Gestures as Intrinsic Creativity Support: Understanding the Usage and Function of Hand Gestures in Computer-Mediated Group Brainstorming

JINGXIAN LIAO, University of California, Davis, USA

HAO-CHUAN WANG, University of California, Davis, USA

Interpersonal communication is essential to group creativity tasks, such as group brainstorming. However, what's easily overlooked in supporting group creativity is the potential use of nonverbal behavior in communication. When people communicate verbally (e.g., discussing a topic through conversation), they may also co-produce hand movements along with verbal contents as part of the communication process. Going beyond using external interventions for creativity gain, we examine the potential to facilitate worker's in-conversation gesture use as an intrinsic mechanism for bolstering group creativity. In this paper, we aim to gain a deeper understanding of the usage and function of hand gestures in computer-mediated group brainstorming. Through a laboratory study, we verified that metaphoric gestures, or producing spatial cues with hands to convey intended concepts, can best influence self's and partner's idea generation. Also, the positive effect of metaphoric gesture is independent of media richness of communication medium (e.g., whether there's visibility or not). The results help to fill in the knowledge gap regarding how gesture use may relate to group creativity, and reveal the potential viability of shaping metaphoric gesture use as an intrinsic creativity support.

CCS Concepts: • **Human-centered computing** → **Laboratory experiments**; **Collaborative interaction**; *HCI theory, concepts and models*; Visualization techniques.

Additional Key Words and Phrases: Gesture; Computer-Mediated Communication; Computer-Supported Collaboration; Collaborative Creativity; Group Brainstorming; Online Work

ACM Reference Format:

Jingxian Liao and Hao-Chuan Wang. 2019. Gestures as Intrinsic Creativity Support: Understanding the Usage and Function of Hand Gestures in Computer-Mediated Group Brainstorming. *Proc. ACM Hum.-Comput. Interact.* 3, GROUP, Article 243 (December 2019), 16 pages. <https://doi.org/10.1145/3361124>

1 INTRODUCTION

Understanding and supporting the interaction processes of group creativity continue to be a topic of importance in the Group and HCI communities, especially when considering how to support design activities that demand novel and useful design ideas [33]. For example, there has been much work exploring the design space of creativity support tools by employing multimodal interfaces and information representations to assist the sharing, exchange, and integration of information in groups for purposes of creative design. Group brainstorming as a common practice to generate ideas through collaborative teamwork is in particular of relevance and interest in this regard [21, 39].

Prior work has provided theoretical frameworks and empirical understandings about the mechanisms and characteristics of group brainstorming. Group brainstorming can be modeled as a

Authors' addresses: Jingxian Liao, jxliao@ucdavis.edu, University of California, Davis, Davis, CA, 95616, USA; Hao-Chuan Wang, hciwang@ucdavis.edu, University of California, Davis, Davis, CA, 95616, USA.

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for components of this work owned by others than the author(s) must be honored. Abstracting with credit is permitted. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee. Request permissions from permissions@acm.org.

© 2019 Copyright held by the owner/author(s). Publication rights licensed to ACM.

2573-0142/2019/12-ART243 \$15.00

<https://doi.org/10.1145/3361124>

socio-cognitive process that involves both social exchange of information among team members, as well as cognitive operations on information received by individuals (e.g., ideas shared by other team members during a brainstorm) [11]. Research also showed that the social process of information exchange, as well as the cognitive process of creative perception and thinking, are interdependent. Effective brainstorming relies on using the ideas shared through team communication as stimuli for creative thinking [28]. Facilitating a smooth exchange of concepts and ideas in brainstorming groups is an important aspect in group brainstorming. Specifically, the styles of communication and collaboration can have significant effects on creativity tasks [30, 35]. The joint development and selection of ideas in group brainstorming would also require social interactions among group members inherently.

To improve communication and idea-sharing in brainstorming groups, previous work focused on extending group discussion with external support. One line of work investigated using shared large displays to achieve unhampered social interactions during brainstorming activities [4, 17]. As the physical properties and functions of such interactive displays allow co-located workers to more easily see and make use of ideas shared by peers, the approach enables interface designs for coordinating multiple participants' attentions and collaborative behaviors. Another line of work explored using visual representations of concepts, such as photos and drawings, to elevate the stimulating utility of shared ideas in creative thinking [18, 32, 39]. In Wang et al. [39], ideas shared verbally by workers were used as queries to retrieve relevant pictures from an image database to represent the ideas. These language-retrieved pictures serve as multimodal representations that help to expand the space of concepts accessible to workers. For the purpose of concept expansion, affinity diagram and similar representations highlighting inter-concept connections were introduced to structure collective ideas and links between them [41].

In summary, most of the previous work focuses exclusively on external support. The supportive mechanisms, including social displays and visual representations of verbal content, are extraneous to individuals, requiring workers to use specific tools (e.g., [32, 39]) or work at specific locations (e.g., [14, 17, 18]) to improve brainstorming outputs. Existing brainstorming tools are mostly designed to expose individuals to diverse stimuli provided by other group members and to organize ideas that are fragmentary and unstructured [18]. However, when team members don't have access to these specialized tools, brainstorming falls back to an unaided mode, raising needs to investigate supportive mechanism relatively intrinsic to individuals.

We note that the use of gesture in conversation is *intrinsic* to individuals, typically requiring no specific external tool to perform, which has the potential to serve as the basis of intrinsic support for brainstorming. However, little is known regarding how nonverbal hand gestures co-produced by people during conversations may affect group brainstorming. In this paper, we aim to understand how worker's nonverbal behaviors, such as hand gestures, related to group brainstorming when collaborating in face-to-face as well as in computer-mediated settings. Specifically, rather than targeting at the general process of hand gesture use in generic communication, we instead focus on the self-supporting properties of gestures for idea generation and creativity.

In our laboratory experiment, brainstorming tasks were undertaken by manipulating the factors of language fluency (i.e., fluency in the common language chosen for teamwork), communication medium (i.e., properties of the communication tool used to communicate) and brainstorming topic in order to study verbal and non-verbal behaviors in cross-lingual group brainstorming, which is increasingly popular in today's global organizations. We used Microsoft's Kinect sensors to capture non-verbal hand movements throughout the whole process, so that we can obtain time-stamped sequences of spatial positions of hand movements. Also, we derived two types of gestural measurement from raw sensing data: unit motion and gesture type. Unit motion is defined to represent the frequency of discrete hand motions segmented from raw motion-sensing data. Also,

based on the video recordings and text transcripts of the brainstorming sessions, we coded specific types of spontaneous gestures proposed previously by the literature [15, 20, 25], including iconic gesture, metaphoric gesture, and pointing gesture.

After proper data coding and analysis, the results revealed that not all hand movements play the same role in group brainstorming. We found that metaphoric gestures had the most positive correlation with participants' idea generation outputs, regardless of which communication medium was used. Medium, on the other hand, did not impact individual's creativity production. We also verified that the visibility of partners helped participants producing more hand movements and semantic-rich gestures. The results provided a proof-of-concept, suggesting that nonverbal gestures have the potential to work as an intrinsic mechanism for supporting group brainstorming, and this mechanism is mostly independent of communication media. Based on the results, we recommend researchers and designers to further assess various gesture-based solutions, including skill development programs for training productive gesture use or visualization designs for visualizing nonverbal behaviors to amplify individual's and group's creative potential.

2 BACKGROUND AND RELATED WORK

2.1 Communication medium and creativity

Creativity is an essential part of everyday life and work and has been commonly recognized as the main vehicle of a project, an organization, and even the whole society. Scholars spanning across different fields, including sciences and engineering, have been studying creativity in diverse contexts and attempting to support it over the centuries [33]. One common definition of creativity focuses on the production aspect, specifically the generation of novel and useful ideas/products for meeting practical needs [1]. Creativity can also be seen as relatively stable behavioral traits and cognitive abilities of creative people [16]. Creativity could also be a personal or a social and cultural phenomenon [37]. The current scope of this paper is limited to the first angle, focusing on creativity as the generation of creative ideas in teamwork.

Prior work has also looked into how different factors influence creativity at the individual and the collective levels, as well as in different contexts of work [8, 37]. In the individual level, one focus is on the enhancement of individual expertise, such as trying to figure how people could be more creative during the work, or to improve individual's productivity on specific tasks [8]. From a collective perspective, they pay attention instead on the interaction between group members [30] and how different social factors impact creativity, including cultural difference, language difference, evaluation process, etc. Specific factors identified in previous work include but are not limited to group creative style [30], collaboration atmosphere [35], group size [13], and individual cognition [9]. However, little attention has been allocated to examine the influence of the properties of communication media (e.g., video or audio) on group creativity in the literature. As computer-mediated creative work in online settings is increasingly commonplace, there's emerging need to fill this gap in research.

The relationship between communication medium and creativity roots in information exchange and interpersonal communication from the perspective of collective creativity. In management, scholars have explored the effects of specialized computer-based collaboration support tools on brainstorming tasks, resulting in the research paradigm of "electronic brainstorming"(EBS) [10]. Studies have shown that EBS improves productivity, especially in small groups [10]. Previous work also verifies that these support tools may minimize the negative process of production block due to turn-taking by allowing group members to discuss/work simultaneously to produce ideas [27]. On the other hand, these researches of system-regulated brainstorming participation aren't fully

compatible with the norm of free-form, naturalistic social communication that's common in typical teamwork [7].

In regular face-to-face communication, there is no limit on verbal or non-verbal expressions, and turn-taking is typical for conversations. While in computer-mediated remote teamwork, some aspects of non-verbal communication may be restrained due to technological limitations. For example, in video conferencing the field of view of the camera used is limited even though it may still provide some visibility of team workers' facial expressions (but possibly no visibility of hand movements). On the other side, audio conferencing or telephone call can only support audibility, and there will be no visibility at all. In group creativity tasks, medium properties may affect how people express and receive ideas in the group, and may also affect what are to be shared when the expression of certain concepts is hindered by medium constraints.

2.2 Gesture and creativity

Speech-accompanying hand movements, or hand gestures, are produced spontaneously during people's thinking and speaking. Non-verbal communication behavior, including hand gestures, accounts for about two-thirds of human interaction [19]. Gestures can be categorized into a couple of types based on interpreted meaning: emblems, iconic gestures, metaphoric gestures, beat gestures, and some others [20]. Research has established that different types of gestures can exert different functions in communication and social interactions. As group creativity depends on smooth exchange of concepts and ideas among team workers, it's essential to investigate the roles of hand gesture used in group brainstorming tasks.

The general functions of gesture used in conversations can be of two folds, communicative versus non-communicative [6]. Gestures produced by individuals may convey information to other participants to supplement communication goals, but may also directly associate with gesturer's own cognitive processes, such as memory retrieval and speech production [5, 20].

Gestures, with its non-communicative and self-oriented functions, are interdependent of gesturer's thinking as the inner cognitive representations. And mechanisms for thinking and gesturing may be identical. Work in embodied cognition demonstrates that cognitive processes can be shaped by the activation of other parts of the human body beyond just the brain, such as hand movement and facial expression [12]. On the other hand, gestures also complement speech in communication. Some gestures provide clear social functions substituting language itself, such as finger gestures that represent numbers, hand-waving gestures that convey social intentions (e.g., welcoming or agreement), etc. When people describe the size and shape of an object, they may use their hand gestures to show the dimensions of the object in the air. If the object is nearby, people will directly point to it. The usage of gestures is inherent to individuals and is an intrinsic device that people may use to express and demonstrate intents. Both non-communicative and communicative functions of gestures may bolster communication of concepts that's essential to group creativity [5, 20]. For example, with appropriate gesture use, people may be able to produce or share ideas that are otherwise difficult to obtain in verbal means.

Now we shift the focus to the technological aspect. In prior technical work of gesture recognition and communication applications, there has been a substantial effort into computer vision techniques to perform gesture recognition [19]. One important decision to make in these systems and applications resides on determining what characteristics or features of static hand gesture and dynamic hand movement are captured and modeled [2, 29, 43]. Another challenge resides in the source and modality of annotated data. The state of art technical research tends to focus on using multimodal sensing to derive rich representations of gestures (e.g., using RGB and depth camera like Microsoft's Kinect), and to build community-shared gesture datasets, like NATOPS Aircraft Handling Signals Database (Naval Air Training and Operating Procedures Standardization) [34],

Kinect gesture dataset [24], NYU Hand Pose Dataset [38], for modeling and benchmarking purposes. While vision-based gesture recognition has been increasingly mature in certain application scenarios (e.g., content analysis of political communication), in the arena of group creativity, we still need to obtain an understanding regarding how different types of gestures affect brainstorming communication between people to determine how we may shape intrinsic brainstorming support with gesture recognition to bolster group creativity.

2.3 Current study

In the current study, we investigated the roles of hand movements in cross-lingual group brainstorming across different media conditions (face-to-face, video, audio). The reason we manipulated communication medium is to examine the variability of gesture use patterns in face-to-face (offline) and in computer-mediated communication (online) settings. Based on the related work and discussion above, we proposed three hypotheses to examine in the study:

- *H1: Medium and Group Creativity.* In group brainstorm, individuals and their partners will be more creative in rich media (e.g., face-to-face) than lean media (e.g., audio). Richer media provides more communication channels and better visibility for people, therefore people may make use of the great bandwidth to exchange concepts and ideas better with one another through verbal and non-verbal expressions. We expect people will produce more ideas face-to-face than through video, and bring up more ideas via video than audio.
- *H2: Medium and Gesture.* Individuals will make more gestures in rich media than lean media. Since rich media affords visibility and gestures of one person will then become visible to another one, people can make use of it to use gestures to convey information. We expect that individuals will gesture more face-to-face than in the video. Similarly, compared to video, they will gesture less when communicating only via audio.
- *H3: Gesture and Group Creativity.* Individuals who use more gestures during the brainstorming tasks will produce more ideas. Gestures are shown to be potentially functional to depict or complement the verbal contents in communication [6], through communicative and non-communicative mechanisms. Overall, we expect that individuals (and groups) who produce more hand gestures will also produce more ideas in the brainstorming session.

To clarify the roles of hand gestures in group creativity, we also performed exploratory analyses to examine the specifics of the relationship between different types of hand gestures and brainstorming performance across conditions.

3 METHOD

3.1 Participants and procedure

Seventy-two participants (33 females) were invited to the experiment from a major university and the surrounding community in north Taiwan. Participants were asked to identify the native languages they use, and to self-report their language proficiency in English. Based on their report of language background and proficiency, they were paired to form two kinds of language groups: *L1-L2 group* and *L2-L2 group*. Group L1-L2 consists of one English fluent speaker (L1) and one non-fluent speaker (L2); participants in group L2-L2 are both non-fluent speakers. Fluent English speakers (L1) are considered to be those who live in an English-speaking country for more than 7 years and speak English for at least half of their time there. For fulfilling the basic requirement in using English as the common language in the collaborative work, all non-fluent speakers were required to show that they scored at least 80/120 in TOEFL iBT test or an equivalent language test. Participants also didn't know the team member paired with them prior to the experiment.

Participants were introduced about the study and procedure first. They were asked to discuss three brainstorming topics with the goal to generate as many ideas as possible under different medium settings. The three brainstorming tasks share a similar structure and ask participants to brainstorm about "How do you think if all humans having an extra thumb (an extra eye / a pair of wings) in the year 2020? List the possible benefits, drawbacks, and changes to people if this were to happen" [40]. Participants were instructed to discuss mainly the benefits, drawbacks, and general influence of these hypothetical situations. Before working on each topic, they had 5 minutes to think about the question and prepare for the discussion. Each session lasted 10 minutes while there was an alarm 2 minutes before it ended to help participants wrap up the conversation.

3.2 Experiment design

Three communication medium conditions we designed are: face-to-face conversation (F2F), audio-only conversation (Audio) and video-mediated conversation (Video or V-Handvis). In the video condition, the HandVis video conferencing system we adopted also provides trace visualizations of hand movement as communication support [22, 23].

This HandVis tool highlights the positions of participant's left and right hands with circles on the screen. HandVis updates the visual highlights dynamically in real-time in order to reduce the participant's cognitive burden in tracing and understanding hand gestures. We choose to use HandVis as the video conferencing tool rather than a regular video tool in order to observe whether the design of extrinsic communication support (e.g., visualization) has the potential to influence idea generation, as well as to affect people's intrinsic use of gestures. In terms of media richness, HandVis affords a similar level of visibility as a regular video conferencing tool. Details about the design of this HandVis system were described in [22, 23].

The study was designed as a within-subject experiment. The presentation orders of medium conditions and task were counterbalanced. To capture and analyze participants' hand movements during conversations, we adopted the method of Kinect-taping and used motion sensors to quantify and compare hand movement sequences [40]. Two Microsoft Kinect sensors were used to simultaneously capture the movements of all upper body joints of two participants working in the same group over the course of the brainstorming discussion.

In all conditions, participants were sitting in a fixed chair which was 120cm away from sensors, as illustrated in Figure 1(A). Figure 1(A) provides the bird's eye view of half of the experimental space. 42-inch displays were put on a table, locating in the middle of the room, and Kinect sensors were settled in front of the displays. And there were two regular RGB cameras placed on top of the displays to record videos of the whole discussion.

In F2F condition, participants could see each other directly in the same room with the displays removed. For Audio, two participants were separated by the displays and displays were turned off to simply block the visibility. So they could only hear each other and communicate over speech, but there's no access to images. For Video or V-Handvis condition, the 42-inch displays were showing the HandVis interface designed by another project [22]. HandVis interface displayed live streaming videos of participants in real-time [22]. A screenshot of the Video condition is shown in Figure 1(B).

3.3 Measures

To preprocess the data, raw videos were collected and the speeches were transcribed into texts. Two coders were then recruited to code and count the number of ideas generated individually and in the group from the transcripts. The two coders were also trained to encode different types of gestures from the video logs and count the frequency of each type of gesture. Note that the audio files of two L1-L2 groups were missing due to technical issues, so they were excluded from the following analysis. Total time and quantity of unit motions (defined in section 3.3.1) were calculated from

Fig. 1. Overview of the HandVis video conferencing system used in the study: (A) physical configuration of the video setting [23]; (B) user interfaces seen by both users of a video chat [22]

```
00000000.026
head 0.07 0.3 1.31
shoulder center 0.08 0.13 1.3
shoulder left -0.07 0.03 1.33
shoulder right 0.22 0.04 1.3
elbow left -0.11 -0.15 1.25
elbow right 0.27 -0.15 1.23
wrist left -0.08 -0.27 1.15
wrist right 0.22 -0.26 1.12
hand left -0.12 -0.28 1.13
hand right 0.2 -0.3 1.09
=====
```

Fig. 2. Sample data of joint positions captured by the Kinect sensor used in the study.

Fig. 3. Using speed thresholds to define unit motions from the sensor-captured motion data.

raw data recorded by Kinect sensors [23]. The independent variables involved in the experiment include task, media condition, gender, English fluency, and group language composition. All of them are categorical variables.

3.3.1 Unit Motion. Following the analysis and definition of Yabe & Tanaka [42], a gestural unit motion is defined as being static at the beginning of the motion, and then the speed increases gradually. Once the speed reaches the maximum, it starts to slow down until the movement becomes static again. Microsoft Kinect sensors were applied to track upper body joints of participants and record the skeleton data they had at the frequency of 30 frames per second, which was proposed and used previously by Wang and Lai [40]. Figure 2 shows a slice of the sample data we collected. The dataset consists of three-dimensional spatial positions of 10 different points of the upper body over time. Four joints related to hand movements were chosen (left hand, right hand, left elbow, right elbow). Then Euclidean speed of every joint was computed using two successive positions in the space at time t and $t + 1$. And then we could derive the time/count of unit motion through speed data by applying the filtering threshold of speed. Figure 3 shows an example of a speed-based time series plot. When we set 2 (meter/s) as the filtering threshold of speed for coding and counting unit motions, there are 2 motions identified and the total amount of time of hand movement is about 3 seconds. In our experiment, we computed motion data with different speed thresholds and chose 0.15 m/s for the following analysis through trials and this threshold appears to provide us with a representative cleaned dataset consisting of multiple unit motions. The details of the data processing technique can be found in [40].

3.3.2 Gesture and idea count. As mentioned above, two coders were recruited and trained to watch the experiment videos and annotate gestures and ideas. They were trained to search and mark the time on the video when a gesture occurred. Before the two coders processed the whole dataset, they were asked to work on the same set of four videos first and Kappa agreement statistic was calculated to evaluate the coding reliability. The two coders achieved a satisfactory coding agreement of Kappa higher than .9.

Coders also counted the ideas generated in the video while coding the gestures. Ideas are defined as conceptually relevant contributions relevant to the given brainstorming topics. When an idea was co-constructed by two people through the conversation, the speaker who first initiated the conversational thread of the idea was identified as the contributor for data analysis.

According to the literature of gesture analysis, four categories of gestures are under consideration in our study: *Iconic Gesture* (IG), *Metaphoric Gesture* (MG), *Pointing Gesture* (PG) and *Other Gesture* (OG) [15, 20, 25]. Iconic gesture refers to hand gestures that represent meanings relevant to the concurrent semantic content. (e.g., it may look in some way like what it's intended to mean). Metaphoric gesture is similar to iconic gesture in that they exhibit or strengthen the meaning relevant to speech, but the gesture is used to present images of abstract concepts instead of concrete objects. Pointing gestures are those gestures which serve as a spatial reference. For the rest of the gestures that are not classified as IG, MG or PG, we coded them as other gestures.

3.4 Methodology of data analysis

Mixed effect analysis of variance model (Mixed-effect ANOVA) is introduced to conduct data analyses. Mixed-effect ANOVA is applicable when some of the factors have fixed factor levels while others have random factor levels [26]. A classic mixed ANOVA model for two factors without interaction term, where factor A is fixed and factor B is random can be encoded as following:

$$Y_{ijk} = \mu_{...} + \alpha_i + \beta_j + \epsilon_{ijk}$$

Here, we assume $\mu_{...}$ is constant. α_i represents constant level effect for A, with the restriction that $\sum \alpha_i = 0$. β_j follows $N(0, \sigma_\beta^2)$, where σ_β^2 is the variance of factor B. And ϵ_{ijk} s are independent $N(0, \sigma^2)$, the random error term. β_j and ϵ_{ijk} are independent.

Our experiment used a randomized block design with each participant as a subject. The model was run as individual-level analysis. Every participant was assigned to one language group (L1-L2 or L2-L2) and the assignment stayed constant. Therefore, each participant was nested in one language group in modeling. By considering the possible individual difference in brainstorming performance, we implemented a random effect to account for variance between individuals. Therefore, the final model is a mixed-effect ANOVA with multiple fixed factors, such as group language composition; individual was included as a nested random factor within language group. The dependent variables varied according to hypotheses and research questions, and we took necessary pre-processing steps to ensure the premises and assumptions for the aforementioned statistical models were met. For post-hoc analyses for mixed-effect ANOVA models, we applied Tukey-Kramer's method to perform multiple comparisons of the means of different levels. It's similar to Tukey's test, but it can be applied to datasets with unequal sample sizes, such as ours. The modeling and analysis were conducted by R 3.0.

4 RESULTS AND DISCUSSION

4.1 Analysis of H1: Medium and Group Creativity

To explore the relationship between communication medium and idea count, figure 4 shows the distributions of idea counts by the three medium conditions. The black dots are raw idea

Fig. 4. Scatter plot and box plot of idea count by medium conditions

Fig. 5. Gesture count by medium condition as estimated by mixed-effect ANOVA models

In Figure 4, the black dots are raw idea count data while light triangle points are means on each group.

In the Figure 5, bars represent the estimates of variants of gesture count. And small intervals shown at the top of bars are their 95% confidence intervals. Mean and standard deviation are estimated by mixed ANOVA model.

Table 1. Regression coefficients of mixed-effect models 1 and 2

		Model 1	Model 2
		$\sqrt{\text{Idea-self}}$	$\sqrt{\text{Hand-unit-motion}}$
Fixed factor	Intercept	2.3705***	7.3241***
	V-HandVis	0.1013	1.6532***
	F2F	0.0160	0.7166**
	Extra thumb	—	0.5963*
	Extra wing	—	-0.4201
standard deviation of random effect residuals			
	Group	0.2854	0.5011
	Individual	0.4072	1.9472

The intercept represents the baseline situation for audio medium condition and topic of having extra eye.

Significance code: $p < 0.01$: ***; $p < 0.05$: **; $p < 0.1$ * .

counts, light triangles are means on each group and boxes represent the quarters. The means and quantiles of idea count in V-Handvis ($mean = 6.40$, $median = 6$) are slightly greater than F2F ($mean = 5.99$, $median = 5.5$) and audio ($mean = 5.91$, $median = 5$) conditions. To complement the descriptive statistics and visual pattern shown in Figure 4, we used mixed-effect ANOVA to see whether they are statistically correlated shown in Table 1. In Model 1 of the table, both V-Handvis and F2F conditions show no statistical difference on idea count: $p = 0.15$ for V-Handvis, while $p = 0.82$ for F2F, with audio condition as a baseline. H1 is thus not supported.

4.2 Analysis of H2: Medium and Gesture

The analysis between medium and gesture is split into two parts: the analysis for unit motion count, and the analysis for gesture subtypes. Note that not every unit motion counted here corresponds to a semantic-rich gesture (e.g., iconic or metaphoric gesture), and the gross unit motion count mainly serves as a proxy measure of the frequency of gesture use.

We applied a mixed-effect ANOVA to explore how medium influences gesture use by using the count of unit motions as the dependent variable (denoted as Model 2). Model 2 detects significant effects of communication medium and task (as a control variable) on unit motion count (V-HandVis:

$p = 0.000$, F2F: $p = 0.034$; Task-thumb: $p = 0.076$, Task-wing: $p = 0.211$). It shows that participants in medium conditions with visibility, especially in V-Handvis condition ($mean = 9.03$, $sd = 2.41$), tend to produce more unit hand motions than in the audio condition ($mean = 7.39$, $sd = 2.68$).

A further detailed analysis was conducted to examine the effect of medium on each gesture subtype. We re-ran the same model (Model 2) with the frequency of gesture performed in each gesture category (IG, MG, PG, OG) as the dependent variable each time. Their results are consistent across different gestural categories as shown in Figure 5. In F2F and V-Handvis conditions (i.e., conditions with visibility), all kinds of gestures are more frequent than that in audio-only conversations (all p -values are $0.000 < 0.05$). The exposure to visual images in communication may encourage speakers to use gestures more frequently during their social interactions.

H2 is supported by results from the mixed-model ANOVAs in part. Through the analysis of medium effects on hand unit motions and the frequencies of different gesture subtypes, there is a main effect of media condition on gesture usage. However, we didn't see statistically significant differences between Face-to-Face and V-HandVis conditions. The effects of medium only appears when we compare audio to another medium condition that affords visibility. It's more important for people to see one another during the conversation, rather than visual quality. Restricted visibility afforded by our video conferencing tool is sufficient to trigger more frequent gesture use by participants.

4.3 Analysis of H3: Gesture and Group Creativity

4.3.1 Gestures effect on self's and partner's ideation. To analyze the associations between idea generation and gesture use, we conducted a list of parallel analyses, including an exploratory correlation, ANOVAs for examining factors influencing self's and partner's idea count, and the impact of visibility on gesture and idea count.

Table 2 shows an exploratory analysis that looks into the correlations between different gesture subtypes, hand unit motion and individual's idea count. We see a negative correlation between general hand unit motion and idea count ($r = -0.14$, $p = 0.040$). Higher hand unit motion level implies a less idea count in return. On the other hand, there exist significant positive yet moderate correlations between idea count and iconic gesture ($r = 0.28$, $p = 0.000$), as well as between idea count and metaphoric gesture ($r = 0.39$, $p = 0.000$). More frequent metaphoric and iconic gesture usages appear to connect to greater idea productions by individuals.

With preliminary findings from the correlational analyses shown above, mixed-effect ANOVAs were applied to examine factors underlying individuals' idea generation, by including gesture subtypes as predictors (see Table 3 for model construction) and other control variables. As shown in Model 3 in Table 3, individual's idea generation is positively and significantly associated with subject's metaphoric gestures performance ($F(1, 135) = 3.91$, $p = 0.000$) as well as proficiency in English ($F(33, 135) = 1.52$, $p = 0.01$). Frequent metaphoric gesture usage predicts greater productivity in idea generation. However, we confirm that iconic gesture has no effect on idea count. Neither motion count nor motion time is statistically significant in predicting the count of idea generation.

On the other side, we aim to examine the influence of individual's gesture on his partner. Model 4 in Table 3 uses idea counts from participants' partners as the dependent variable, and all the other settings are the same as Model 3. The result indicates that speaker's other gesture (OG) use has a significant negative effect on partner's idea productivity ($F(1, 133) = 3.91$, $p = 0.000$). Note the coefficient for other gesture is negative, which means that the more other gestures performed, the less productive the partner was in idea generation. It's again noteworthy that speaker's metaphoric gestures have a significant positive effect on partner's productivity in idea generation ($F(1, 133) = 3.91$, $p = 0.016$).

Table 2. Correlation between gesture subtypes, hand unit motion, and idea count

	Iconic	Metaphoric	Other	Pointing	Hand unit motion	Idea
Iconic gesture	1.0000					
Metaphoric gesture	0.6051	1.0000				
Other gesture	0.0008	-0.0873	1.0000			
Pointing gesture	0.1243	0.0899	0.1337	1.0000		
Hand unit motion	0.0751	0.0386	0.1780	0.1250	1.0000	
Idea	0.2777	0.3942	0.0081	0.1625	-0.1439	1.0000

Table 3. Regression coefficients of idea models

		Model 3	Model 4
Predictors		$\sqrt{\text{Idea-self}}$	$\sqrt{\text{Idea-other}}$
Fixed factor	Intercept	2.5189***	2.4567***
	L2-L2 group	-0.2622**	—
	Motion count	—	0.0023**
	Metaphoric gesture	0.0246***	0.0151**
	other gesture	—	-0.0110***
Standard deviation of random effect residuals	Group	0.1973	0.2673
	Individual	0.2028	0.1593

The intercept represents the baseline situation for L1-L2 language group.

Significance code: $p < 0.01$: ***; $p < 0.05$: **; $p < 0.1$: *.

Table 4. Conditional correlation tests

	Visible	Invisible	Correlation Test p-value
Data size	136	68	
Iconic gesture	0.3449	0.1076	0.0963*
Metaphoric gesture	0.4109	0.3649	0.7209
other gesture	0.0457	-0.1014	0.3297
Pointing gesture	0.1628	0.2012	0.7931

4.3.2 Visibility and idea generation. To further assess the influences of different types of gestures by medium, we created a new variable called *visibility* to split the dataset, inspired by the earlier analysis of medium and gesture reported in section 4.3. The two medium conditions with visibility, V-Handvis, and F2F, were combined into one level of the new dummy variable named visibility, where audio was another level. Steiger Test [36] was applied to compare correlation values between idea count and the counts of multiple types of gestures in conditions of visibility and invisibility. From table 4, the only significant gesture subtype is iconic gesture. Its positive correlation with idea count is significantly larger in the visible condition than in the invisible. However, for metaphoric gestures, there's no difference in its correlation with idea count in both visibility conditions.

As discussed earlier in the paper, gestures can have communicative (other-oriented) and non-communicative (self-oriented) functions. Results of Model 3 and Model 4 reflect that the two functions are not mutually exclusive, which is consistent with the findings in previous work

[20]. Metaphoric gestures contribute to the process of creation of both the speaker and his/her partner since it is a significant factor for both speaker's and her/his partner's idea generation. Also in assessing medium influence, we may differentiate visible and invisible conditions by media properties naturally. For audio, participants can't see one another and thus gestures can't convey information to their partners. In this case, gestures can only serve the non-communicative or self-oriented function. In contrast, through media with visibility (V-Handvis and F2F), gestures can convey information when people communicate, and there may also exist communicative or other-oriented function with gesture use. In Table 4, iconic gestures are of greater correlation with idea count in visible conditions than in the invisible condition, but we didn't see a significant impact of iconic gestures on self's or partner's idea count.

To summarize, we found that metaphoric gestures have a positive impact on self's and partner's idea productivity. The effects of metaphoric gestures on ideation are independent of the property of communication media.

5 DISCUSSION

Collaborative idea generation is an intricate process that involves both individual ideation and social interaction. Our experiment sets up to closely examine the function of one kind of nonverbal communication behavior - hand gestures - during group brainstorming under different medium conditions. We seek to understand the potential influence of different types of hand gestures on creativity performance. In summary, the results don't support H1 (rich media improve group creativity outcomes), but they are partially in favor of H2 (media richness increases the presence of hand motion/gesture) and H3 (gestures have beneficial effects on people's creativity).

We note that brainstorming performance is independent of medium condition. The lack of medium effect on creative performance stays constant regardless of whether a group involves non-native speakers or not. Previous work has mixed findings and arguments regarding whether the choice of communication medium affects work outcomes, and whether language and cultural differences further interact with media properties [3, 31]. The current study contributes another set of empirical results to this line of work, and we didn't find that some simple manipulation of media properties can provide effective external support for group brainstorming, either in intralingual or interlingual groups.

5.1 Roles of Gestures in Computer-Mediated Group Brainstorming

In testing whether and how medium properties affect the process of communication, the results show that the frequency of gestures is influenced by the visibility of the communication media. When participants are visible to each other, the amount of hand motions and gestures is also amplified. The results support the hypothesis that a person's gesture usage will be influenced by whether his gestures can be seen by the partner. What's noteworthy is that the video conferencing tool we used in the study can achieve the same effect as face-to-face communication in enhancing the amount of gesture use in conversations.

We also see interesting patterns on how general hand movement as well as the use of specific types of gestures associated with idea generation performance. The general usage of hand movement (quantified as unit motions) correlated negatively with idea counts. Team members tend to produce fewer ideas if they have a greater amount of general hand movements. Nevertheless, when examining the details of how specific types of gestures affect idea generation, we found that participants who have more metaphoric gestures are more productive in creative outputs. Other types of gestures and general hand movement don't contribute to the outcome. Note that these specific types of gestures are systematically coded according to the definitions established from previous work [15, 20, 25]. More importantly, the impact of metaphoric gesture is both self-oriented

(i.e., impacting self's idea generation) and other-oriented (i.e., impacting partner's idea generation). This finding offers a novel contribution to the understanding of how speech-accompanying gestures may play a role in group creativity work.

In this study, we coded three types of semantic-rich gestures, including iconic gestures, metaphoric gestures, and pointing gestures. However, only metaphoric gestures showed a significant association with self's and partner's idea counts. Different from iconic gestures that are for gesturally representing physical objects, metaphoric gestures are about the presentation of abstract concepts with hand movements. While possible ideas on the three brainstorming topics would arguably involve a lot of physical objects (which may be represented with iconic gestures), it appears that the formation of ideas would still depend on the conceptual parts – the ideas that one express and share to their partner that are represented by metaphoric gestures. We believe that the finding is consistent with the theoretical perspective of creative cognition, as creativity requires associative reasoning that connects remote concepts for novelty. Metaphoric gestures are likely to be an effective device to foster connectivity between concepts through embodied expressions, which appears to be a component critical to the conceptual processing behind creativity.

5.2 Toward Intrinsic Group Creativity Support

Throughout the study, we have identified that the use of metaphoric gestures may play a pivotal role in shaping group brainstorming outcomes, including both self's and partner's idea generation. Also, we found that the utility of different communication media didn't change this result. Both findings suggest that it can be an ideal "intrinsic support" to use metaphoric gestures for group creativity. The choice of communication tool (external support) may become irrelevant for supporting group brainstorming. Rather, metaphoric gestures can be seen as an intrinsic tool that's applicable widely to both offline and online settings.

Another implication from the study is the viability of gesture training as a way to endow individuals with skills for productive gesture use. Individual training of semantic gesture use could be helpful for individuals and the whole group. There're potential benefits to individuals to use own hand gesture during brainstorming conversations and to specifically increase the attention to metaphoric gesture use. Real-time interventions and computer-based tutoring may be devised to improve people's ability in perceiving and producing these gestures in accompanying their idea generation.

Although our focus in this work is on using gestures as an intrinsic mechanism, the results also imply new directions for the design and application of data-driven machine learning techniques to facilitate brainstorming. With the accumulation of modality-rich datasets of hand gesture usage in conversations, data-driven models may be trained to distinguish metaphoric gestures, which involve presentations of abstract concepts, from other types of hand movement. These models can be applied to annotate or highlight these meaningful hand movements in ways that facilitate team worker's self-gesture production and training.

5.3 Limitations and Future Work

Our experiment has some limitations in the applications of these findings. During the conversation, gesture and hand movement patterns could potentially depend on the topics and contents of discussion. For example, some topics may involve more abstract concepts, and some others may involve interaction with physical objects, which may consequently affect what gestures people produce during the interaction. Therefore, it could be a limitation that we only examine a limited selection of brainstorming topics in this laboratory experiment.

Considering the marked difference between different individuals on personal communication styles, prior training, preferences and constraints in expression, and cultural inclination in hand

movement during conversations, the current work didn't examine whether and how semantic-specific gestures developed and employed by different populations (e.g., thumb-up as a gesture to represent affirmation) could be used as intrinsic brainstorming support. Rather, the paper can only speak to the utilities of functional gesture types like metaphoric and iconic gestures. We believe that including and accommodating individuals' gestural differences is also an important direction to pursue in future studies and design work.

6 CONCLUSION

The paper reported a laboratory experiment to investigate the effects of non-verbal hand movement and gestures in group brainstorming tasks in different medium conditions for communication. We found a significant association between metaphoric gestures and idea generation productivity during brainstorming discussions. Metaphoric gestures, which produce spatial cues to convey information of abstract concepts, show a positive impact on group idea generation with positive effects on both interlocutors of a group. The property of communication medium, however, doesn't affect creative outcomes. Visibility of a communication medium is potentially beneficial for boosting interlocutors' hand movements and gestures, yet a more specialized intervention that can support the use of metaphoric gestures is essential for making an impact on creativity. Results from this study can contribute to our understanding of how to shape gesture-based intrinsic brainstorming support in the future.

ACKNOWLEDGMENTS

The research is supported in part by UC Davis through Hao-Chuan Wang's startup grant. The authors would like to thank Kuan-Yu Lin for his assistance with data management and data preprocessing.

REFERENCES

- [1] Teresa M Amabile. 1996. *Creativity in context: Update to the social psychology of creativity*. Hachette UK.
- [2] Jounghoon Beh, David K Han, Ramani Durasiwami, and Hanseok Ko. 2014. Hidden Markov model on a unit hypersphere space for gesture trajectory recognition. *Pattern Recognition Letters* 36 (2014), 144–153.
- [3] Prashant Bordia. 1997. Face-to-face versus computer-mediated communication: A synthesis of the experimental literature. *The Journal of Business Communication* (1973) 34, 1 (1997), 99–118.
- [4] Stéphanie Buisine, Guillaume Besacier, Amélie Aoussat, and Frédéric Vernier. 2012. How do interactive tabletop systems influence collaboration? *Computers in human behavior* 28, 1 (2012), 49–59.
- [5] Mingyuan Chu and Sotaro Kita. 2008. Spontaneous gestures during mental rotation tasks: Insights into the microdevelopment of the motor strategy. *Journal of Experimental Psychology: General* 137, 4 (2008), 706.
- [6] Mingyuan Chu and Sotaro Kita. 2016. Co-thought and co-speech gestures are generated by the same action generation process. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 42, 2 (2016), 257.
- [7] Herbert H Clark, Susan E Brennan, et al. 1991. Grounding in communication. *Perspectives on socially shared cognition* 13, 1991 (1991), 127–149.
- [8] Fariborz Damanpour and Deepa Aravind. 2012. Organizational structure and innovation revisited: From organic to ambidextrous structure. In *Handbook of organizational creativity*. Elsevier, 483–513.
- [9] Alan R Dennis, Randall K Minas, and Akshay P Bhagwatwar. 2013. Sparking creativity: Improving electronic brainstorming with individual cognitive priming. *Journal of Management Information Systems* 29, 4 (2013), 195–216.
- [10] Alan R Dennis and Barbara H Wixom. 2002. Investigating the moderators of the group support systems use with meta-analysis. *Journal of Management Information Systems* 18, 3 (2002), 235–257.
- [11] Michael Diehl and Wolfgang Stroebe. 1991. Productivity loss in idea-generating groups: Tracking down the blocking effect. *Journal of personality and social psychology* 61, 3 (1991), 392.
- [12] Paul Ekman and Wallace V Friesen. 1971. Constants across cultures in the face and emotion. *Journal of personality and social psychology* 17, 2 (1971), 124.
- [13] R. Brent Gallupe, Alan R Dennis, William H Cooper, Joseph S Valacich, Lana M Bastianutti, and Jay F Nunamaker Jr. 1992. Electronic brainstorming and group size. *Academy of Management Journal* 35, 2 (1992), 350–369.

- [14] Florian Geyer, Jochen Budzinski, and Harald Reiterer. 2012. IdeaVis: a hybrid workspace and interactive visualization for paper-based collaborative sketching sessions. In *Proceedings of the 7th Nordic Conference on Human-Computer Interaction: Making Sense Through Design*. ACM, 331–340.
- [15] Susan Goldin-Meadow. 2005. *Hearing gesture: How our hands help us think*. Harvard University Press.
- [16] Joy Pual Guilford. 1950. Creativity. *American Psychologist* 5, 9 (1950), 444–454.
- [17] François Guimbretire, Maureen Stone, and Terry Winograd. 2001. Fluid interaction with high-resolution wall-size displays. In *Proceedings of the 14th annual ACM symposium on User interface software and technology*. ACM, 21–30.
- [18] Gunnar Harboe and Elaine M. Huang. 2015. Real-World Affinity Diagramming Practices: Bridging the Paper-Digital Gap. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI ’15)*. ACM, New York, NY, USA, 95–104. <https://doi.org/10.1145/2702123.2702561>
- [19] Kevin Hogan. 2003. *Can’t get through: eight barriers to communication*. Pelican Publishing.
- [20] Sotaro Kita, Martha W Alibali, and Mingyuan Chu. 2017. How do gestures influence thinking and speaking? The gesture-for-conceptualization hypothesis. *Psychological review* 124, 3 (2017), 245.
- [21] Lassi A. Liikkanen, Kai Kuikkaniemi, Petri Lievonen, and Pauli Ojala. 2011. Next Step in Electronic Brainstorming: Collaborative Creativity with the Web. In *CHI ’11 Extended Abstracts on Human Factors in Computing Systems (CHI EA ’11)*. ACM, New York, NY, USA, 2029–2034. <https://doi.org/10.1145/1979742.1979929>
- [22] Kuan-Yu Lin. 2017. *A Multidimensionally Codified Dataset of Speech-Accompanying Gesture in Cross-Lingual Communication*. Master’s thesis. Department of Computer Science, National Tsing Hua University.
- [23] Kuan-Yu Lin, Seraphina Yong, Shuo-Ping Wang, Chien-Tung Lai, and Hao-Chuan Wang. 2016. HandVis: Visualized Gesture Support for Remote Cross-Lingual Communication. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA ’16)*. ACM, New York, NY, USA, 1236–1242. <https://doi.org/10.1145/2851581.2892431>
- [24] Zhe Lin, Zhuolin Jiang, and Larry S Davis. 2009. Recognizing actions by shape-motion prototype trees. In *Computer Vision, 2009 IEEE 12th International Conference on*. IEEE, 444–451.
- [25] David McNeill. 1992. *Hand and mind: What gestures reveal about thought*. University of Chicago press.
- [26] John Neter, Michael H Kutner, Christopher J Nachtsheim, and William Wasserman. 1996. *Applied linear statistical models*. Vol. 4. Irwin Chicago.
- [27] Jay F. Nunamaker, Alan R Dennis, Joseph S Valacich, Douglas Vogel, and Joey F George. 1991. Electronic meeting systems. *Commun. ACM* 34, 7 (1991), 40–61.
- [28] Paul B Paulus and Vincent R Brown. 2007. Toward more creative and innovative group idea generation: A cognitive-social-motivational perspective of brainstorming. *Social and Personality Psychology Compass* 1, 1 (2007), 248–265.
- [29] Pramod Kumar Pisharady and Martin Saerbeck. 2015. Recent methods and databases in vision-based hand gesture recognition: A review. *Computer Vision and Image Understanding* 141 (2015), 152–165.
- [30] Deepa K. Ray and Nicholas C. Romano. 2013. Creative Problem Solving in GSS Groups: Do Creative Styles Matter? *Group Decision and Negotiation* 22, 6 (01 Nov 2013), 1129–1157. <https://doi.org/10.1007/s10726-012-9309-3>
- [31] Ronald E Rice. 1992. Task analyzability, use of new media, and effectiveness: A multi-site exploration of media richness. *Organization science* 3, 4 (1992), 475–500.
- [32] Yang Shi, Yang Wang, Ye Qi, John Chen, Xiaoyao Xu, and Kwan-Liu Ma. 2017. IdeaWall: Improving creative collaboration through combinatorial visual stimuli. In *Proceedings of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing*. ACM, 594–603.
- [33] Ben Shneiderman. 2009. Creativity support tools: A grand challenge for HCI researchers. In *Engineering the User Interface*. Springer, 1–9.
- [34] Yale Song, David Demirdjian, and Randall Davis. 2011. Tracking body and hands for gesture recognition: Natops aircraft handling signals database. In *Automatic Face & Gesture Recognition and Workshops (FG 2011), 2011 IEEE International Conference on*. IEEE, 500–506.
- [35] Mikel Sorli and Dragan Stokic. 2009. *Innovating in product/process development: Gaining pace in new product development*. Springer Science & Business Media.
- [36] JH Steiger. 1980. Tests for comparing elements of a correlation matrix. *Psychological Bulletin* 87 (01 1980), 245–251. <https://doi.org/10.1037//0033-2909.87.2.245>
- [37] Robert J Sternberg and Robert Jeffrey Sternberg. 1999. *Handbook of creativity*. Cambridge University Press.
- [38] Jonathan Tompson, Murphy Stein, Yann Lecun, and Ken Perlin. 2014. Real-time continuous pose recovery of human hands using convolutional networks. *ACM Transactions on Graphics (ToG)* 33, 5 (2014), 169.
- [39] Hao-Chuan Wang, Dan Cosley, and Susan R. Fussell. 2010. Idea Expander: Supporting Group Brainstorming with Conversationally Triggered Visual Thinking Stimuli. In *Proceedings of the 2010 ACM Conference on Computer Supported Cooperative Work (CSCW ’10)*. ACM, New York, NY, USA, 103–106. <https://doi.org/10.1145/1718918.1718938>
- [40] Hao-Chuan Wang and Chien-Tung Lai. 2014. Kinect-taped communication: using motion sensing to study gesture use and similarity in face-to-face and computer-mediated brainstorming. In *Proceedings of the SIGCHI Conference on*

Human Factors in Computing Systems. ACM, 3205–3214.

- [41] William Widjaja and Makoto Takahashi. 2016. Distributed interface for group affinity-diagram brainstorming. *Concurrent Engineering* 24, 4 (2016), 344–358.
- [42] Takeshi Yabe and Katsumi Tanaka. 1999. Similarity retrieval of human motion as multi-stream time series data. In *Database Applications in Non-Traditional Environments, 1999.(DANTE'99) Proceedings. 1999 International Symposium on*. IEEE, 279–286.
- [43] Ho-Sub Yoon, Jung Soh, Younglae J Bae, and Hyun Seung Yang. 2001. Hand gesture recognition using combined features of location, angle and velocity. *Pattern recognition* 34, 7 (2001), 1491–1501.

Received March 2019; revised June 2019; accepted July 2019