ii) The trying-to-overlap utterance should start after the overlapped utterance (based on the “Start” column of original oracle files);
- (iii) The trying-to-overlap utterance should start before when the overlapped utterance is ended (based on the “End” column of original oracle files);
- (iv) The trying-to-overlap utterance should end earlier than the overlapped utterance so that it’s unsuccessful (based on the “End” column of original oracle files).

Overlapped utterances extracted are regarded as revealing participatory dominance.

The further processing is carried out in 2 phases. Phase 1 adds markers for dominating utterances defined by the 2 sets of standards above to the original transcripts and outputs them as pre-processed enriched files. Phase 2 involves manual labeling based on corresponding videos to rule out “fake” dominating utterances caused by wrong annotations or complex conversation scenarios and produce final enriched transcript files. The final files serve for data visualization to map out the dominating utterances of different participants within the whole time frame of each group.

### 3.3. *Quantitative Dominance*

To determine Quantitative dominance, we analyse the duration of participants’ utterances to determine the proportion of time each participant spent speaking. A Python script determines the total duration of utterances in seconds for the entire group and for each participant. A simple calculation is then performed to determine the percentage of time spent speaking for each participant. The script was also used to determine the number of utterances from each participant. In addition, a Python script was used to generate a dataframe which showed the amount of time each participant spent speaking in a one second interval. This dataframe was then used to generate rolling-window heatmaps for each group. These heatmaps visualised the how much each participant was speaking over the duration of the task, in order to give us a better understanding of how quantitative dominance dynamics changed over time, the average duration of utterances, and how ordered or chaotic conversations appeared. We also visually compared the heatmaps to the sequential and participatory dominance plots when assessing correlation.

### 3.4. *Success*

Task success was determined by simply subtracting the time of the last utterance by the experimenter (marked as ‘Participant 4’) from the time of the last utterance of the participants at the end of all three tasks. Whether or not groups successfully found the answer to task 2, guessed incorrectly and then guessed correctly, or guessed incorrectly twice, was also recorded.

### 3.5. *Correlation*

Correlation between two dimensions of dominance is determined with respect to the probability that after the occurrence of a dominant action of the first kind a dominant action of the second kind performed by the same interlocutor follows within a time frame. Instead of defining a specific time frame, we determine the highest correlation value within 60 seconds. Therefore, for a specific domain of dominance and every value between 1 and 60 seconds (time frame) it is determined how

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<sup>2</sup>We don’t include the constraint of utterance length in the definition of unsuccessful overlaps, as short fillers also signify the dominant status of the overlapped participant. For example, supportive fillers can actually be regarded as symbols of recognition for the dominance of another participant. We manually labeled the nature of overlapping utterances in the processing files.

high the probability is that an interlocutor performs a dominant action of another dimension within this specific time frame. The data of participatory dominant and sequentially dominant actions can be used without modification. However, the data captured by our measurement of quantitative dominance must be slightly modified so that for each window of 15 seconds an interlocutor is determined to be quantitatively dominant if their percentage of speaking time is above 50%. This is necessary to reduce the number of actions marked as quantitatively dominant actions. Based on these values, the maximum correlation value and the corresponding time frame is detected. Further, we determine these values for all groups to compute the average maximum correlation and the average correlated time frame. Similarly, we determine 50% of the maximum correlation, the time frame when this value is achieved and corresponding average values.

### *3.6. Data*

For an example of our analysis, we are using the data provided by Khebour et al. (2023). The data captures the conversations of 10 groups consisting of 3 participants and these groups ought to solve an exercise (determine the weight of a cube). The data already provides transcripts of the conversations and annotations of body movements.

## 4. Results

### 4.1. Sequential dominance

Based on the annotations<sup>3</sup> provided by Khebour et al. (2023), we analysed the actions *head movement* (Head), *deictic reference to blocks* (Blocks) and *deictic reference to scale* (Scale). Table 1 illustrates if a sequentially dominant action occurs. Furthermore, deictic reference to blocks was

Group Action	1	2	3	4	5	6	7	8	9	10
Head	✓	✗	✓	✗	✗	✓	✓	✓	✗	✓
Blocks	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Scale	✓	✗	✗	✗	✗	✓	✓	✓	✗	✗

Table 1: Overview whether a sequentially dominant actions occurs

the most common sequentially dominant action. Table 2 illustrates the number of sequentially dominant actions with respect to the groups and its members. On average, 36.3 sequentially dom-

Participant	Action	Gr 1	Gr 2	Gr 3	Gr 4	Gr 5	Gr 6	Gr 7	Gr 8	Gr 9	Gr 10
Part. 1	Head	1	0	2	0	0	2	0	3	0	2
	Block	28	0	27	8	53	2	31	20	2	1
	Scale	1	0	0	0	0	0	3	1	0	0
Part. 2	Head	0	0	0	0	0	0	2	3	1	1
	Block	0	2	11	5	2	1	42	2	17	4
	Scale	0	0	0	0	0	1	3	2	0	0
Part. 3	Head	1	0	0	0	0	0	1	0	0	0
	Block	4	9	0	2	0	2	29	8	1	12
	Scale	1	0	0	0	0	0	7	0	0	0

Table 2: Overview of number of sequentially dominant actions

inant actions occur in each group whereby 1.9 head movements, 32.5 deictic references to blocks and 1.9 deictic references to the scale were sequentially dominant. Further, the data shows that sequentially dominant deictic references to blocks of an interlocutor occur temporally dense, e.g. multiple sequentially dominant actions of this type tend to occur within a short period.<sup>4</sup>

### 4.2. Participatory dominance

Participant	Action	Gr 1	Gr 2	Gr 3	Gr 4	Gr 5	Gr 6	Gr 7	Gr 8	Gr 9	Gr 10
Part. 1	Interruption	1	4	3	3	11	1	16	9	7	6
	Unsuccessful overlap	24	5	6	6	11	5	6	10	1	10
Part. 2	Interruption	7	1	3	8	6	6	21	6	0	17
	Unsuccessful overlap	5	6	3	3	10	8	12	7	4	14
Part. 3	Interruption	2	2	10	4	6	6	28	2	3	15
	Unsuccessful overlap	1	2	6	8	6	7	20	11	4	20

Table 3: Overview of actions revealing participatory dominance

Table 3 illustrates the number of actions revealing participatory dominance concerning the groups and their participants, based on the extraction of interruptions and unsuccessful overlaps from

<sup>3</sup>If possible the annotation of R. Brutti were used. For group 4 and 6 this was not possible.

<sup>4</sup>A graph illustrating the temporal distribution of sequentially dominant actions of two groups is given in 7.1 and 7.2.

oracle transcripts. On average, 45.5 actions revealing participatory dominance occur in each group, of which 21.4 are dominant actions defined by interruptions and 24.1 are dominant actions defined by unsuccessful overlaps. Reviewing more specifically each group, there are some potential patterns: (1) Actions of participatory dominance concentrate on 1 participant; (2) Actions of participatory dominance mainly distribute among 2 participants of a group, while the absolute number of these actions can be either low or high; (3) Actions of participatory dominance have a comparatively even distribution among all 3 participants, while the absolute number of these actions can be either low or high.

#### 4.3. Quantitative Dominance

Participant	Quantity	Gr 1	Gr 2	Gr 3	Gr 4	Gr 5	Gr 6	Gr 7	Gr 8	Gr 9	Gr 10
Part. 1	Percent Speaking Time	56.7%	46.1%	39.5%	24.6%	41.7%	23.4%	20.7%	34.4%	30.5%	20.9%
	Utterance Count	93	69	103	45	82	43	99	107	32	51
	Avg. Utterance Time (s)	4.00	2.78	3.63	3.13	4.12	3.22	2.60	3.01	2.54	3.30
Part. 2	Percent Speaking Time	26.0%	39.2%	20.6%	30.4%	27.5%	45.2%	32.0%	24.5%	18.5%	38.7%
	Utterance Count	53	63	56	58	54	85	142	83	24	90
	Avg. Utterance Time (s)	3.22	2.58	3.49	3.00	4.13	3.14	2.80	2.76	2.05	3.47
Part. 3	Percent Speaking Time	17.3%	14.7%	39.8%	45.0%	30.8%	31.3%	47.4%	41.1%	51.1%	40.4%
	Utterance Count	49	29	104	55	54	58	217	114	44	92
	Avg. Utterance Time (s)	2.31	2.11	3.62	4.68	4.62	3.19	2.72	3.37	3.10	3.54

Table 4: Overview of Utterance Proportion, Count, and Average Length revealing Quantitative Dominance

Table 4 illustrates the percentage of total speaking time taken by each participant during the tasks, the number of utterances spoken by each participant, and the average utterance duration of each speaker. Some groups, such as group 1, had a single participant who clearly dominated by all three metrics. Others, such as group 2, had two participants who spoke much more than the third participant, and other groups, such as group 5, had a much more even distribution of speaking proportion. Group 7 had by far the highest total number of utterances, with a total of 458 utterances, while group 9 had the lowest with only 100 utterances in total. The participants in group 7 also had some of the shortest average utterance times. The average utterance time for most participants differed from those of their other group members by less than half a second. Groups 1 and 4 are exceptions to this, where one participant speaks on average for much longer than the others.

The heatmaps for each group can be found in the appendix.

#### 4.4. Correlation

Table 5 shows the maximum probability that, after an interlocutor has performed a dominant action of one type, the interlocutor will perform another dominant action of another type (within a given time frame), and the corresponding time frame ( $TF$ ). Recall that the time frame refers to the time between a dominant action and another dominant action of a different type. The table also shows the time frame that provides 50% of the maximum probability. The arrows indicate which type of action occurs first (left) and which occurs later (right). The percentage ( $Max Pr.$ ) illustrates the probability that after the first dominant action a later dominant action is performed by the same interlocutor. Thus, there is a high correlation between participatory and quantitative dominance, and this correlation is established within one minute. There is also a low correlation between sequential dominance and participatory dominance. However, this correlation is established more quickly. Furthermore, sequential dominance and quantitative dominance are not correlated. Finally, note that the 50% probability is reached in less than 50% of the time of the maximum probability for all combinations except the probability of quantitatively dominant

	Seq $\rightarrow$ Part	Part $\rightarrow$ Seq	Seq $\rightarrow$ Quant	Quant $\rightarrow$ Seq	Part $\rightarrow$ Quant	Quant $\rightarrow$ Part
Max. Pr.	40.9%	21%	52.1%	2.5%	78.5%	61.6%
Max Pr. TF	43.80	46.7	0	26.8	46.9	58.9
50% Max. Pr. TF	17.50	15	-	5.4	4.60	23.30
Percentage TFs	39.95%	32.12%	-	20.15%	9.81%	39.56%

Table 5: Average maximal probability and corresponding time frame

actions after sequentially dominant actions.<sup>5</sup>

#### 4.5. Task Success

		Gr 1	Gr 2	Gr 3	Gr 4	Gr 5	Gr 6	Gr 7	Gr 8	Gr 9	Gr 10
	Time Taken (s)	683	742	1381	657	849	764	1997	1246	471	837
Task 2	1st Attempt	✓	✗	✗	✗	✓	✗	✗	✗	✗	✓
	2nd Attempt	-	✓	✗	✗	-	✓	✓	✓	✗	-

Table 6: Overview of Speed of Task Completion and Accuracy of Answers to Task 2

Table 6 shows the time taken for groups to complete all three tasks, as well as whether or not they successfully found the answer to task 2 within the two attempts they were given. The two fastest groups, 9 and 4, both incorrectly answered task 2 on both attempts, and therefore moved on after giving the answer. Group 1 was the fastest group that also correctly answered task 2. Group 7 was the slowest group by a significant margin of more than 10 minutes. Group 3 was the second slowest group, and also failed to answer task 2 correctly.

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<sup>5</sup>The data on the correlations of the different dimensions with respect to the groups is given in 7.9, 7.10 and 7.11.



## 5. Discussion

### 5.1. Correlation

Although there are correlations between the different dimensions of conversational dominance, the data suggests that these dimensions measure different characteristics of conversations that do not imply each other. Nevertheless, these dimensions are related, which supports an analysis of conversational dominance in terms of these measures. Furthermore, the fact that the 50% probability is reached less than 50% of the time suggests that these dimensions are closely related in time.

### 5.2. Sequential dominance

Each sequentially dominant action may resemble a moment when an interlocutor leads the discussion in the sense that they lead the pattern of the discussion. Furthermore, the pattern of these actions can be analysed according to different criteria. First, the distribution of dominant actions with respect to the interlocutor is essential. Secondly, the temporal distribution of these actions is important. For example, an even temporal distribution, where most of the dominant actions are performed by one interlocutor, indicates that this interlocutor leads the discussion and provides new input throughout the conversation.

### 5.3. Participatory dominance

In 4.2 we described several distributive patterns of actions revealing participatory dominance among participants within a group. We claim that these patterns can be analyzed as indicators of different modes of group dynamics. Specifically, pattern (1) in a group indicates that there is 1 participant clearly dominating or leading the group discourse. Pattern (2), on the other hand, signifies that 2 participants are competing for / sharing dominance over the conversational stage, while the absolute number of their dominant actions indicates the degree of competitiveness between them, this in general is potentially revealing a mode of dual leadership. Pattern (3), depending on the absolute number of all dominant actions, can signify several different dynamics. When the absolute number of dominant actions is high, it conveys a situation where all participants are highly competitive towards conversational dominance but none of them can secure it for a significant period. However, when this absolute number is low, it reveals a scenario where the competition to dominate the conversational stage is at a low level. This scenario can be somehow opaque, as it's possible that all conversational activities are organized in an orderly turn-switching manner, while it can also be the case that one participant is dominating and other participants are being cooperative, posing no challenge towards her dominance.

### 5.4. Quantitative Dominance

In 4.3 we observed a number of ways in which time spent speaking, number of utterances, and average utterance duration were distributed within groups. For ease of discussion, we will refer to the participant that speaks for the highest proportion of time as the "first speaker", the participant who speaks the second most as the "second speaker", and the participant who speaks the least as the "third speaker". In groups 1, 4, and 5 the difference between the proportion of speaking time taken by the first speaker and the second speaker is more than 10%, while the difference between the proportion of speaking time taken by the second speaker and the third speaker is less than half of the difference between the first and second. This is most distinct in group 1, where the difference between the first and second speaker was 30.7% and the difference between the second and third was just 8.7%. In groups 2, 3, and 10 the difference in proportion of speaking time between the first and second speakers was less than a third of the difference between the second and third speakers. In group 3, the first and second speakers differed by just 0.3%, while the second and third speakers differed by 18.9%. The final four groups can largely be categorised as having

very similar differences in speaking proportion between the first and second speakers and the second and third speakers, although we note that group 6 is somewhat of an edge case, as the difference between second and third speakers is only slightly above half that of the first and second. We also note that group 9 had the second highest difference between first and second speakers after group 1 at 20.6%. These three categories of speaking time distribution roughly describe three dynamics of quantitative dominance: a leader with fairly equal followers, two leaders and a follower, and a leader, a second, and a follower ("even hierarchy"). The utterance counts largely correlated with percentage speaking time with just a couple of exceptions. Similarly, average utterance duration also correlated with percentage speaking time, however in some groups the range of average utterance duration was just 0.08 seconds (group 6) and in others it was 1.69 seconds (group 1). From this observation we can understand that some participants who showed quantitative dominance still allowed other participants in their group to interject (demonstrating a higher level of interpersonal sensitivity), others spoke for much longer periods than their interlocutors. Finally, the heatmaps were useful in revealing two factors that were also identified by the other dominance metrics: chaos and competition. With a visualisation of how frequently turns are being taken and how long they are taken for, we could see how chaotic a discussion may have been, as well as identify which participants were competing for quantitative dominance and when.

## 5.5. *Discussion of individual cases*

### 5.5.1. *Group 9*

#### 5.5.1.1. *Sequential dominance*

Only movements of deictic reference to blocks were identified. These actions are evenly distributed over time and each interlocutor performs at least one sequentially dominant action, with the second participant performing several interlocutors within a short period of time (less than 30 seconds). Thus, each participant is temporally sequentially dominant, and these sequences of dominance are evenly distributed.

#### 5.5.1.2. *Participatory dominance*

The overall number of participatory-dominance actions is rather low (19). All 3 participants are identified to have a non-trivial number of actions revealing participatory dominance, but 78.9% of these actions are distributed among Participant 1 and Participant 3, while Participant 2 takes a smaller share of 21.1%. It's also noteworthy that participant 1 and 3 share their portion rather evenly, with the former taking 42.1% and the latter taking 36.8%. Therefore, although a limited number of participatory-dominance actions are shared by all participants, participants 1 and 3 form a more significant dyad dominating over the stage. This is close to the pattern (2) we described in 4.2.

#### 5.5.1.3. *Quantitative Dominance*

As discussed in 5.4, group 9 displays an "even hierarchy" pattern of distribution, with participant 3 speaking for more than half the time and participant 2 speaking for less than a fifth of the time. There was a 1.05s difference between the average utterance duration of participant 3 and participant 2. The heatmap for this group shows participant 1 speaking more at the beginning and end of the experiment, but speaking very little in the middle. Participant 3 largely holds dominance throughout, except for at the very beginning.

#### 5.5.1.4. *Overall*

Levels of participatory and sequential dominance were much more evenly distributed than quantitative dominance. However, that participants 1 and 3 held more participatory dominance than participant 2 aligns well with the hierarchy displayed by the quantitative dominance measures and particularly the heatmap, which shows participant 1 holding quantitative dominance at the

beginning of the discussion.

This was the fastest group to complete all three tasks, although it is worth noting that they did not correctly determine the answer to task 2.

### *5.5.2. Group 1*

#### *5.5.2.1. Sequential dominance*

Only movements of deictic reference to blocks and head movements were recorded for participant 1 and participant 3. Importantly, these actions were mostly performed by participant 1 within the first 200 seconds of the conversation. This suggests a conversation in which participant 1 is dominant and determines the patterns of the conversation at the beginning.

#### *5.5.2.2. Participatory dominance*

The overall number of participatory-dominance actions is close to the average (40). All 3 participants are identified to have actions revealing participatory dominance, but the percentage of share is significantly skewed to Participant 1, who takes up 62.5% of all actions revealing participatory dominance alone. More specifically, the majority of his participatory-dominance actions are identified by unsuccessful overlaps, revealing his firm control of the conversational stage. For the other 2 participants, participant 2 takes up 30%, and participant 3 shares only 7.5%. Thus participant 1 is the major role of participatory dominance in this group. This is close to the pattern (1) we described in 4.2.

#### *5.5.2.3. Quantitative Dominance*

This group displayed a pattern of distribution with a clear leader (participant 1) and a more even distribution between participants 2 and 3. Participant 1 had the greatest majority of speaking time compared to any other participant in any other group. Group 1 also had the greatest range in average utterance duration between participants, with participant 1 speaking for an average 4 seconds per utterance and participant 3 speaking for just 2.31 seconds on average. This suggests that participant 1 did not allow others to interrupt him, which is confirmed by the findings of participatory dominance. The heatmap for this group clearly demonstrates continuous dominance from participant 1 throughout the experiment.

#### *5.5.2.4. Overall*

The findings of all three dominance metrics align well here, showing that participant 1 held the highest level of dominance by all three metrics, followed by participant 3 and then participant 2.

This group was the fastest to complete all three tasks and answer task 2 correctly. Combining this with the findings of group 9, this suggests that having a clear leadership in the group is beneficial to task success. The two highest speaking time percentages of any participant were found in groups 9 and 1.

### *5.5.3. Group 7*

#### *5.5.3.1. Sequential dominance*

Each participant performs several dominant actions of each type. Furthermore, these action moments are densely distributed in time, with several participants performing dominant actions one after the other. Therefore, no participant can dominate the period sequentially for an extended period, indicating a chaotic conversation in which several participants compete for dominance.

#### *5.5.3.2. Participatory dominance*

The overall number of participatory-dominance actions is rather high in this group (103). All participants are identified to have a significant number of participatory-dominance actions, with a rather even gap between their individual shares. Participant 3 is taking the largest share (46.6%),

followed by participant 2 (32%). Participant 1 occupies a share of 21.4%. Temporally speaking, these actions by different participants are scattered along the process without one of them securing dominance over the conversation stage for a significant period. This may signify a competitive situation around participatory dominance. This is close to the pattern (3) with a high absolute utterance number we described in 4.2.

#### *5.5.3.3. Quantitative Dominance*

This group also displayed a clear even hierarchy. What was significant about this group was that they had by far the highest number of total utterances and some of the shortest average utterance durations of all the participants. The heatmap reflects this quite clearly, showing participants speaking in short bursts. There is a lot of back and forth between participants and the pattern of speaking is rather chaotic.

#### *5.5.3.4. Overall*

The hierarchy of dominance shown by the quantitative metrics aligns very well with the results of participatory dominance. Sequential dominance demonstrated high levels of chaos within the group, which was reflected well by the heatmap.

This was by far the slowest group to complete all three tasks. The high levels of chaos within the group dynamics is likely a key factor in this.

#### *5.5.4. Group 8*

##### *5.5.4.1. Sequential dominance*

Like Group 7, each participant performs several dominant actions, but the total number of dominant actions is lower. However, when one participant performs a dominant action, another participant performs a dominant action as well. Thus, several participants compete for dominance.

##### *5.5.4.2. Participatory dominance*

The overall number of participatory-dominance actions is at the average level (45). All participants are identified to have a non-trivial share of participatory-dominance actions: participant 1 has the largest share of 42.2%, while participants 2 and 3 evenly share the remaining portion (57.8% in total, 28.9% each). Compared to our observation of Group 9, they similarly have a pair of participants with roughly the same share of participatory-dominance actions, but the difference is that in Group 9, the pair is composed of the top 2 on the rank, while in Group 8 this pair is formed by the latter 2. Consequently, here in Group 8, the tendency of “a significant dyad of participatory dominance” is not obvious. There seems to be a more significant sole dominator (participant 1), but his dominance is not absolute and subject to challenges. Additionally from the temporal perspective, in the first half ( $< 600s$ ), all 3 participants are competitive with participatory-dominance actions, while in the latter half, only participants 1 and 3 remain as main competitors. Thus this group is more leaning toward pattern (3) with a lower absolute utterance number we described in 4.2.

##### *5.5.4.3. Quantitative Dominance*

This group had one of the smallest ranges in proportion of time spent speaking at just 16.55%. They also displayed an even hierarchy, and the range in average utterance duration was just 0.61s.

The heatmap for this group showed a fairly even distribution of turn taking with short-term quantitative dominance being transferred frequently between participants, particularly 1 and 3.

##### *5.5.4.4. Overall*

This case is interesting because the findings of the participatory dominance metrics did not match those of quantitative dominance. While participant 3 spoke for the majority of the time and for the longest per utterance, it was participant 1 who had the largest share of participatory dominance actions. However, the fact that the percentages for both participatory dominance actions and

speaking time were comparatively close together could account for this discrepancy to an extent.

This group was also one of the slowest to complete all three tasks.

#### *5.5.5. Group 6*

##### *5.5.5.1. Sequential dominance*

Only a small number of dominant actions are identified. Furthermore, these actions are evenly distributed in time and in terms of participants. Therefore, each participant dominates sequentially over time, and these sequences of dominance are evenly distributed.

##### *5.5.5.2. Participatory dominance*

The overall number of participatory-dominance actions is lower than average (33). The distributive pattern is similar to our observation for Group 9: all participants are identified to have a non-trivial share of participatory-dominance actions, with Participant 2 (42.4%) and Participant 3 (39.4%) taking up the major share (81.8%) while participant 1 has a lower share of (18.2%). Participants 2 and 3 form a more significant dyad in dominating the conversational stage. This is close to the pattern (2) we described in 4.2.

##### *5.5.5.3. Quantitative Dominance*

This was another even hierarchy group. It was also the group with the smallest range in average utterance length of just 0.06s. The heatmap for this group showed participant 2 largely maintaining dominance throughout, with some moments of continuous speaking from both participants 1 and 3 towards the end of the experiment.

##### *5.5.5.4. Overall*

The patterns observed by both the quantitative and participatory dominance metrics largely match up, but the sequential dominance metric suggests a more even distribution than was shown by the other two metrics. This group was the fifth fastest team to complete all the tasks.

## 6. Conclusion and future research

In this research, we’ve shown that several types of conversational dominance can be modeled quantitatively. Sequential dominance can be tracked with participants’ body movements and interpersonal imitative behaviors based on data annotations. Participatory dominance can be observed and presented through time windows where different participants compete for the control of the conversational stage. As for quantitative dominance, it can be revealed in utterance count and time percentage each participant occupies during the whole period of a conversation.

Furthermore, this research also cautiously claims that there are correlations between some types of conversational dominance discussed, especially from a temporal perspective. Specifically, there is a high correlation between participatory and quantitative dominance and a low correlation between sequential dominance and participatory dominance. Meanwhile, though correlations stated previously are confirmed, stable implications between them are not established.

Another important observation from case studies is that, for most groups, results from different types of dominance analysis collectively indicate a certain kind of group dynamics, which is further related to group performance. Overall, more successful groups are of 2 types: (1) While all participants have non-trivial shares of dominant actions, there are two participants evenly dividing the majority of dominant actions and the degree of inter-participant competitiveness is not very high, revealing a stable “dual-leadership” to some extent (e.g. Group 9); (2) There is obviously a main “dominator” (discussion leader) during the whole conversational process leading the entire task discussion (e.g. Group 1). Both types implicate the existence of a leadership. On the contrary, if all participants are highly competitive trying to dominate the conversational stage but no one can secure it (e.g. Group 7) or there is a potential major “dominator” but their status is open to challenges, still leading to a “all-competitive” situation (e.g. Group 8), the group performance can be negatively affected.

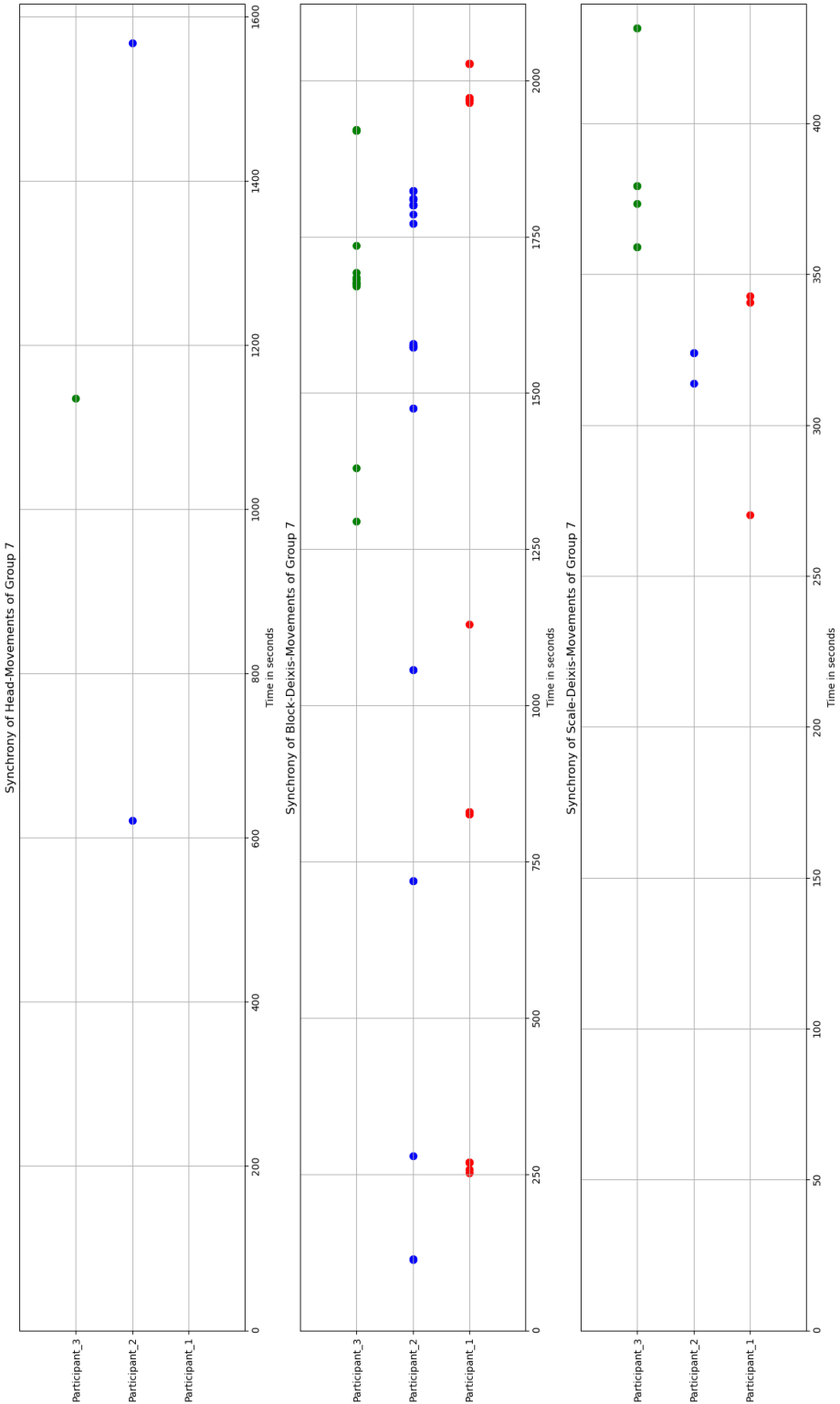
Due to the limited time frame, this research has some notable spaces for improvement that can be fulfilled in future research:

1. Widening of sequential dominance: First, the scope of sequential dominance is still limited. For example, linguistic phenomena such as imitation of token use and introduction of topics are important phenomena where integration of a computational approach capturing these phenomena (like provided in Duran et al. (2019)) needs further research. Furthermore, the analysis of body movements currently relies on manual annotations. However, a computational approach to determining body motion would potentially introduce inaccuracies caused by manual annotations.
2. Integration of many and limited data points: Our approach treats each dominant action equally. However, this can lead to undesirable and biased results. For example, the number of quantitatively dominant actions identified differs significantly from the number of sequentially dominant actions. This could have an impact on our correlation analysis. Therefore, an approach that tries to relax this imbalance in the number of dominant actions identified might lead to different insights into the correlation of the dimensions.
3. The current automatic detection for participatory-dominance actions based on transcribed texts is somehow simplistic. Although efforts are made to manually review some of the “suspicious” results extracted by this detection, they are limited and carried out by one group member only. In future research with a longer time frame, it would be ideal to organize a

full manual review for all extracted results based on video materials by a group of reviewers. The reviewers should first provide reviewing results independently, then at the second stage, they should strive for consensus case by case where independent reviewing results don't align. This improved process should provide more accurate data for participatory dominance.

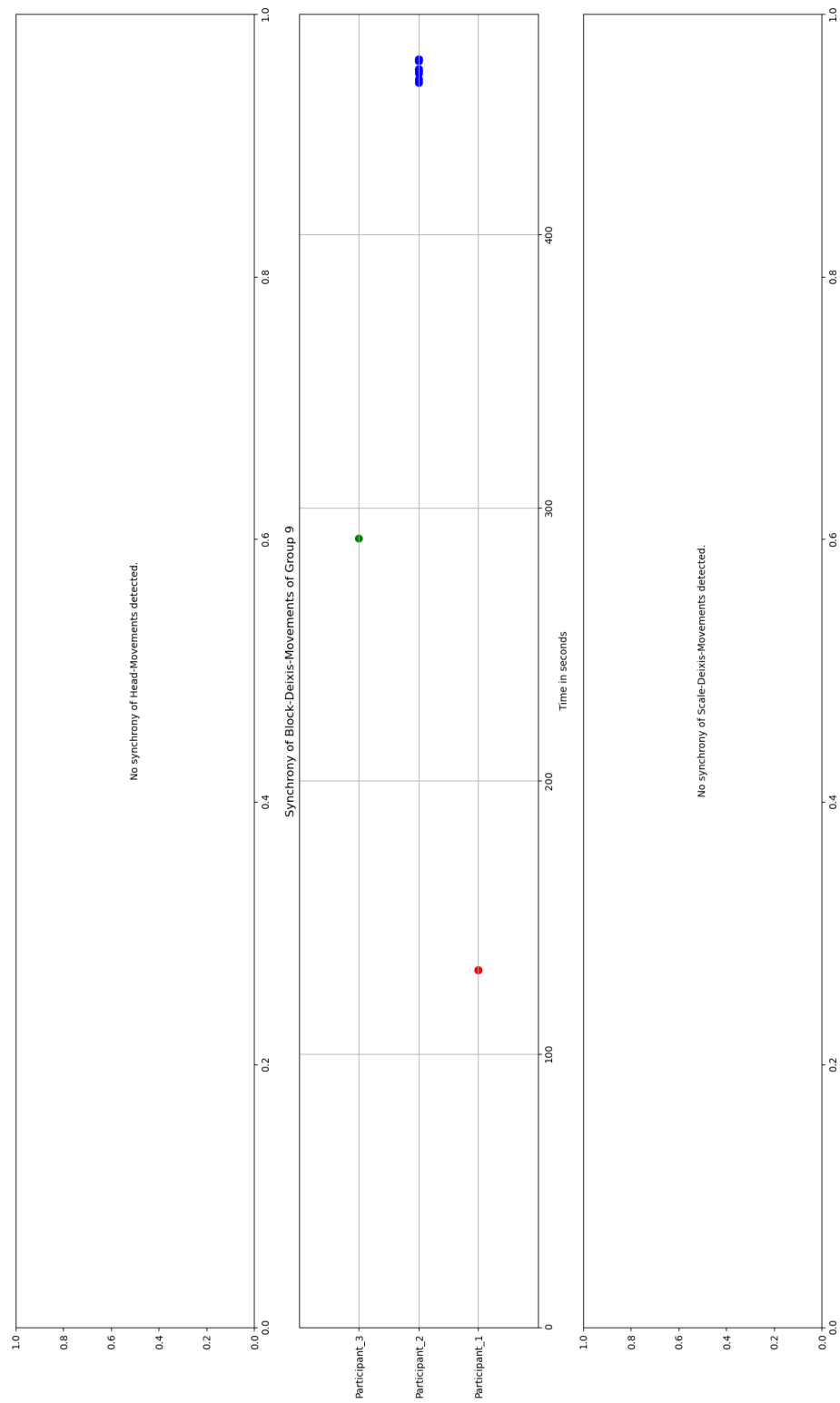
7. Appendix

7.1. Temporal distribution of sequentially dominant actions for Group 7

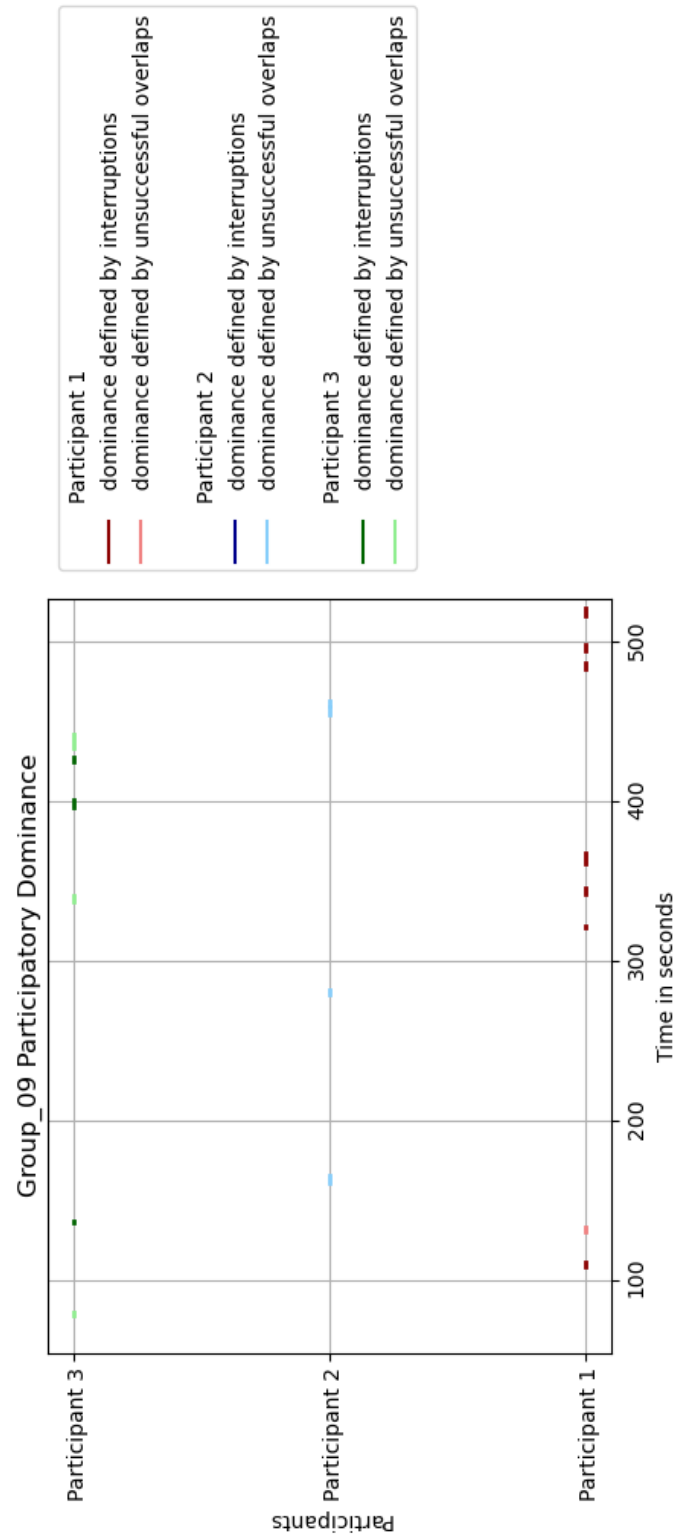




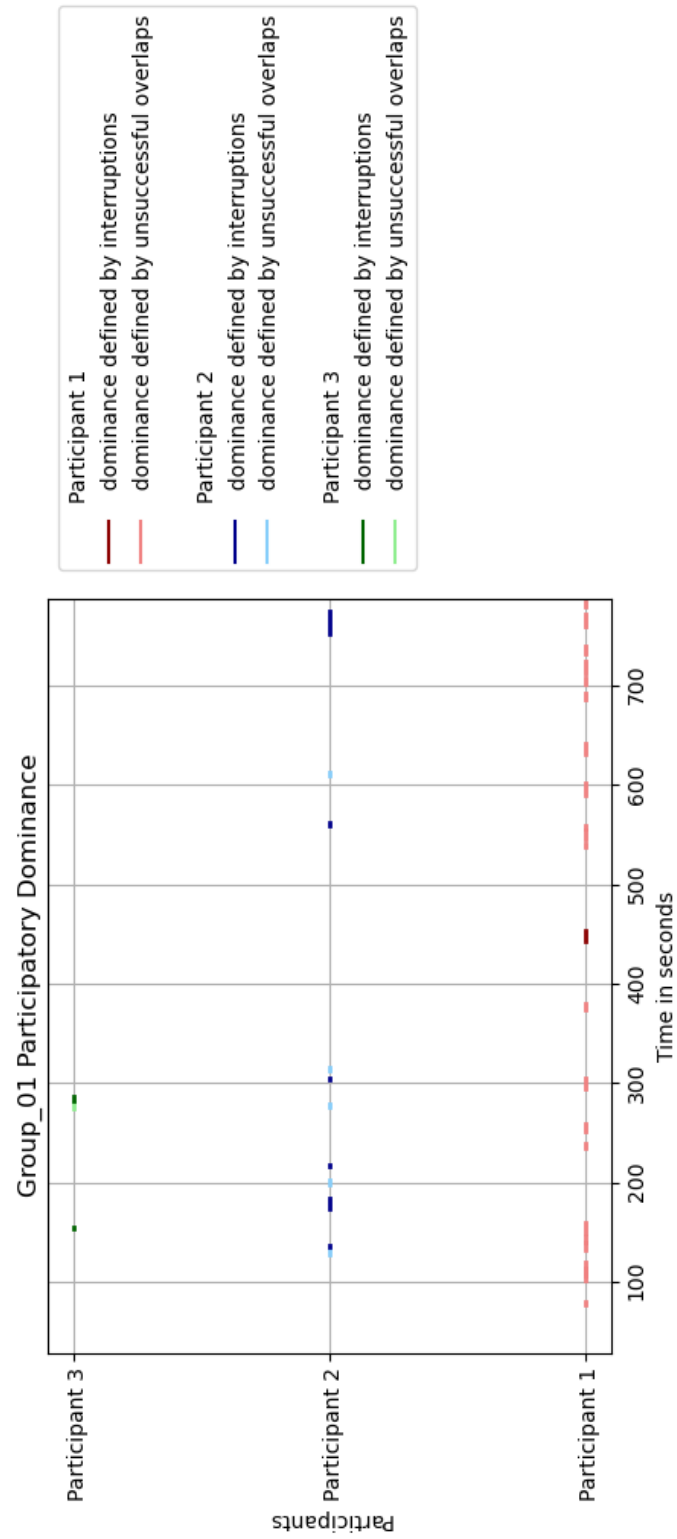
## 7.2. Temporal distribution of sequentially dominant actions for Group 9



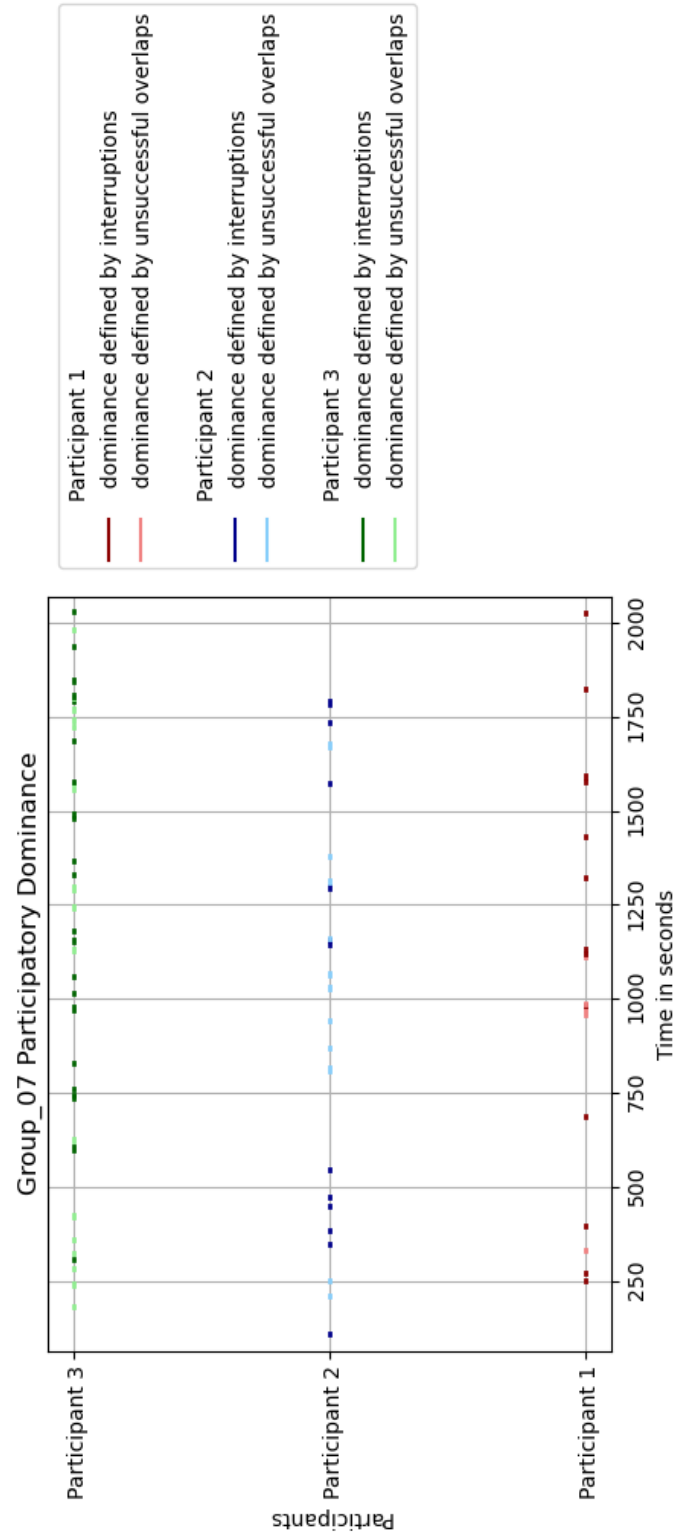
7.3. Temporal distribution of participatory - dominance actions for Group 9



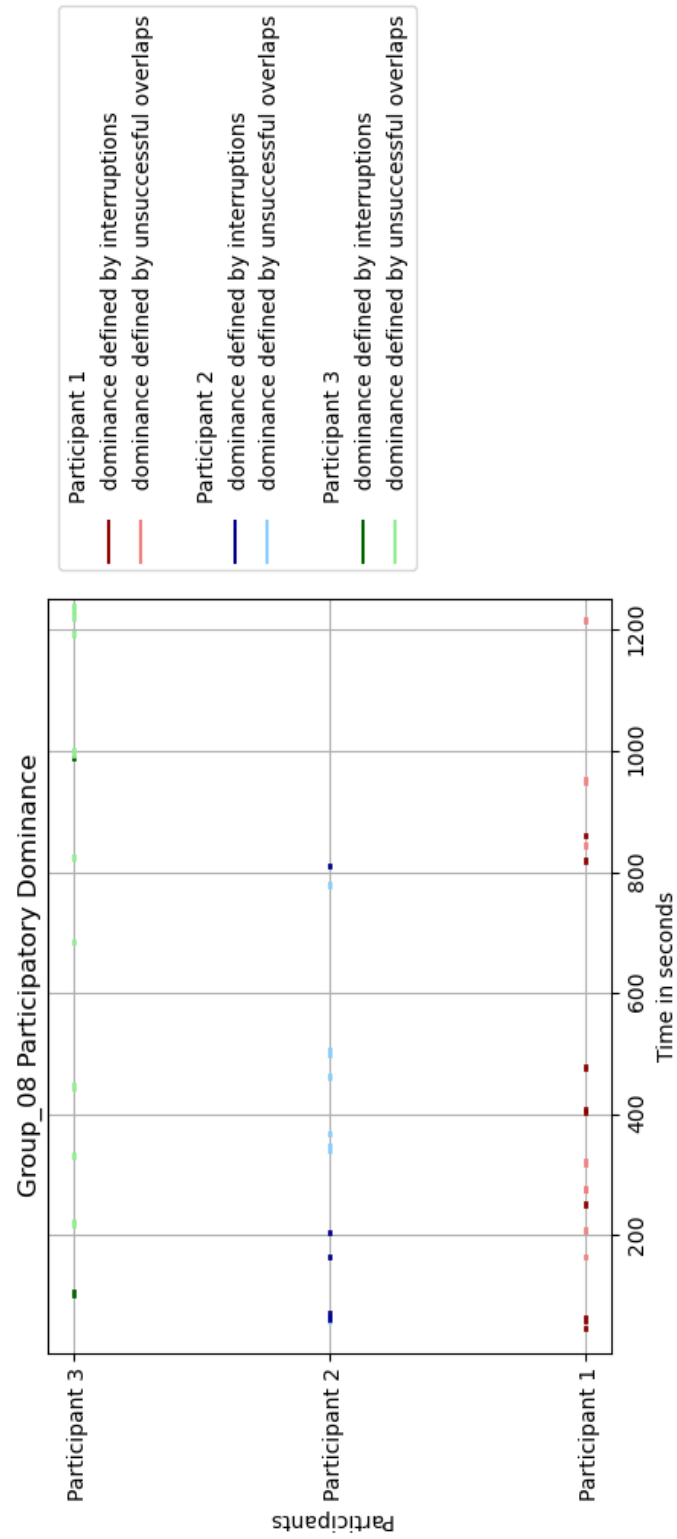
7.4. Temporal distribution of participatory - dominance actions for Group 1



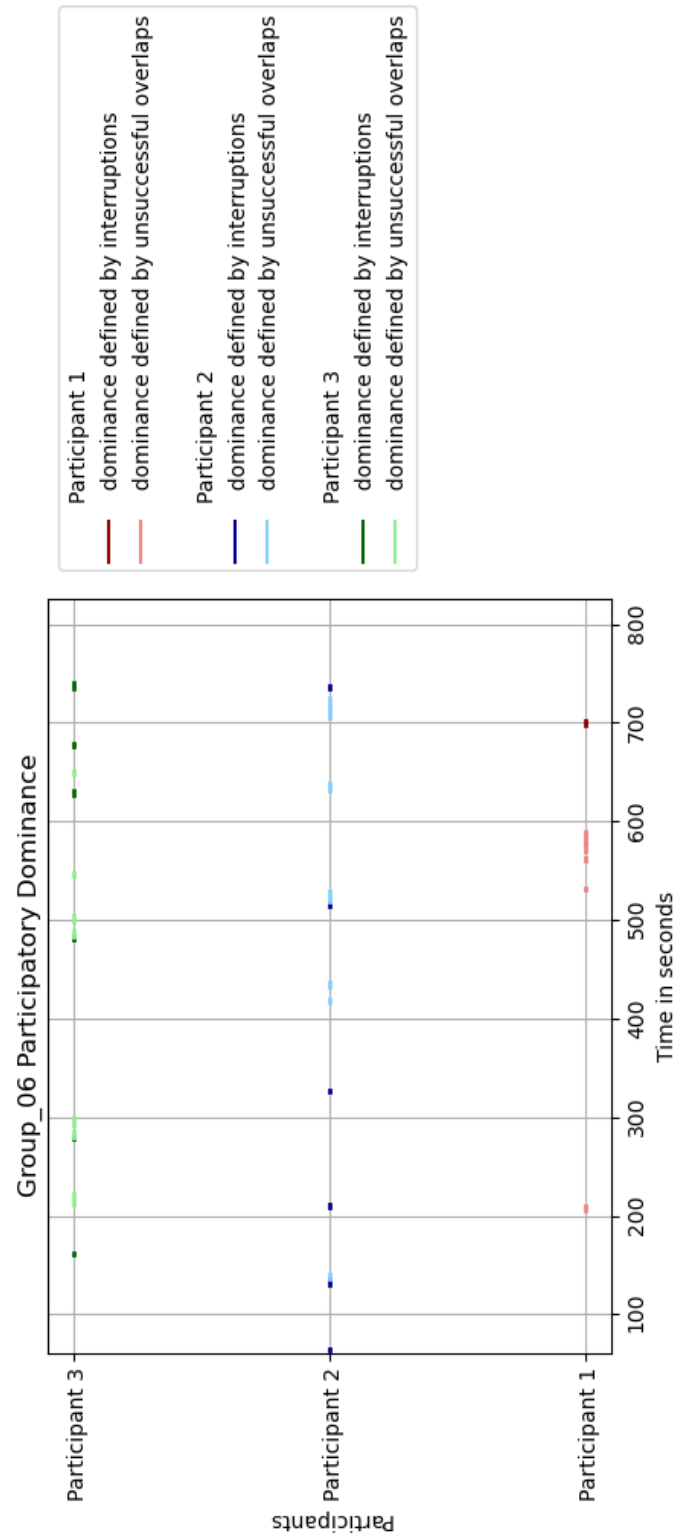
7.5. Temporal distribution of participatory - dominance actions for Group 7



7.6. Temporal distribution of participatory - dominance actions for Group 8



7.7. Temporal distribution of participatory - dominance actions for Group 6



## 7.8. Heatmaps displaying Quantitative Dominance

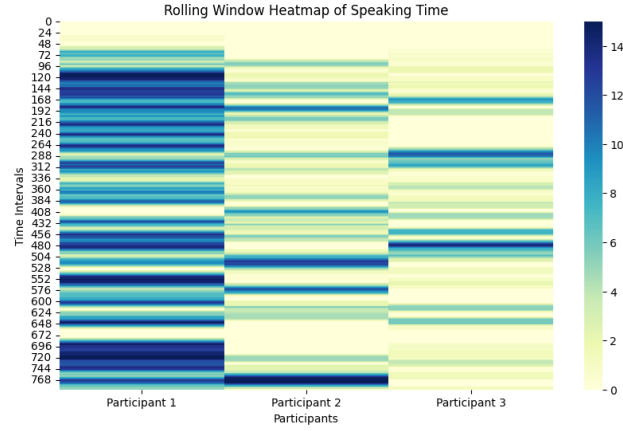


Figure 1: Group 1

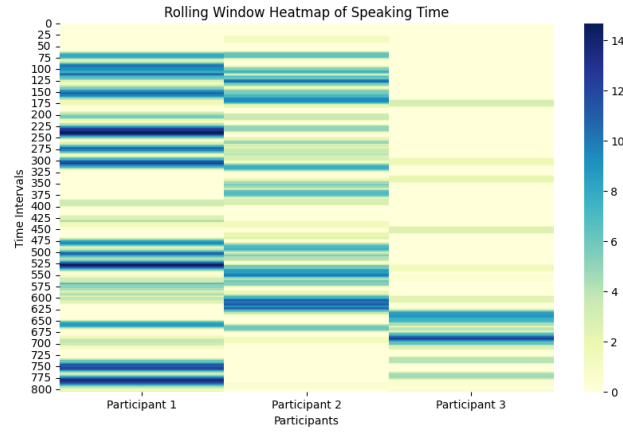


Figure 2: Group 2

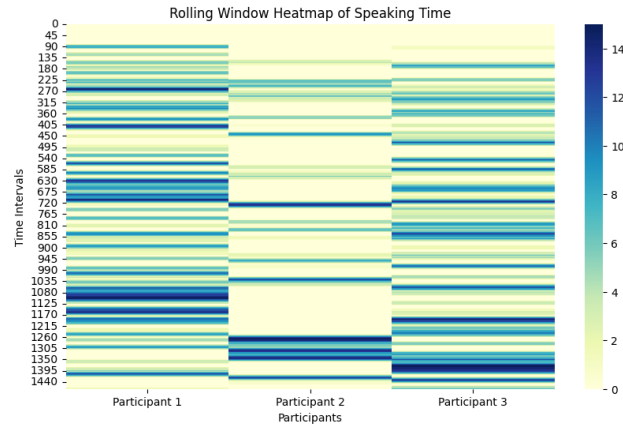


Figure 3: Group 3

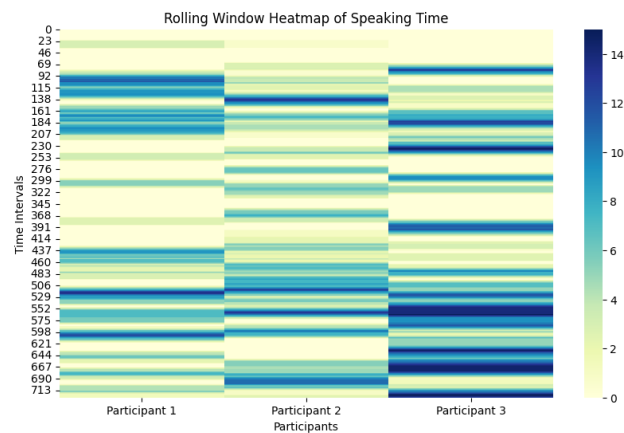


Figure 4: Group 4

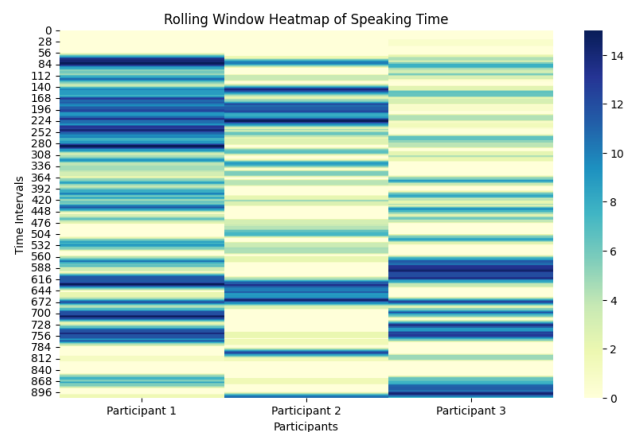


Figure 5: Group 5

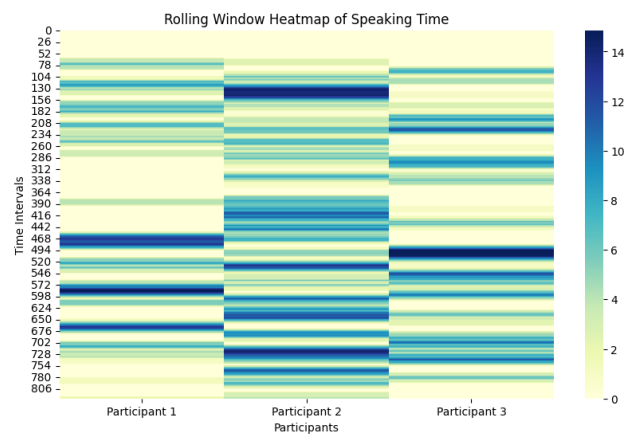


Figure 6: Group 6



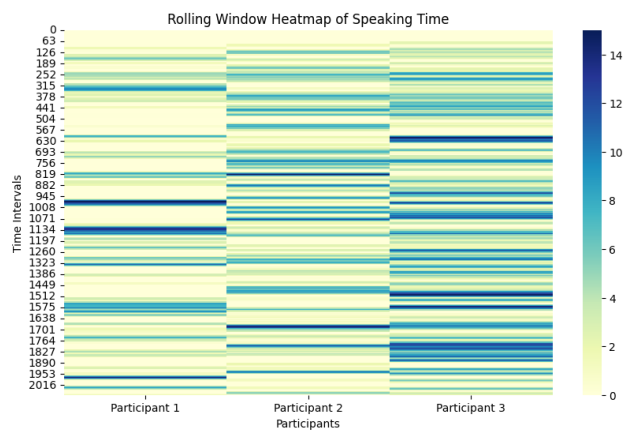


Figure 7: Group 7

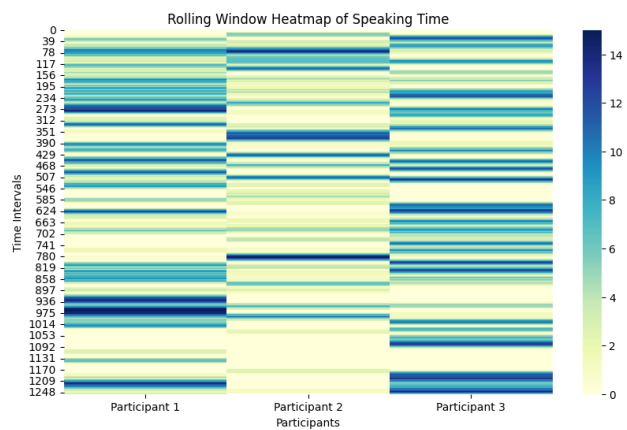


Figure 8: Group 8

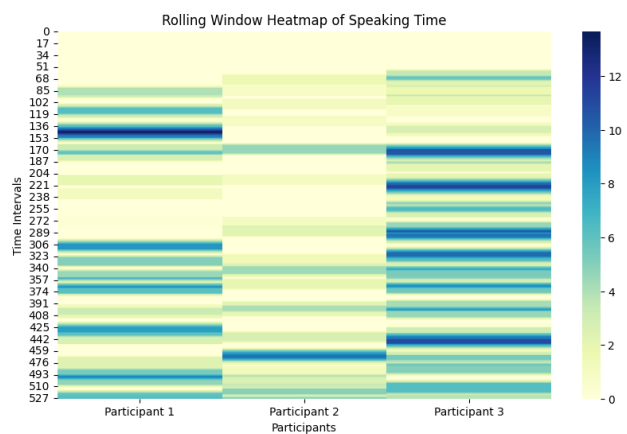


Figure 9: Group 9

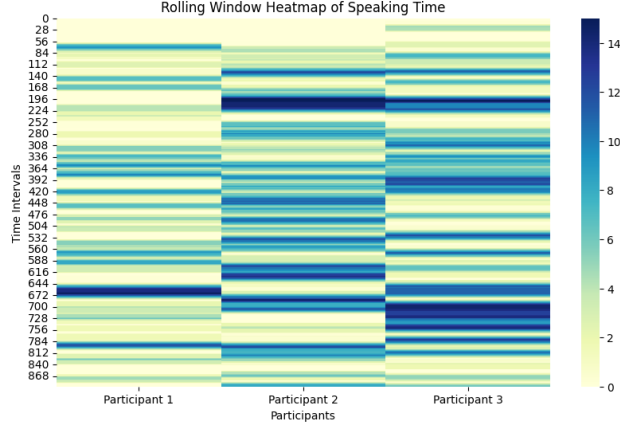


Figure 10: Group 10

### 7.9. Data on the correlation of sequential dominance and participatory dominance

	sequential dom. → participatory dom.				participatory dom. → sequential dom.			
	Max. Pr.	Max Pr. TF	Max Pr. 50% TF	TFs%	Max Pr.	Max Pr. TF	Max Pr. 50% TF	TFs %
Gr 1	19.4%	40	6	15%	30.8%	50	24	48%
Gr 2	72.7%	42	38	90.48%	10%	45	33	73.33%
Gr 3	20%	21	16	76.19%	16.1%	55	16	29.09%
Gr 4	60%	45	29	64.44%	20.7%	48	3	6.25%
Gr 5	29.1%	54	12	22.22%	20.8%	48	25	52.08%
Gr 6	37.5%	55	20	36.36%	18.8%	44	2	45.45%
Gr 7	39%	60	17	28.33%	31.6%	56	11	19.64%
Gr 8	41%	30	18	60%	26.2%	49	26	53.06%
Gr 9	25%	49	4	8.16%	22.2%	23	1	4.35%
Gr 10	65%	42	15	35.71%	13.2%	49	9	18.37%
AVG	40.9%	43.8	17.5	39.95%	21%	46.7	15	32.12%

7.10. *Data on the correlation of sequential dominance and quantitative dominance*

	sequential dom. → quantitative dom.				quantitative dom. → sequential dom.			
	Max. Pr.	Max Pr. TF	Max Pr. 50% TF	TSs %	Max Pr.	Max Pr. TF	Max Pr. 50% TF	TFs %
Gr 1	30.6%	0	-	-	1.4%	1	1	100%
Gr 2	72.7%	0	-	-	2.1%	2	1	50%
Gr 3	40%	0	-	-	1.8%	44	1	2.27%
Gr 4	60%	0	-	-	2%	28	1	3.57%
Gr 5	32.7%	0	-	-	3%	25	1	4%
Gr 6	62.5%	0	-	-	1.4%	32	25	78.13%
Gr 7	50.8%	0	-	-	6.1%	57	9	15.79%
Gr 8	51.3%	0	-	-	2.9%	35	8	22.86%
Gr 9	50%	0	-	-	2.7%	1	1	100%
Gr 10	70%	0	-	-	1.1%	43	6	13.95%
AVG	52.1%	0	-	-	2.5%	26.8	5.4	20.15%

7.11. *Data on the correlation of participatory dominance and quantitative dominance*

	participatory dom. → quantitative dom.				quantitative dom. → participatory dom.			
	Max. Pr.	Max Pr. TF	Max Pr. 50% TF	%	Max Pr.	Max Pr. TF	Max Pr. 50% TF	TFs %
Gr 1	71.8%	22	1	4.55%	81.2%	60	18	30%
Gr 2	80%	43	2	4.65%	64.1%	55	29	52.73%
Gr 3	83.9%	38	5	13.16%	38.1%	60	38	63.33%
Gr 4	79.3%	49	3	6.12%	61.3%	56	25	44.64%
Gr 5	62.5%	56	1	1.79%	73.5%	60	18	30%
Gr 6	87.5%	42	5	11.90%	58.1%	60	23	38.33%
Gr 7	67.3%	58	8	13.79%	68.1%	60	20	33.33%
Gr 8	92.9%	57	5	8.77%	46.3%	60	18	30%
Gr 9	77.8%	45	8	17.78%	42%	58	26	44.83%
Gr 10	81.6%	59	8	13.56%	83.6%	60	18	30%
AVG	78.5%	46.9	4.6	9.81%	61.6%	58.9	23.3	39.56%

7.12. *The full documentation of materials*

All the processing codes, files produced, and final results are stored at [this link](#).

## References

- Burgoon, J. K., Manusov, V., & Guerrero, L. K. (2021). *Nonverbal communication*. Routledge.
- Dale, R., Bryant, G. A., Manson, J. H., & Gervais, M. M. (2020). Body synchrony in triadic interaction. *Royal Society open science*, 7(9), 200095.
- Dindar, M., Järvelä, S., Ahola, S., Huang, X., & Zhao, G. (2022). Leaders and followers identified by emotional mimicry during collaborative learning: A facial expression recognition study on emotional valence. *IEEE Transactions on Affective Computing*, 13(3), 1390–1400.
- Duran, N. D., Paxton, A., & Fusaroli, R. (2019). Align: Analyzing linguistic interactions with generalizable techniques—a python library. *Psychological methods*, 24(4), 419.
- Hale, J., Ward, J. A., Buccheri, F., Oliver, D., & Hamilton, A. F. d. C. (2020). Are you on my wavelength? interpersonal coordination in dyadic conversations. *Journal of nonverbal behavior*, 44, 63–83.
- Itakura, H. (2001). Describing conversational dominance. *Journal of Pragmatics*, 33(12), 1859–1880.
- Jayagopi, D. B., Hung, H., Yeo, C., & Gatica-Perez, D. (2009). Modeling dominance in group conversations using nonverbal activity cues. *IEEE Transactions on Audio, Speech, and Language Processing*, 17(3), 501–513.
- Khebour, I., Brutti, R., Dey, I., Dickler, R., Sikes, K., Lai, K., Bradford, M., Cates, B., Hansen, P., Jung, C., Wisniewski, B., Terpstra, C., Hirshfield, L., Puntambekar, S., Blanchard, N., Pustejovsky, J., & Krishnaswamy, N. (2023, December). The Weights Task Dataset: A Multimodal Dataset of Collaboration in a Situated Task. <https://doi.org/10.5281/zenodo.10252341>
- Klug, M., & Bagrow, J. P. (2016). Understanding the group dynamics and success of teams. *Royal Society open science*, 3(4), 160007–160007.
- Lehmann-Willenbrock, N., Chiu, M. M., Lei, Z., & Kauffeld, S. (2017). Understanding positivity within dynamic team interactions : A statistical discourse analysis.
- Lehmann-Willenbrock, N., & Chiu, M. M. (2018). Igniting and resolving content disagreements during team interactions: A statistical discourse analysis of team dynamics at work. *Journal of organizational behavior*, 39(9), 1142–1162.
- Licorish, S. A., da Costa, D. A., Zolduoarrati, E., & Grattan, N. (2024). Relating team atmosphere and group dynamics to student software development teams’ performance. *Information and software technology*, 167, 107377–.
- Manusov, V., & Patterson, M. L. (2006). *The sage handbook of nonverbal communication*. Sage.
- Paggio, P. (2016). Coordination of head movements and speech in first encounter dialogues. *Proceedings from the 3rd European Symposium on Multimodal Communication, Dublin, September*, 69–74.
- Patrick Bourgeois, U. H. (2008). The impact of social context on mimicry. *Biological Psychology*, 77, 343–352.
- Richardson, B. H., McCulloch, K. C., Taylor, P. J., & Wall, H. J. (2019). Cooperation link: Power and context moderate verbal mimicry. *Journal of Experimental Psychology: Applied*, 25(1), 62–76.
- Rick van Baaren, T. L. C., Loes Janssen, & Dijksterhuis, A. (2009). Where is the love? the social aspects of mimicry. *Philosophical Transactions: Biological Sciences*, 364(1528), 2381–2389.
- Rienks, R., & Heylen, D. (2005). Dominance detection in meetings using easily obtainable features. *International Workshop on Machine Learning for Multimodal Interaction*, 76–86.

- Rienks, R., Zhang, D., Gatica-Perez, D., & Post, W. (2006). Detection and application of influence rankings in small group meetings. *Proceedings of the 8th International Conference on Multimodal interfaces*, 257–264.
- Shazia Akbar Ghilzai, M. B. (2016). Conversational analysis of turn taking behavior and gender differences in multimodal conversation. *Perspectives in Language, Linguistics and Media*, 1, 1–13.