Meeting Mediator: Enhancing Group Collaboration using Sociometric Feedback

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ABSTRACT
We present the Meeting Mediator (MM), a real-time portable system that detects social interactions and provides persuasive feedback to enhance group collaboration. Social interactions is captured using Sociometric badges [17] and are visualized on mobile phones to promote behavioral change. Particularly in distributed collaborations, MM attempts to bridge the gap among the distributed groups by detecting and communicating social signals. In a study on brainstorming and problem solving meetings, MM had a significant effect on overlapping speaking time and interactivity level without distracting the subjects. The Sociometric badges were also able to detect dominant players in the group and measure their influence on other participants. Most interestingly, in groups with one or more dominant people, MM effectively reduced the dynamical difference between co-located and distributed collaboration as well as the behavioral difference between dominant and non-dominant people. Our system encourages change in group dynamics that may lead to higher performance and satisfaction. We envision that MM will be deployed in real-world organizations to improve interactions across various group collaboration contexts.

Author Keywords
CSCW, Social visualization, Meeting support, Sociometric sensors, Dominance

ACM Classification Keywords
H.5.3 Group and Organization Interfaces: Computer-supported cooperative work

Figure 1. The Meeting Mediator: Sociometric badges (right bottom) capture group dynamics which is displayed as real-time feedback on mobile phones (left top).

INTRODUCTION AND RELATED WORK
Social scientists have long been interested in small group collaboration, trying to answer questions such as: How can we assist groups to be more effective? Why do distributed groups and co-located groups perform differently? What impact does dominant behavior have on group dynamics and performance? Group dynamics have been the focus of increasing interest as they are a key factor affecting the performance and satisfaction of the group [22]. Shaw defines group dynamics as the activities, processes, operations, changes, interdependencies, and interrelationships that transpire in social groups. Feedback on group dynamics has been proven to help participants modify their behaviors, which may lead to higher satisfaction and performance [23]. Hence methods for accurate group dynamics measurement and persuasive feedback provision are critical issues to be solved. Scholars across many disciplines have studied these questions using different approaches. Traditionally, sociologists have employed human observers or surveys to understand group dynamics for successful intervention, but data acquired by these methods are inevitably subjective and not in micro scale or real-time. There have been efforts to use computational methods to understand and enhance group dynamics. Bergstrom and Karahalios used audio volume to show the interaction history of the participants on table tops [5], while DiMicco et al. detected participants' speaking time and visualized the information on a large shared display. These systems have demonstrated the potential benefits of feedback on group dynamics [9]. However, these systems only capture one aspect of speech, which is a limited representation of the group's social interaction. Furthermore, public displays are not optimal because they are not always available for ad-hoc meetings, and their public nature may cause discomfort to users [10] .

Distributed collaboration has become an indispensable form of communication in today's global society. Hinds and Bailey [13] have demonstrated that distributed collaboration may have very different dynamics compared to co-located collaboration, and that these differences often lead to poorer performance. Many researchers have tried to overcome the limitations of distributed collaboration by augmenting communication with additional channels such as voice, chat and video [18, 24, 27]. Yankelovich [30] verified the benefit of high audio quality on users' subjective rating of quality and social presence; however, the gain was offset by larger costs. Additional to the disadvantage of cost, Mark and her colleagues found that these added communication channels often cause distraction to the users [15]. They also discovered that even with rich communication channels participants still pay less attention to the group dynamics when distributed compared to when the group was co-located. One of the solutions suggested by Mark et. al was to include an extra member whose explicit role was to facilitate the meeting. However, when human resources are precious, employing an additional member is usually not a viable option. Hence an automated real-time facilitation may be an affordable alternative option.

Dominant behavior is a key determinant in the formation of a group's social structure, and consequently group dynamics [3]. A dominant participant may have a negative effect on group's dynamics by discouraging participation of other members or imposing their thoughts on the whole group [7]. However, we believe dominance is not necessarily an undesirable behavior. This behavioral characteristic can also be referred as "protagonistic" as in [2], since dominance is also a necessary characteristic of a successful mediator who balances participation and derives consensus for better performance [1]. However for the scope of this paper, we use the term "dominance" to express the protagonistic character of a participant. In our surveys for this experiment, we intentionally omitted the word "dominance" to avoid confusion with the traditional negative connotation. Measuring dominance has not been easy as it is a purely subjective measure, leaving only post-surveys (self-evaluation or peer review) as possible methods. Recommending change of behavior based on these subjective measurements is often socially unacceptable or offensive to individuals. Furthermore, dominance and its influence changes when groups are distributed [7]. This leads us to question the relationship between dominance and group dynamics and how that effects group performance. Only when we better understand this relationship can we provide appropriate interventions for performance improvement.

To address these various limitations, we created the Meeting Mediator (MM), a system which provides real-time feedback on group dynamics data collected by Sociometric badges [17]. The badge can collect unbiased and richer data than traditional methods by sensing body movement, proximity to other badges, and speech characteristics such as speaking speed and tone of voice. By visualizing this data in real-time on the mobile phone of each user, our system encourages changes in group collaboration patterns by using persuasive computing methods [12]. During a meeting, the phone display is intended to be in the periphery of the user's attention to minimize distraction [28]. Distributed collaboration support starts with detecting the proximity data of the wearers. Knowing how the group is distributed, MM attempts to bridge the gap by detecting and communicating social signals from one side of the group to the other distributed participants. MM also detects dominance expressed through non-verbal cues and its effect on other participants. This allows us to understand the effect of dominance on performance and other group members.

In the following sections we describe the MM system in further detail. First we present the system description of MM and the design of the feedback. Next we explain the design of the controlled study and the measures that we used. Finally we present the findings from the evaluation, and the effect of MM and dominance on group dynamics in different meeting situations.

SYSTEM DESCRIPTION

Sociometric badges

The Sociometric badge (figure 1) is an electronic sensing device that collects and analyzes social behavioral data. It is intended to be worn around one's neck allowing voice capture and IR transmission and reception [17]. Its current capabilities include:

- Extracting speech features in real-time to measure non-linguistic social signals: The badge does not record any speech content, but is capable of identifying social signals such as enthusiasm, interest level, persuasiveness [19] and nervous energy [25] of the user. Turn taking or short affirming phrases reveal social dynamics that can be measured through synchronization of multiple badges.
- Measuring body movement using a single 3-axis accelerometer: This can detect individual activities such as gesturing, walking, and sitting as well as social interactions such as body movement mimicry or rhythmic patterns.
- Detecting proximity data using a 2.4 GHz radio or Bluetooth to understand the relational distance and position of multiple wearers: This function can be used to detect the distribution of group members.
- Capturing and identifying face-to-face interaction using an IR sensor: By detecting the face-to-face alignment of individuals we are able to detect encounters as well as postural direction.
- Real-time sending and receiving of information over 2.4GHz radio to and from different users and base stations for real-time communication: The data transfer between individuals can be both on a one-to-one level or initiated by a central server to obtain data from the whole network.
- Performing indoor user localization by measuring received signal strength from fixed based stations.
- Communicating with Bluetooth enabled devices such as mobile phones or Bluetooth headsets: Coupling with other commercial devices allow flexibility in output channels.

In organizations, group collaborations are not always preplanned: groups of varying sizes are dynamically formed for unpredictable durations. Sociometric badges can detect these various social situations and autonomously provide real-time feedback. However, for the purpose of this paper we examine the effect of MM on meeting dynamics by conducting a controlled study where the number of participants was fixed for the full duration of the meeting. Thus we analyze only the speech features and body movement features of the Sociometric badge data to analyze collaboration dynamics.

Visualization on mobile phones

MM's mobile phone application was developed for J2ME-enabled smart phones with Bluetooth. Each participant is provided with one mobile phone and one Sociometric badge that are paired via Bluetooth. The four badges communicate their wearer's speaking and movement status to each other over the 2.4GHz radio.

The phone visualization is designed for certain types of collaborations for which balanced participation and high interactivity is desirable. Being a persuasive and peripheral interface, it encourages participants to change their behavior in a direction beneficial to group collaboration. Each of the four participants is represented as colored squares in the corners of the screen (figure 2). In the user study, the square colors were identical to the color of each participant's badge and seat. The color of the central circle gradually shifts between white and green to encourage interactivity, with green corresponding to a higher interactivity level. Balance in participation is displayed through the location of the circle: the analogy is such that the more a participant talks, the stronger they are pulling the circle closer to their corner. We further promote balanced speech by displaying each member's speaking time through the thickness of the line connecting the central circle with each member's corner. The visualization is updated every 5 seconds and can be re-initialized every time a new meeting session starts. The data is accumulated throughout the meeting, showing the accumulated group dynamics from the start of the meeting to the current time.

The phones are on the table facing each user, intended to be in the periphery of the user's attention. The display updates gradually so that it does not require constant attention from the user. Text and small details were also purposefully avoided so that a mere glimpse would be sufficient for information retrieval. The display is designed to be viewed occasionally for most cases. Only an extreme change in the group dynamics will draw the user's immediate attention.

THEORY AND HYPOTHESES

Management science has identified the most common collaboration challenges to be social loafing (individuals making less effort when working in a group), production blocking (over-participators monopolizing the floor), and incomplete information exchange [6, 8]. We believe that MM can address these challenges by tracking group dynamics in real-time and promoting change in individual and group behavior.

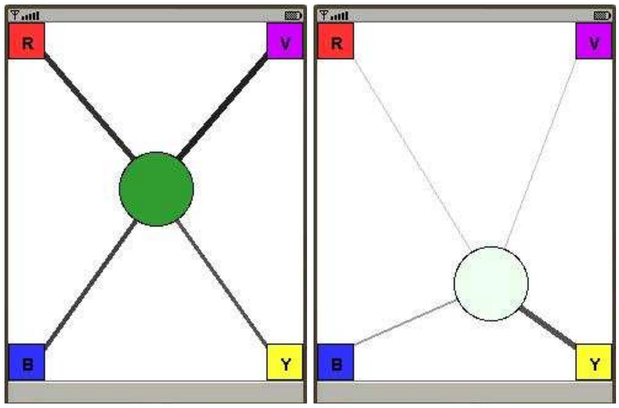


Figure 2. Visualization on the phone emphasizes balance and interactivity in group collaborations: balanced and highly-interactive (left) or un-balanced and less-interactive (right). Circle color denotes group interactivity level, circle position denotes balance in participation, and line thickness denotes speaking time.

Effects of MM

MM phone interface motivates speech by visualizing the absolute amount of talking per person through the thickness of the lines between the circle and the corner representing each participant. Hence, we hypothesize that MM will encourage meeting participants to speak more. Secondly, by the color of the center circle, MM will encourage participants to be more interactive. We define interactivity as the frequency with which the main speaker changes; i.e., shorter speech segments corresponds to higher interactivity. Lastly, we hypothesize that MM, as a peripheral and personal display, will not be a source of discomfort the the participants. We use post-task surveys and bodily nervous energy to estimate the distraction level [25]. We therefore expect that the movement energy and its variation will not show significant difference between participants with MM and participants without it.

H1. *MM will encourage more speaking*

H2. *MM will motivate groups to have higher interactivity*

H3. *MM's phone interface is not distracting*

Effects of Dominance

Since dominance has a strong influence on group dynamics and performance, we want to be able to accurately detect dominance to further understand this phenomenon and provide insight into how to improve group efficiency. Dominance has been suggested to be communicated through subtle social signals [16]. Levine has reported typical behavior of dominant people as: standing up straight; maintaining eye contact; being physically and verbally intrusive; speaking more often than others; and being spoken to more often than others [14]. Some of these behaviors are social signals that can be easily detected by the Sociometric badge. Therefore we hypothesize that MM can identify individuals showing dominant characteristics.

Another interesting phenomenon verified by previous studies is mood contagion from dominant people to other members of the group. For example, when leaders are in a positive mood, group members also experience positive mood and acquire positive tone and more coordination [26]. Mood is communicated via facial, vocal and postural cues; thus, behavioral data can be used to keep track of work group moods as well as traditional method of self-reported moods [4]. We can identify the dominant person's influence on non-dominant people.

H4. *MM can identify dominant individuals*

H5. *MM can identify the dominant person's influence on non-dominant people*

Interaction between MM and Dominance

Hinds and Bailey [13] verified that groups behave differently when they are distributed compared to when they were co-located. Moreover, Rosa and Mazur [21] found that groups signal social information, such as dominance, differently when they are distributed compared to when all members were face-to-face. MM detects major social signals that occur during collaboration, such as speaking style and body movement. In distributed collaborations where many social signals are lost, the communication is further hindered since people pay less attention to the remaining social signals [15]. By augmenting these lost and weakened social signals through feedback, MM may reduce the behavioral difference between distributed groups and co-located groups.

Secondly, since mood contagion is communicated through social signals, we hypothesize that MM,by augmenting and emphasizing the social signals, will strengthen this mood contagion. A denser communication of these social signals will lead to stronger mood contagion effect, thus reducing the difference between dominant people and non-dominant people.

H6. *MM will reduce the difference between co-located and distributed collaboration*

H7. *MM will reduce the difference between dominant people and non-dominant people*

EVALUATION

Participants

To evaluate our hypotheses, we conducted a study of 36 groups of four subjects each, a total of 144 participants (71 male, 73 female, mean age 27.7). Subjects were recruited on a university campus and through public internet message boards and were given monetary compensation for their time. As the groups collaborated on a task, a sociometric badge was provided to all subjects to measure the group dynamics. Due to microphone failure in one badge, one participant's audio features were not recorded for 13 out of the 36 groups. Since we cannot compare the internal group dynamics calculated using 3 people to that calculated using 4 people, we chose to randomly discard one person's audio data from groups with no audio failure. This was based on the assumption that data from three participants can sufficiently represent the dynamics of a group of 4 people. To verify the assumption, we have correlated the group dynamics calculated using 4 badges to the group dynamics calculated from the 3 randomly selected badges. The correlation value for each voice feature is shown in Table 1 (N=23). The high correlation values indicate that three person's data of a group is linearly scaled with that of four people, hence being a sufficient represenatation of the whole group's dynamics. In the following sections voice features of all groups are calculated using 3 of the 4 participants' data.

	Correlation value (N=23)
Total speaking time	0.99
Overlap speaking time	0.96
Turn taking per second	0.88
Average length of speech	0.92
Average speaking energy	0.91
Average speaking speed	0.90

Table 1. We verify that 3 people's data is sufficient in representing the dynamics of 4 people group. Table shows the correlation of data calculated with 3 people data to that data calculated with 4 people data for each voice feature.

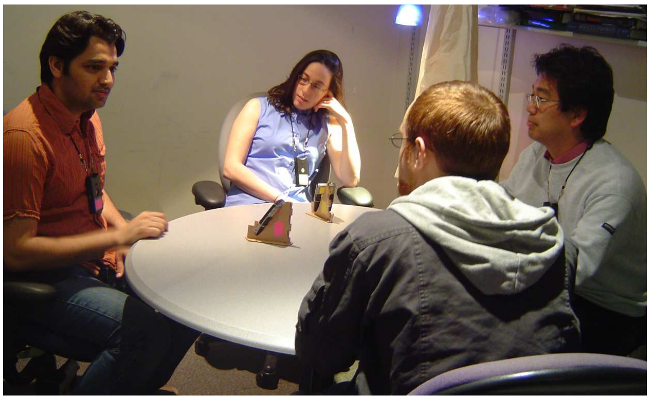


Figure 3. The experimental setup: Four subjects participate in brainstorming and problem-solving meetings wearing Sociometric badges.

Tasks and procedures

To verify the effects of MM, we performed a between-subject experiment comparing 18 groups with MM feedback on their mobile phones (experimental condition) to 18 groups without mobile phones (control condition). Each team began with one short practice task for which no score was recorded, and then performed two scored tasks. In one task, which we call the co-located case, all four participants were co-located having all audio and video communication available. In the other task, which we call the distributed case, the group was divided into pairs and a conference call setting was simulated by having a curtain between the two pairs. The sequence of co-located and distributed case were counter balanced to eliminate learning effects.

We chose to evaluate two meeting types in our experiment, brainstorming and problem solving, to encompass common meeting purposes [20]. The task given to subjects was based

Task 1 Co-located
Brainstorming phase (8 minutes)
Problem Solving phase (10 minutes)
—- Post-task questionnaire
Task 2 Distributed
Brainstorming phase (8 minutes)
Problem Solving phase (10 minutes)
—- Post-task questionnaire

Table 2. Experimental procedure. Each team performed both task 1 and task 2. The sequence of the tasks was counter-balanced.

on a modification of the game “Twenty-Questions”, which integrated both brainstorming and problem-solving scenarios by closely replicating Wilson’s experiments [29]. At the beginning of a task, each group was given a set of ten yes/no question-and-answer pairs. For the first phase of each task, groups were given 8 minutes to collaboratively brainstorm as many ideas that satisfy the set of question-and-answers. Then, continuing into the second phase, groups were given 10 minutes to ask the remaining ten questions of the Twenty-Question Game to determine the correct solution. Following each task, subjects filled out a post-experiment questionnaire comprised of five-point Likert scale questions regarding their own personality, the group dynamics and each individual’s performance for each phase, and if applicable, the utility of the MM system (Table 2). As mentioned earlier all groups were given two tasks: groups worked on one task in a co-located setting and the other task in a distributed setting.

Performance (i.e. scoring) was determined by (1) the number of correct ideas in the brainstorming phase and (2) the number of questions used to arrive at the correct answer in the problem-solving phase. In the brainstorming phase, the groups were encouraged to generate as many ideas as possible and were not penalized for duplicated or incorrect ideas. In the problem solving phase, groups were encouraged to freely discuss their ideas before deciding on a question to ask the experimenter that would be counted off from the ten possible questions. An additional goal incentive was provided in the form of gift certificates for the top-scoring team.

Measures

Speaking time

We define total speaking time as the fraction of time during which an individual speaks, regardless of interruptions or overlap speech from others. Fraction of overlap speech time for individuals is the time that another person in the group is speaking at the same time the individual is speaking divided by the total time elapsed in the phase.

Average speech segment length

We define a turn as each instance a participant takes over a conversation either from another participant or from silence. Next, we define a speech segment as any one continuous stream of speech from an individual, regardless of interruption or overlap from other participants. A segment will end either by an interruption caused by another participant that resulted in the speaker to stop speaking or a significant length of silence.

	Number of groups
No dominant person in group	17
1 dominant person in group	12
2 dominant people in group	6
3 dominant people in group	1
4 dominant people in group	0
total	36

Table 3. Number of groups with certain number of dominant people. For analysis, we compared groups with no dominant people to groups with one or more dominant people.

Variation in speech energy

We measure the variation in speech energy, in other words, the variation in speech volume. Higher variation in speech energy makes the speaker sound more expressive and energetic in speech.

Variation in movement

We define movement energy as the average amount of body movement over a fixed unit of time, i.e. the amount of gesturing during conversation. Movement energy variance is the variation in movement energy.

Self perceived dominance

In the post-task questionnaire one of the questions asked users to rate the self-perceived level of dominance. The subjects answered using a 5-point Likert scale. Out of all participants, subjects with values higher than one standard deviation over the mean were considered dominant, yielding 19.4% of all subjects to be labeled as dominant. After determining dominant subjects, we differentiated the groups with one or more dominant person from groups in which all participants were non-dominant. 19 out of the 36 groups (52.8%) had one or more dominant persons as participants (Table 3).

We also asked all participants to rate each other’s dominance level. The average level of peer rated dominance had a high correlation to self perceived dominance (r=0.73). The anlaysis showed similar results using either measure hence we only report on the analysis based on self-perceived dominance.

Number of ideas generated in the Brainstorming phase

In the brainstorming phase, all participants were asked to write down possible ideas that satisfy the 10 question-and-answer pairs. As the goal of brainstorming is to generate as many ideas as possible, we use the total number of ideas generated as a measure for the performance of the brainstorming phase. For the two brainstorming phases (8 minute co-located and 8 minute distributed), individuals generated a mean of 9.4 ideas.

Number of questions used to arrive at solution

In the problem solving phase, groups asked up to 10 questions to find the correct solution. They received a higher score if they used fewer questions and a zero score if they could not get the answer correct within 10 questions. Hence we use the number of questions each team used as a negated measure of the team's performance. On average, groups used 5.03 out of 10 possible questions to arrive at solution.

RESULTS

Effects of MM

MM reduces the amount of overlapping speaking time (H1)
MM had a very strong effect on speaking dynamics. The primary effect was a dramatic reduction in overlapping conversations. This is in line with our qualitative observation that groups without MM tended to divide into sub-groups and have separate conversations instead of working as one team. The average overlap speaking time is significantly lower for subjects with MM (mean=31.8% of the total time) than subjects without MM (mean=49.2% of total time, F(1,106)=17.8, p<.0001, Fig. 4). Due to the large difference in overlapping speaking time, the total speaking time was significantly shorter for subjects with MM (mean = 41.0% of the total time) than subjects without MM (mean = 57.1% of the total time, F(1,106)=15.2, p<.001). Therefore, when subjects were provided with visual feedback through MM, despite speaking less, they were more likely to collaborate with their teammates as one group.

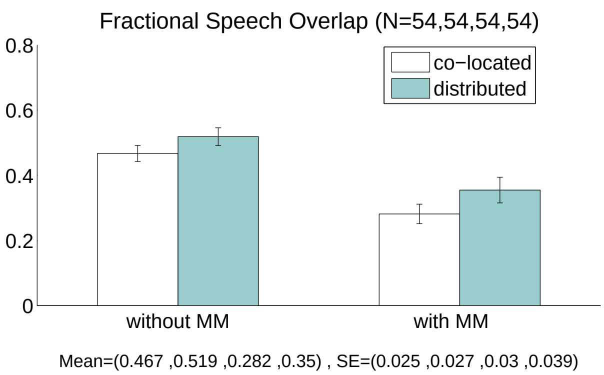


Figure 4. MM reduces overlapping speech time. Mean = (49.2% of total time without phone, 31.8% of total time with phone), F(1,106)=17.8, p<.001. In both cases, there is more speech overlap in the distributed case

MM encourages higher level of interaction (H2)
Further analysis of speech gives us new insights into the group interactivity level. Subjects with MM have significantly shorter speech segment lengths (mean = 7.4sec) compared to those without MM (mean =10.3sec, F(1,106)=16.8, p<.0001, Fig. 5). This relationship is maintained in both brainstorming and problem-solving phases. This supports H2 in that MM increased interactivity level of the group. There was no significant effect on the overall number of turns per individual (3.40 turns/min without MM, 3.16 turns/min with MM, F=2.0, p=.16). However, subjects with MM have significantly fewer turns in the brainstorming phase (3.37 turns/min without MM, 2.90 turns/min with MM, F=5.9, p=.017) while they have significantly more number of turns in the problem-solving phase (3.03 turns/min without MM, 3.59 turns/min with MM, F=4.1, p=.047). This may be due to the high amount of speech overlap in brainstorming.

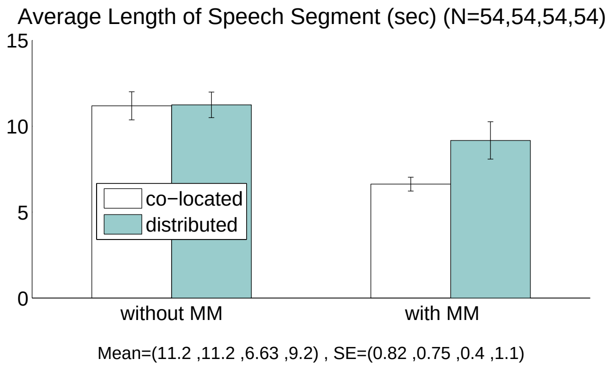


Figure 5. MM encourages more interactions (shorter average speech segment length). Mean = (10.3sec without phone, 7.4sec with phone), F(1,106)=16.8, p<.0001. This effect is stronger in the co-located case.

MM's phone interface is not distracting (H3)
Post-task survey data showed no significant difference in the level of distraction (mean = 1.57 without MM, 1.71 with MM on a 5-point Likert scale, F=1.66, p=.20). These results are different from those of DiMicco, where subjects felt discomfort due to the public display. Consistent with these results, the analysis of movement energy supports H3 indicating that subjects with MM did not display more nervous energy. Average movement energy of people with MM had no significant difference compared to that of subjects without MM (mean = 1.33g without MM, 1.35g with MM respectively, F(1,106)=2.15, p=.14, $g = 9.8m/sec^2$). Likewise, there was no significant difference between subjects in the movement energy variance (mean=0.066g without MM, 0.064g with MM respectively, F(1,106)=0.12, p=.72, $g = 9.8m/sec^2$).

Effects of dominance

Dominant people have distinct behavioral characteristics (H4)
Using the Sociometric badge, we observed how dominant people's behavior is different from that of non-dominant people. In this analysis we used data collected from only the 18 groups that did not have MM feedback to measure uninfluenced behavior of dominant people. Out of 54 participants without mobile phone feedback, 11 participants (20.4%) perceived themselves as dominant. Out of 18 groups, 9 groups (50%) had one or more dominant person among its group members.

One major characteristic of dominant participants agrees with common intuition: dominant people speak more than people who are not (Mean=54.5% of total time for non-dominant people, 67.2% of total time for dominant people, F(1,52)=4.54, p<.05). Dominance is often expressed through amount of speech, which was detected by the Sociometric badges.

Another characteristic of dominant people is the large variation in speech energy; i.e., dominant people have more variance in volume when they speak (mean = $350c$ Pa for non-dominant people, $512c$ Pa for dominant people, F(1,52)=6.07, p<.05, $c = constant$). This verifies that dominant people are more energetic in their speech, being more expressive and emphasizing when they are talking compared to non-dominant people.

We did not find any significant difference between the body movement energies of dominant people and non-dominant people (mean = 1.34g for non-dominant people, 1.33g for dominant people, F(1,52)=0, p=.98, $g = 9.8m/sec^2$) or body movement energy variance (mean = 0.067g for non-dominant people, 0.060g for dominant people, F(1,52)=0.86, p=.36, $g = 9.8m/sec^2$).

When non-dominant people are grouped with a dominant person they behave more like the dominant person (H5)

We conducted a between-subject comparison on the behavior of (a) non-dominant people grouped with only non-dominant people (N=27) and (b) non-dominant people grouped with one or more dominant people (N=16). This allowed us to measure the influence of dominant people on non-dominant people, and to understand how the average of non-dominant people's behavior is different from that of non-dominant people grouped with only non-dominant people. Again, to eliminate the effect of MM we only observed the behavior of subjects without MM.

One evidence for H5 is found in speaking time. When non-dominant people are grouped with a dominant person, they tend to speak more than they would if they were in a group with only non-dominant people. The difference is significant when the group is distributed (Mean = 50.7% of total time when grouped with only non-dominant people, 60.6% of total time when there is a dominant person in the group, two-sample T-test: t(41)=-2.23, p<.05). Their behaviors become more similar to that of the dominant person, as we have seen that dominant people speak more than non-dominant people. Thus, we can understand that the talkativeness of dominant people also draws more speech participation from non-dominant people.

Interaction between MM and dominance

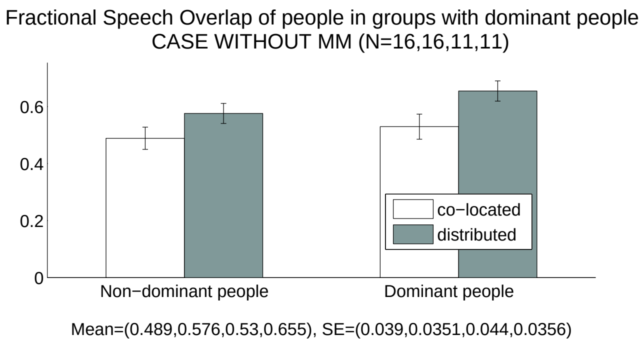
While analyzing the effects of MM on group dynamics, we discovered that there existed a strong interaction effect between MM and dominance. Groups with one or more dominant participants seemed to react differently to MM as compared to groups with no dominant people. Moreover, MM had a different effect on dominant people compared to its effect on non-dominant people.

MM influences distributed collaboration to be more like co-located collaboration(H6)

In H6, we hypothesized that MM will make distributed collaboration more like co-located collaboration. This hypothesis was not supported when we analyzed all groups. However, when we restricted our observation to groups with one or more dominant people, we found evidence that MM indeed reduces the difference between co-located and distributed collaboration.

In groups with one or more dominant person, people have more speech overlap when groups are distributed and this effect is significant for dominant people (Mean = 48.9% of total time when co-located, 57.6% of total time when distributed, t(15)=-2.06, p=.06 for non-dominant people, mean = 53.0% of total time when co-located, 65.5% of total time when distributed, t(10)=-3.15, p<.05 for dominant people). This may be because in distributed settings it is more difficult to signal people to let them know that they are being intrusive or impolite. However, when MM is present the signal may be reintroduced through the visual feedback on the mobile phones.

There is no significant difference between the co-located case and the distributed case (Mean = 32.7% of total time when co-located, 36.4% of total time when distributed, t(19)=-0.41, p=.69 for non-dominant people, mean = 35.8% of total time when co-located, 41.4% of total time when distributed, t(9)=-0.41, p=.69 for dominant people, Fig. 6). Confirming our hypothesis, MM has made the distributed scenario more like the co-located scenario by enhancing social signals. As mentioned earlier, this hypothesis does not hold for groups without a dominant person–a possible explanation is that non-dominant people are equally polite regardless of distribution.



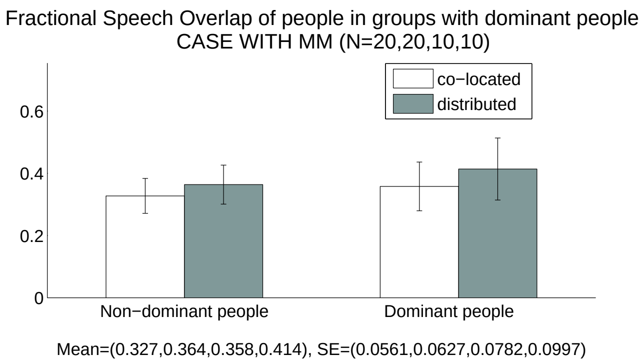


Figure 6. People in groups with a dominant person have more speech overlap when they are in distributed settings. When MM is introduced speaking times are not significantly different.

We found additional support for H6 by observing the variation of speech energy in the problem-solving phase. Again, the hypothesis was supported only when there was one or more dominant people in the group. In this case, the participants' variation of speech energy is higher when the group is distributed and the difference is significant for non-dominant people (Mean = 346c when co-located, 538c when distributed, t(15)=-2.13, p<.05 for non-dominant people, mean = 523c Pa when co-located, 698c Pa when distributed, t(10)=-1.52, p=.16 for dominant people, $c = constant$). This may be due to participants trying to compensate for the lost social signals by being even more expressive in their voice, similar to the phenomenon of people speaking on the phone shouting and gesturing intensively.

It is intersting to mention that this was only true for the problem-solving phase and not the brainstorming phase and is significant only for non-dominant people. Exaggeration of speech expressions was more necessary in the problem-solving phase in which the goal is to persuade others in order to bring about a favorable consensus. Additionally the change of behavior is greater for non-dominant people who tend to be less expressive in their speech. When MM is introduced, there is no significant differnce between distributed and co-located scenarios (Mean = 511c Pa when co-located, 555c Pa when distributed, t(19)=-0.55, p=.59 for non-dominant people, mean = 558c Pa when co-located, 623c Pa when distributed, t(9)=-0.34, p=.74 for dominant people, $c = constant$, Fig. 7). In other words, MM helped to reduce the difference in behavior between co-located and distributed settings especially for non-dominant participants in the group.

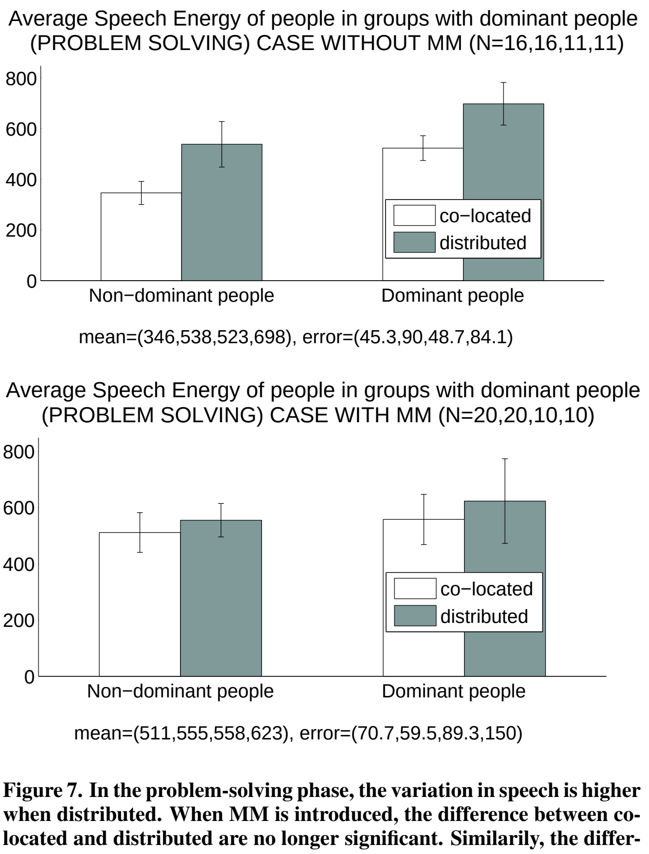


Figure 7. In the problem-solving phase, the variation in speech is higher when distributed. When MM is introduced, the difference between co-located and distributed are no longer significant. Similarily, the difference between dominant and non-dominant people reduce when MM is present.

MM reduces the difference between dominant people and non-dominant people(H7)

In an earlier section (H5) we mentioned our finding that when a dominant person is in the group, non-dominant people start behaving more like the dominant person, thereby reducing the behavioral difference between the two parties. By observing the interaction effect of MM and dominance, we have a result showing that this effect is stronger when MM is present.

In the problem-solving phase, the overlapping speaking time of non-dominant people was lower than dominant people (Mean = 58.1% of total time for non-dominant people, 71.6% of total time for dominant people, t(25)=-2.47, p<.05 when co-located, mean = 76.4% of total time for non-dominant people, 77.0% of total time for dominant people, t(25)=-0.08, p=.94 when distributed). As confirmed in H4, dominant people have longer overlapping speech time than non-dominant people, and the difference is significant when they are co-located. However when MM is introduced, all participants' overlap speaking time is lowered reducing the difference between dominant and non-dominant people to be no longer significant (Mean = 44.0% of total time for non-dominant people, 49.6% of total time for dominant people, t(28)=-0.50, p=.62 when co-located, mean = 52.3% of total time for non-dominant people, 51.7% of total time for dominant people, t(28)=-0.06, p=.96 when distributed, Fig. 8). This can be understood as MM spreading out the energy of the dominant person, allowing every participant to be more energetic and involved in the communication.

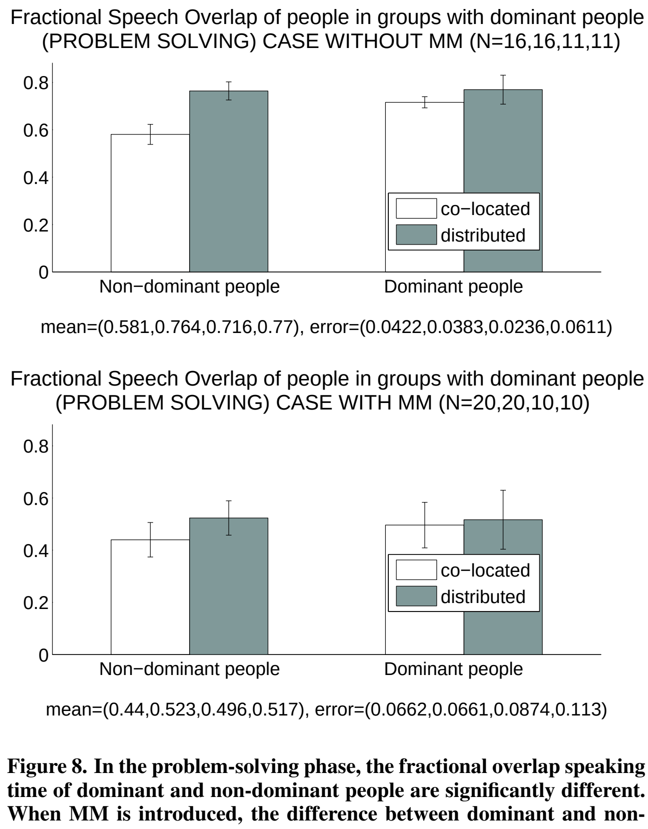


Figure 8. In the problem-solving phase, the fractional overlap speaking time of dominant and non-dominant people are significantly different. When MM is introduced, the difference between dominant and non-dominant people are no longer significant.

Another result supporting H7 was also found in the problem-solving phase. The average variation in speech energy of non-dominant people was lower than dominant people (Mean = 346c Pa for non-dominant people, 523c Pa for dominant people, t(25)=-2.60, $p < .05$ when co-located, mean = 538c Pa for non-dominant people, 698c Pa for dominant people, t(25)=-1.24, p=.23 when distributed, $c = constant$). Dominant people are much more energetic than the non-domiant people and the difference is significant in the co-located case. However when MM is introduced, the energy variation of the non-dominant people increases, reducing the difference between dominant and non-dominant people to be no longer significant (Mean = 511c Pa for non-dominant people, 558c Pa for dominant people, t(28)=-2.60, p=.69 when co-located, mean = 555c Pa for non-dominant people, 623c Pa for dominant people, t(28)=-0.51, p=.62 when distributed, $c = constant$, Fig. 7). This we also attribute to MM's ability to strengthen the mood contagion effect.

DISCUSSION

Our results suggest that MM indeed changes the group dynamics. When MM is introduced, groups become more polite and collaborative: they work better as one team, and there is more interaction and balance in the participation. We also observed that this effect occurs without bringing additional stress or dissatisfaction to the group (satisfaction mean = 4.27 for groups without MM, 4.21 for groups with MM on a 5-point Likert scale, F(1,106)=0.29, p=.59). However, there was no significant correlation between MM and performance. In the brainstorming session, though there were changes in the interactivity level of the group, there were no significant changes in the number of ideas generated (Mean = 10.7 without MM, 8.11 with MM, F(1,106)=3.01, p=.08). This may be interpreted through Wilson's work [29], where he found that if the given task was easy, more collaboration lead to worse performance. Similarily, in the problem-solving phase we did not discover any significant effects with the use of MM (Mean = 4.84 for groups without MM, and 5.2 for groups with MM , F(1,106)=1.49, p=.23). Our qualitative observations revealed that in some groups the dominant person would take over the conversation, limiting participation of others, while in other groups the dominant person acted as a facilitator [15] who brings out ideas of all participants leading to better performance.

Dominant people had distinct characteristics detectable by the Sociometric badge. By capturing the speaking time, average speech segment length, and speech energy of each participant, we were able to correctly identify 76% of the people who were perceived to be "dominant" by themselves (predicted using multi-linear regression. constant term = -1.74, quadratic terms = [2.83, 0.004; 0.004, -0.00]). Dominance had an interesting effect on performance: having a dominant person in the group had a significant negative effect on brainstorming but no effect on problem-solving. In the brainstorming phase, groups with dominant people tended to generate fewer ideas (mean = 24.3 ideas for groups with no dominant people, 16.9 ideas for groups with dominant people, F(1,16) = 4.06, p=.06). This is because non-dominant people, when grouped with dominant people, generate significantly fewer ideas than they would have if there were only non-dominant people in the group (Mean = 6.21 ideas when they are in only non-dominant group, 3.85 ideas when there was a dominant person in the group, t(41)=2.83, $p < .01$). It should be noted that even though the non-dominant people's social behavior tended to align with the dominant person (H5), their performance dropped, possibly because of social loafing or free-riding in the group. In the problem-solving phase, there were no performance differences (mean = 4.89 questions for groups without a dominant person, 4.78 questions for groups with dominant person, F(1,16)=0.02, p=.89). This is in agreement with our qualitative observation: a dominant person would guide the decision making and consensus generation process leading to better performance.

When one or more dominant person was present in the group, MM had a significant effect on reducing the difference between co-located and distributed collaboration. The dominant person's influence on other members was dampened when the group was divided and many of the social signals were lost. However, MM augments these social signals and makes the group dynamics of distributed collaboration similar to those of co-located situations. Interestingly, this change is not significant in groups with no dominant people. This may be because social signals expressed by dominant participants were more easily detected and restored compared to those of non-dominant people. Restoration of the lost social signals by MM has also strengthened the influence of the dominant person on the non-dominant people, causing the non-dominant people to behave more like the dominant person.

CONCLUSION AND FUTURE WORK

MM is a mobile system that can quantify meeting dynamics and provide real-time feedback to change collaboration patterns and performance. Our controlled study has shown that it indeed has a significant effect on various aspects of group dynamics while not being a distracting factor to the subjects. Our study also quantified the distinct characteristics of dominant people and their influence on other group members. There also existed a strong interaction effect between MM and dominance. In groups with one or more dominant people, MM was able to change distributed groups so that they collaborated more like co-located groups, and reduced the difference between dominant and non-dominant people by making everyone more energetic and involved.

We plan to incorporate into future studies our findings of how task type, dominance structure, and distribution affect the group dynamics. Using the ability to automatically detect these group characteristics, we plan to provide personalized feedback to maximize group performance and satisfaction. Continued studies will work toward the application of MM in real-world settings in order to enhance group interactions across various group collaboration contexts.

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