# Leveraging Gesture and Voice Data to Improve Group Brainstorming

**Deirdre Garrahan**
Wellesley College
106 Central St.
Wellesley, MA 02481 USA
deirdre.garrahan@gmail.com

**Orit Shaer**
Wellesley College
106 Central St.
Wellesley, MA 02481 USA
oshaer@wellesley.edu

**Andreya Piplica**
Wellesley College
106 Central St.
Wellesley, MA 02481 USA
apiplica@wellesley.edu

**Kevin Gold**
Wellesley College
106 Central St.
Wellesley, MA 02481
kgold@wellesley.edu


*CHI 2010*, April 10–15, 2010, Atlanta, Georgia, USA.
ACM 978-1-60558-930-5/10/04.

## Abstract
We seek to investigate how co-located group brainstorming could be enhanced through computational tools that leverage gestures and voice cues. To pursue this goal we are developing a computer mediated brainstorming environment that utilizes reality-based interaction techniques and sensor-driven Hidden Markov Models (HMMs) tracking group engagement to computationally augment existing brainstorming practices. In this paper, we report the results of a preliminary user study of brainstorming practices that indicate that gesture and voice data can serve as signals for group brainstorming success.

## Keywords
Brainstorming, Gestures, Voice Analysis, Innovation

## ACM Classification Keywords
H5.3 Group and Organization Interface: Computer supported cooperative work

## General Terms
Human Factors, Design

## Introduction
Brainstorming [13] is a structured technique for generating new ideas, providing project motivation, and

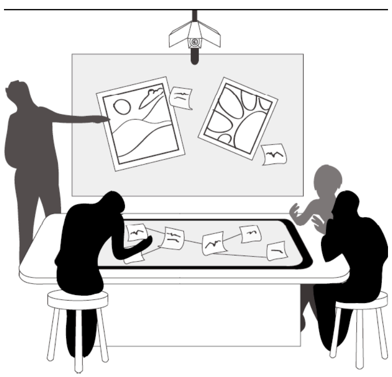

**figure 1.** A design sketch of a proposed computer mediated brainstorming environment for groups that consists of a multi-touch surface, a wall display, and a set of cameras. The system reacts to explicit multi-touch input as well as responds to implicit prosody, and gesture input.

developing teams. During a successful group brainstorming session, participants draw on each other's ideas and pre-existing knowledge to combine ideas in ways not previously considered [5]. While intuition suggests that groups are more productive at brainstorming [13], a greater number of ideas and better quality ideas are found in individual brainstorming [3]. Explanations for this phenomenon focus on the negative externalities often found in groups including peer judgment, free riding, and production blocking [7].

In a preliminary study of current group brainstorming practices, we examined the relationships between gestures, prosody, and the outcomes of co-located group brainstorming. Our findings indicate that gesture and voice data can serve as signals for group brainstorming success. More specifically, our findings indicate a positive correlation between gestures and positive outcomes of group brainstorming such as number of ideas, quality of ideas, and teamwork. We also found more frequent high pitch accents per minute when discussing ideas that survive to the idea selection and elaboration phase than those that do not.

Motivated by these findings, our continued research seeks to investigate how co-located group brainstorming could be enhanced through computational tools that leverage gestures and voice cues. To accomplish this goal, we are developing a computer mediated brainstorming environment (figure 1) that utilizes reality-based interaction techniques and Hidden Markov Models (HMMs) to computationally augment existing brainstorming practices.

Reality-based interaction (RBI) techniques [8] leverage users' pre-existing social, communication, spatial, and motor skills, and makes interaction with computers more similar to interaction with the day-to-day non-digital world. Existing research indicates that RBI interaction techniques such as tabletop and tangible interaction support co-located collaboration [6], facilitates active reading [11], and afford distributed cognition [14]. Thus, we integrated multi-touch and tangible interaction to our preliminary system design (see figure 1). We assume that this design will enable participants to easily add, explore, develop, and relate multiple ideas in parallel.

Following, we describe the results of a preliminary study of group brainstorming practices that motivate and inform the design of the computer mediated brainstorming environment currently under development. This study consisted of both qualitative and quantitative components.

### Qualitative Study of Brainstorming

Our qualitative study consisted of interviews, focus groups, and observations of group brainstorming sessions. We first conducted a set of informal interviews with 22 female undergraduate students at a Liberal Arts college and two focus group discussions on brainstorming with undergraduate students at an Engineering college (13 male, 7 female). We then observed four student groups (with 3-4 participants each) brainstorming for a project-based class on a system design problem (all female). Finally, to further understand brainstorming practices for complex problems, we conducted a series of interviews with 15-science faculty from a Liberal Arts college and an Engineering college (11 males, 4 females). Following, we describe findings related to the definition of success and to the role of gestures in group brainstorming.

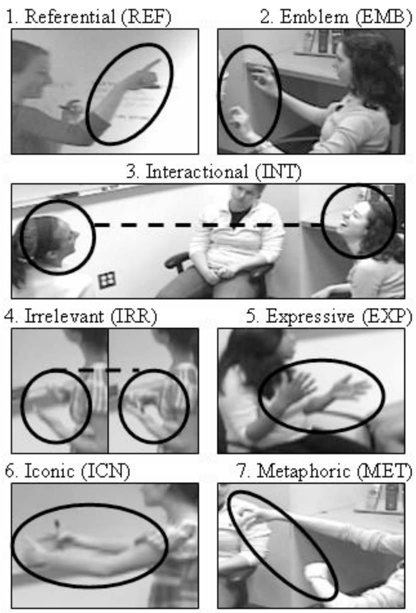


**figure 2.** Classification System of Gesture Primitives.

***Defining Success in Brainstorming.*** *B*ased on our interviews we defined "success" in co-located group brainstorming based on three factors: quantity of ideas, overall quality of ideas (e.g. feasibility, innovativeness), and overall teamwork (e.g. inclusiveness).

***Gestures and Brainstorming.*** Group brainstorming involves communicating complex or novel thoughts. Gestures are known to reveal thoughts [4, 9, 10] and to be specific to a certain social context. Looking at brainstorming, we found that many of the evolutionary roles of gestures are directly related to brainstorming. These include facilitating lexical recall [1, 4, 10] reducing cognitive load [1, 4], and helping world-word interaction [4, 9]. Based on our literature review and on our observations we created taxonomy of brainstorming gesture primitives (figure 2):

1. **Referential** (REF) (i.e. pointing): REF gestures involve pointing in reference to an idea, object or person. REF gestures can be parameterized for recognition [2], are important for inferring intent [12], and can be separated according to specificity (i.e. object, class) or function [9].
2. **Emblem** (EMB) (i.e. making "quote" sign): EMB gestures (i.e. symbolic gestures) are set movements that contain a coined meaning.
3. **Interactional** (INT) (i.e. synchronization): INT gestures are most often seen as collaboration signals involving turn taking, synchronizing, and cooperation in behavior.
4. **Irrelevant** (IRR) (i.e. fiddling by taping a marker): IRR gestures do not carry literal meaning. They represent extraneous motion and include subconscious beat movements, self-touch, and other fidgeting behavior.
5. **Expressive** (EXP) (i.e. hands out emphasizing an idea): EXP gestures coincide with articulation of words and might also show degrees of emotion, emphasis, or flow. EXP gestures can reduce cognitive load and help articulate concepts [4].
6. **Iconic** (ICN) (i.e. circular hole): ICN gestures represent concrete imaginary objects. Such gestures help to visualize ideas.
7. **Metaphoric** (MET) (i.e. shaping an object): MET gestures move beyond ICN gestures to represent new objects or ideas that need shaping or creation.

***Gestures and Voice***
Gestures and speech are complementary modalities [9]. Intuitively, one cannot gain full meaning watching television on silent. However, the reverse is also true – we do not get a full meaning if we only hear audio. As one faculty interviewee put it, "There's something about being in the same room and seeing the other person that you can't get over the phone." In our analysis of brainstorming, we investigated high pitch accents in addition to gestures because, like gestures, pitch is not always content specific and can be generalized to certain social contexts.

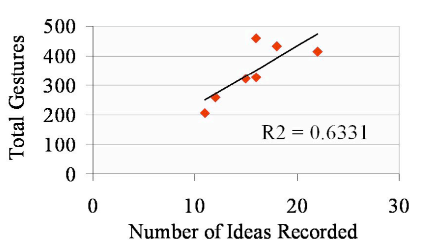


**figure 3.** Correlation between the number of ideas recorded and total number of gestures.

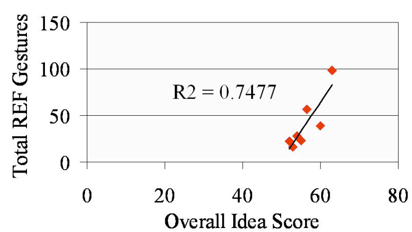


**figure 4.** Correlation between overall idea score and total number of referential gestures.

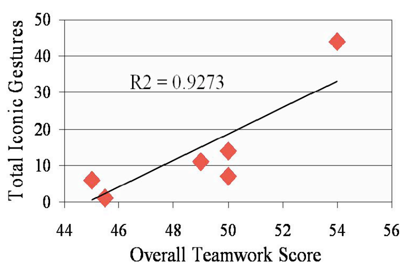


**figure 5.** Correlation between overall teamwork score and total number of iconic gestures.

## Quantitative Study of Brainstorming

To quantify the relationship between gestures, prosody, and brainstorming qualities such as number of ideas, overall quality of ideas, and overall teamwork, we observed 7 co-located group brainstorming sessions. Participants were 21 female Liberal Arts college students. Overall, participants had mediocre (*M* = 2.13 out of 5, *SD* = 0.66) experience brainstorming. Participants were separated randomly into groups of three. Group members were moderately familiar with another (*M* = 3.71 out of 5, *SD* = 1.71). Each session worked on the same design problem for the same amount of time and consisted of 2 phases: idea generation, and an idea selection and elaboration.

Video analysis included counting gestures by type and counting the overall number of ideas. Voice analysis measured high pitch accents per minute. A subjective self-assessed questionnaire measured different qualities of brainstorming including idea quality and teamwork. In particular we looked at the affect of gesture categories (REF, EMB, INT, IRR, EXP, ICN, MET, and Total) and pitch accents (H* or L*) over Part 1 (idea generation) and Part 2 (idea selection and elaboration) of the study compared to number of ideas recorded, overall idea score, and overall teamwork score. Inter-coder reliability based on a random sampling of 22 % of the data was very good (6’s Kappa = 0.86).

In addition, we used the voice data to look at the number of high accents per minute during “used idea times” (ideas in Part 1 that were kept in Part 2) versus “non-used idea times” (all other times). The voice data was coded by a coder trained in the TOBI pitch accent classification system, based on the prosody theory of Pierrehumbert and Hirschberg [15, 16].

***Results***. A Pearson correlation found the relationship between total number of gestures (*M* = 346.1, *SD* = 94.1) and number of ideas recorded (*M* = 15.7, *SD*= 3.7) to be significant ($p < 0.05$) and positive (figure 3). A Pearson correlation found the relationship between total REF gestures and overall idea score (*M* = 15.7, *SD* = 3.7) to be significant ($p < 0.05$) and positive (figure 4). The total high accents per minute positively and significantly ($p < 0.05$) correlated with a group’s overall idea score.

We investigated these relationships further by looking at the components that constitute the overall idea score (novelty, innovation, diversity, quality, and winning qualities). The overall rate of high accents was significantly correlated with innovation ($p < 0.05$) while the number of gestures was significantly correlated with diversity of ideas ($p < 0.05$). The correlation between overall teamwork score and both total gestures and high accents were not significant. We investigated this relationship further by looking at the relationship between specific gestures primitives and overall teamwork score components (satisfaction, inclusion, team mentality, and focus). A Pearson correlation found the relationship between overall teamwork score (*M* = 48.36, *SD*= 3.38) and total ICN gestures (*M* = 12.7, *SD* = 14.4) to be significant and positive ($p < 0.05$, figure 5).

In addition to these strong results, repeating this study with more participants may confirm some of our results that are trending toward significance: EXP gestures during idea generation than idea selection ($p < 0.08$); negative correlation between innovation score and IRR gestures in idea selection (p < 0.19); more INT gestures during idea generation ($p < 0.11$); correlation between rate of idea generation and rate of high accents ($p < 0.08$), especially for those ideas that were eventually chosen as the best ($p < 0.06$); and more high accents per minute during discussion of the best ideas than other ideas ($p < 0.10$).

***Discussion.*** Our findings suggest that gestures and prosody are markers of idea productivity and positive outcomes of group brainstorming. In particular:

- There is a difference in terms of number and type of gestures between the idea generation phase and the idea selection and elaboration phase.
- There is a positive relationship between the number of H* pitch accents per minute and self-reported measures of brainstorming success.
- There is a positive relationship between the number and types of gestures and self-reported measures of brainstorming success.
- There are more H* pitches per minute when discussing ideas that survive to the idea selection and elaboration phase than those that do not.

It is important to note that the positive relationship between gestures and brainstorming ratings that we found is correlation, not causation; thus the system we are developing seeks to *monitor* these measures, rather than intervene to increase them.

## Conclusions and Future Work

While our preliminary study indicates positive relationships between gestures, prosody, and group brainstorming success, it also suffers from some limitations. In particular, all of our subjects were female. This choice eliminated a confounding variable of gender, but does not represent most brainstorming realties of mixed gender groups. To avoid gender bias and increase the external validity of our preliminary study, we plan to repeat our observational study with an equal number of male and female participants. We also hope to expand our sample size, to determine whether the effects that trended toward significance in our pilot study are significant, and if so, measure the effect size. In addition, we attempt to leverage gesture and voice cues further by:

- Creating and validating a set of voice, video, and multimodal HMMs for tracking group brainstorming over time. We are developing the following HMMs: voice based HMMs that detect when a speaker introduces ideas that are considered new; video-based HMMs that distinguish between repetitive gestures indicating lack of engagement, more energetic gestures indicating excitement, and more structured "idea-enabling" gestures; and multimodal HMMs incorporating both kinds of data into an overall judgment of group state. These tools should be useful as metrics for group brainstorming success when self-report data is unavailable, and should also be useful for feedback, indexing, and retrieval. However, developing such HMMs will be challenging, as the recognition technology will need to integrate models of each individual into an overall model of the brainstorming group's success.
- Development and evaluation of a reality-based user interface for co-located group brainstorming that leverages gesture and voice cues. The system will consist of a tabletop and a large wall display that employ multi-touch and tangible interaction techniques to leverage existing collaborative brainstorming practices, and a set of cameras and microphones for recording gesture and voice data. The system will

augment current practices by enabling users to fluidly explore, develop, and record ideas, and by responding to changes in the affect of the group over time as monitored by the set of HMMs discussed above.

Finally, we hope that other researchers will expand upon our classification system for brainstorming gesture primitives and draw upon our bi-modal analysis approach to design computational tools that support and enhance collaborative problem solving.

## Acknowledgements

We thank the students and faculty who participated in our study. We also thank Jennie Pyers for her feedback, and Lia Napolitano for her illustrations.

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