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Gesture and Language Production in Communication through Bar Graphs

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Abstract

Bar graphs and line graphs are commonly used ways of graphical communication. Due to the difference in their perceptual visuo-spatial properties, they facilitate comprehension of different events. Bar graphs are commonly used in the domain of precipitation although the data intrinsically carry information that is averaged over long time spans. In this study, we investigate how the presence of incongruence between consecutive graph pairs influences conceptualization of the represented information about precipitation. For this, we analyzed gestures and verbal descriptions produced by the participants as indicators of event conceptualizations. The results of the experimental investigation reveals that when incongruent graph pairs are presented, the participants show tendency to produce directional gestures that accompany the verbal descriptions of the specific regions represented by one/two bars, indicating that bar graphs presented in consecutive order facilitates comprehension of trend information as well as of discrete entities. Additionally, the presence of incongruence seems to enhance the production of comparative words accompanied with non-directional gestures.

Keywords: Gesture production; language production; bar graph comprehension; multimodal communication

Visualization – Bar and Line Graphs

The primary goal of visualizing data is to (re-)present them in a format more suitable for using them in thinking, problem solving and communication (This view is taken implicitly or explicitly in most seminal publications on graphs, as well as on visualization during the last decades, see, e.g., Tufte 1983, Kosslyn 1989, 2006, Hegarty 2011). Line graphs and bar graphs are successful means to present data, both in the task of analyzing the data and in the task of communicating the results of data analysis. Communicating visualized data using bars or lines is used extensively in scientific publications, textbooks, magazines and news-papers; Zacks, Levy, Tversky, & Schiano's (2002) study on the use of graphs in the print media shows that line graphs and bar graphs are the dominant, i.e. most frequently used, types of graphs in addressing non-experts in communication through graphs.

The primary gain in using graphs is not to make individual data points visible but to provide visual access to relations between data points ('*x1-y1 has a larger y-value than x2-y2*') or to second-order entities as 'trends'. This advantage can be ascribed to humans' pattern perception processes, in particular visual chunking (see, Shah, Mayer & Hegarty, 1999). Beyond these commonalities, there seem to be functional differences between bar graphs and line graphs. Zacks and Tversky (1999) investigate the *bar–line message correspondence*, which considers the systematic relations between the type of graph used and the type of message intended to be communicated. Zacks and Tversky point to a preferred "use of bar graphs to depict comparisons among discrete data points, and line graphs to depict trends" (p. 1073). On the other hand, participants in their experiments had a strong tendency for relational descriptions (e.g., "A is higher than B") after comprehending bar graphs and for process-oriented second-order descriptions as 'trends' (e.g., "X increases from A to B") in the of line graphs (p. 1078). Shah, Meyer and Hegarty (1999) report—with respect to these tendencies—a comparable view, but in presenting their *perceptual organization hypothesis* they lay an additional focus on Gestalt principles realizable in the graph types in question.

In addition to text-graphics documents, in many professional communication settings as well as in classroom settings, graphs, spoken language, and often gestures, accompany each other forming multimodal communication. In dynamic communication of this type, often recipients have to integrate messages communicated by a sequence of graphs. The present study investigates participants' verbal descriptions of pairs of succeeding bar graphs and the gestures produced during these descriptions. The first graph of each pair depicts averages (monthly precipitation over three decades) whereas the second graph depicts instances (monthly precipitation of a specific year). Due to the average-instance constellation, commonalities and differences, which we regard as 'incongruences', between the graphs play a major role in comprehending the graphs and in following production of verbal descriptions; in this setting the *within-the-bar bias* (Newman & Scholl, 2012) did not occur.

Gesture and Language

The studies on gesture-language interaction are mainly based on the assumption that concepts are sensorimotor, by emphasizing that they are grounded in physical world and based on perceptual experience (Barsalou, 1999; Garbarini & Adenzato, 2004). There are several frameworks that investigate gestures from various perspectives, but all of them agree on that gestures rely on spatial representations. According to the GSA framework ('Gesture-as-simulated-action', Hostetter & Alibali, 2008), one of the frameworks that focus on how gestures are produced, gestures are byproduct of speech. In particular, linguistic planning involves simulation of visuo-spatial events; this activation during articulation is considered as a source of speech accompanying gestures. Another framework, that is closely aligned with the GSA framework and that focuses on how gesture and language production are integrated is the "Interface Hypothesis" (Kita & Özyurek, 2003). The preparation for language production requires organization of rich and comprehensive information into small packages that contain appropriate amount of informational complexity within a processing unit. According to the "Interface Hypothesis", this processing unit may correspond to a clause for speech production, and the contents of a representational gesture are affected by the organization of these information-processing units, which are prepared for speech production. Therefore this close relationship between the gestures and language makes gestures an effective tool in the assessment of the reader's conceptualization of event, which is simultaneously described verbally (Goldin-Meadow & Beilock, 2010).

Although the interaction between language and gesture has been investigated for the past several decades in a variety of domains (Goldin-Meadow, 2003; Hostetter & Alibali, 2008; Hostetter & Sullivan, 2011; McNeill, 1992; 2005) specific investigations of graph comprehension in interaction with language and gesture, has been one of the scarce topics in the field of multimodal interaction. Gestures and graphical communications are visuo-spatial modalities, and they share similar perceptual visuo-spatial features to convey meaning such as quantity, direction and relations. (Tversky, 2011). Therefore during describing a visualization with an accompanying gesture, the places (or punctual events in the domain of our interest) become "fleeting positions" while marks and forms on the visualization become "fleeting actions" (Tversky et. al., 2009). Following this idea originated from the resemblance between two modalities, the vocabularies of gestures, speech and diagrams can be considered as parallel (Tversky, 2011).

For instance, within the context of communication through graphs, a fluctuating increase in a line graph may be verbally described by the term "increase" and it may be simultaneously accompanied by a gesture that represents the fluctuation in the increase. One of the studies focused on communication through line graphs (Acartürk & Alaçam, 2012), showed that the perceptual features of the annotation that highlights the event presented in the sub-region of the graph (e.g., a graphical cue such as an arrow) have an effect on the conceptualization of the event, and this effect is observable in the gestures produced by graph readers. The results of this study indicated that in order to emphasize processes (e.g., increase, decrease) more vertical and diagonal gestures were produced by humans, whereas more pointing gestures were produced for emphasizing punctual states (e.g., a peak).

To sum-up, gestures can be used as a tool to assess how the graph reader interprets the graph and conceptualizes the event represented by the graph, because gestures provide additional information which is aligned with the visuo-spatial aspects of the graphical communication. Therefore gesture analysis helps to detect the hard-to-encode information and disambiguates, that are generally highlighted with the presence of accompanying gestures.

In the domain of bar graph comprehension and in communication through bar graphs, differences in gesture production are expected due to perceptual properties of bar graphs that contrast to those of line graphs. Bar graphs enhance comprehension of discrete events, since each bar on the graph perceptually corresponds to a single entity in the domain of discourse, while line graphs facilitate comprehension of trends. On the other hand, although the perceptual properties of graphs are crucial in the conceptualization, the comprehension is still highly dependent on their conceptual properties too (Zacks & Tversky, 1999). Our goal in this study is to investigate the conceptualization of events that belong to average data (in the domain of precipitation, which is frequently represented with bar graphs), by analyzing the gestures produced during the description of the represented events.

We hypothesize that relations between events of the same domain that are represented with the same graph type (bar graphs) may be conceptualized differently when a perceptual change regarding small areas on the graph (in the case of incongruence) is introduced. In our experimental design, comparisons between regions of two consecutive graphs are required, rather than a comparison between two discrete entities in one graph. Therefore, in addition to discrete comparisons, trend evaluation may also play a major role during comprehension. Moreover, the differences in event conceptualization are examined by analyzing the speech accompanied gestures produced by the graph readers during the verbal description.

Experiment

Participants, Materials and Design

Twelve participants (university students at the Department of Human Computer Interaction, University of Hamburg, 4 female, Mean age = 24.2, SD = 3.21) participated in the study. The experiment was conducted in German, the native language of all participants.

Each participant was presented six precipitation graph pairs (two additional pairs of the graphs were employed for the familiarization part). The graphs represented average precipitation data of various cities. In the first graph of each graph pair, a bar graph that represented the monthly precipitation data average for the time period between 1970 and 2011 was shown for 10 seconds on a computer screen (the data were retrieved from Turkish State Meteorological Service). After the graph disappeared, the participant was asked to present a single-sentence verbal description of the first graph to a hypothetical audience. After then, the second graph of the graph pair was presented. The second graph represented monthly precipitation data for the specific year (2011 for all stimuli) for the same city presented before, again for 10 seconds. The participant was asked to give a verbal description by taking into account both the first graph and the second graph. This procedure was applied for 6 graph pairs. The first graph in each graph pair was always the representation of the monthly precipitation data averaged over 1970-2011, whereas the second graph was always the representation of the monthly precipitation data for 2011 only (see Figure 1 and Figure 2). Participants' spontaneous gestures for 6 precipitation-graph pairs were video-recorded. The participants were informed only about producing verbal descriptions, therefore the gestures produced by the participants were spontaneous gestures.

The second within-subject condition in the experiment design was the congruency between the two graphs in each graph pair. In three graph pairs, the second graph was the same as the first graph, thus leading to a congruent graph pair (Figure 1). In the other three graph pairs, the second graph involved deviant bars (compared to the first graph), thus leading to an incongruent graph pair (Figure 2). The deviant bars were obtained by either increasing or decreasing the value of two/three bars drastically. The motivation for testing the congruency effect was to investigate how conceptualization differed when the congruency between the two related stimuli was systematically changed, even in the same domain and same graph type.

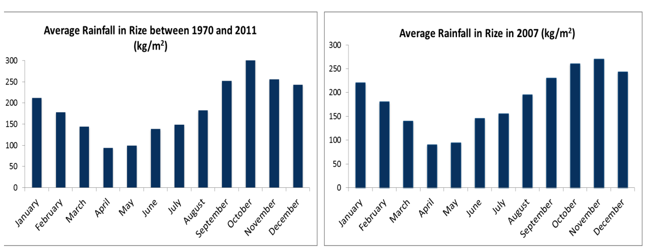

Figure 1: Sample graph for the average data (left) and the data for "instance" year with congruent graph (right)

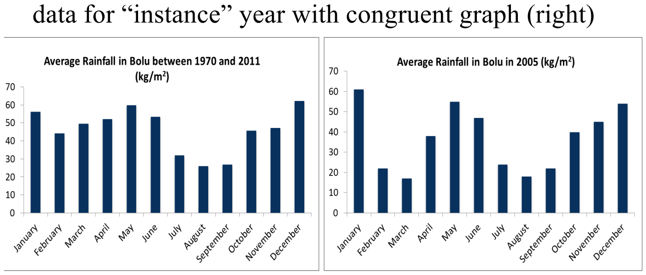

Figure 2: Sample graph for the average precipitation data (left) and the data for "instance" year with anomaly in the distribution (right)

Coding

The main experiment session consisted of six pairs of stimuli, all presented to each participant. Twelve participants produced 144 sentences in verbal descriptions, 547 time period phrases in the sentences and 165 gestures that accompanied the verbal descriptions.

Gesture Annotation. The coding scheme was based on both McNeil's (2005) semantic gesture classification and syntactic features. The ANVIL software tool was employed for gesture annotation. In the first classification, the gestures were categorized according to their semantic classifications, such as beat gestures and representational gestures. Then each representational gesture was classified in terms of its directionality: non-directional, and directional (vertical/diagonal/horizontal). According to this classification, the hand movements conducted in small space without having any directed trajectory were categorized as non-directional gesture, whereas the hand movements with aimed trajectory on the air were classified as directional gestures.

Spoken Language Transcription. The sentences produced by the participants were transcribed and then the parts of the sentences were segmented into phrases. After this process, the phrases, which referred to temporal information on the graph, were classified into two categories in terms of the size of time interval. The time phrases that referred to multiple bars (such as in "summer" and "towards to winter") were classified into the "long-term" category. The second group covered the time phrases for specific time intervals (such as "in May" or "in July and August"). Finally, the phrases that referred to the previous graph in the comparative context were classified into the "comparatives" category.

Results

The results revealed similar time spent for the description for the overall-data graph (i.e., the graph that represented monthly data averaged over 1970-2011, $M = 30.2$ seconds, $SD = 10.6$) and for the specific-year graph ($M = 30.6$ seconds, $SD = 11.3$; $t = -0.38$, $p > .05$. As for the congruency, the participants spent similar time both for the congruent graphs ($M = 28.4$ seconds, $SD = 10.9$) and for the incongruent graphs ($M = 32.8$, $SD = 11.7$; $t = -0.93$, $p > .05$). Sample pairs of participants' verbal descriptions are presented in Table 1 and Table 2 below.

Table 1: Sample description for a congruent graph (translated from German)

Precipitation averaged over 30 years:
Looking at the past 30 years in Antalya there ***was almost no rain*** **in the months of summer**, but instead very very much **in winter**, it ***falls and then rises*** **from the winter to the summer** very strongly, **in August** I believe ***no rain at all***, **in the adjacent months** only ***very very little.***

The specific year:

Also in Antalya 2011 ***reflects*** the past 30 years, because here we ***also have relatively little rain*** **in the summer** and in contrast very much **in the winter** and it ***is a quite steady decline and increase*** **in the months in between.**

Table 2: Sample description for an incongruent graph (translated from German)

Precipitation averaged over 30 years:

In this graph, again in June, July and August, **in the months of summer** we ***have the least precipitation*** and it ***increases*** **from August to September/December and January**, where ***the highest point is reached*** and **from January** it ***decreases*** again slightly until it ***reaches the lowest point***.

The specific year:

In this graph it is striking, that does not look like the average at all, ***because at the point where the lowest point*** should be we now ***have a little deflection upwards*** with much precipitation and also ***have less precipitation*** than expected ***in the months where a lot of rain falls***.

In order to understand the underlying differences and similarities induced by the congruency, the speech parts accompanied by the gestures were focalized. The gestures were classified according to temporal information ("*specific time*" and "*long term time*" interval) referred in the accompanied speech parts as explained in the "Coding" section. Eight of 12 participants (2 female, *Mean age = 24.3, SD = 0.98*) produced gestures during verbal description of the graphs. Five of those eight participants produced representational gestures (N=146) classified according to scheme presented above. Two coders analyzed and classified the data. Interrater reliability between coders was calculated by Cohen's kappa. The results revealed an agreement value of .77. According to Landis and Koch (1977), a value above .61 indicates substantial interrater agreement. The results of Chi-square test revealed that during the congruent graph description, the gestures accompanied to "specific time" phrases (N=25) were observed more than that for "long term" phrases (N=7), $\chi2(1) = 10.1, p < .05$. On the other hand, in the description of the incongruent graphs, similar usage of gesture accompanied "specific" (N=30) and "long-term" phrases (N=20) was observed ($\chi2(1) = 2.0, p > .05$). The production of non-directional and directional gestures were similar within congruency conditions, see Table 3.

Table 3: Number of gestures classified w.r.t. temporal information (NDir: Non-Directional, Dir.: Directional)

	Congruent		Incongruent	
	NDir.	Dir.	NDir.	Dir.
Specific	10	15	19	11
Long-Term	4	3	9	11

The overall results that focuses on the difference between overall and instance graphs showed that the participants tend to produce the same amount of gesture for the first stimuli corresponding to overall precipitation amount for 30 years (N=64) and for the second stimuli corresponding to specific year 2011 (N=82), $\chi2(1) = 2.22$, $p > .05$. Additionally, the number of non-directional gestures (N=78) and directional gestures (N=68) produced during the course of verbal descriptions were similar. see Table 4 ($\chi2(1) = .65, p > .05$).

Table 4: Number of gestures produced during the verbal description for "Overall" and "Instance" Graphs (NDir: Non-Directional, Dir.: Directional)

	Congruent		Incongruent	
	NDir.	Dir.	NDir.	Dir.
Overall	18	18	18	10
Instance	14	18	28	22

Since the congruency is always presented in the second stimulus ("Instance" graph), more detailed analysis was conducted on the scores of second stimulus (see Table 4). The results of a Chi-Square test, conducted to compare the overall number of gesture accompanied time phrases across different congruency groups, showed that more gestures were produced during incongruent graph description (N = 50) than that during congruent graph description (N = 32), $\chi2(1) = 3.95, p < .05$. On the other hand, the results of the test, which compared the number of directional gestures (N = 40) and non-directional gestures (N = 42) that accompanied the phrases, revealed no significant difference, $\chi2(1) = .05, p > .05$. Similarly, there was also no difference within the incongruent graphs ($\chi2(1) = .72, p > .05$) and congruent graphs ($\chi2(1) = .50, p > .05$) in terms of the directionality of the gesture. However, in the description of the incongruent graphs, the participants produced more directional gestures compared to their previous description about overall data, indicating that incongruence on the data had a positive effect on the directional gesture production, ($\chi2(1) = 4.5, p < .05$, while it had no effect on the production of non-directional gestures (see Figure 3). For the description of the congruent graphs, no such a significant difference in the production of non-directional and directional gestures was observed.

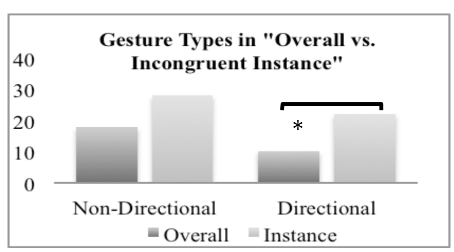

Figure 3: Gestures that accompany the description of the overall graph and the incongruent graph

More detailed analysis on the sub-regions with the incongruent data revealed the source of the increase in the directional gestures. The results of Chi-square test showed that for the description of the incongruent regions, more directional gestures (N = 12) were observed than non-directional gestures (N = 3), $\chi^2(1) = 5.40, p < .05$. See Table 5 for the examples of produced sentences and Figure 2 for the corresponding graphs. These regions represented with one or two bars on the graph, their descriptions were accompanied with directional gestures.

Table 5: Directional Gestures that accompany the descriptions for the regions that present incongruence (translated from German)

Overall Rainfall over 30 years (see Figure 2 – Left for the corresponding graph):
Ok, so here we have seen **<u>in the first months the rainfall was quite … (non-directional)</u>**, while in the months of summer relatively fast, quite low at about 20 and within the year the rainfall increased really significantly to **<u>about 30 I assume (directional).</u>**
The specific year (see Figure 2 – Right for the corresponding graph) :
We have seen, that in this year the rainfall **<u>came off a little more steady (horizontal)</u>**. They have decreased **<u>from month to month and overall in the first months came off smaller (diagonal)</u>** in general but in the months of summer the rainfall increased a little, but not so much, as now **<u>the rainfall in the former months have won (non-directional),</u>** especially not **<u>this time relatively steady decreasing from the average rainfall (diagonal)</u>** and in the end again there was a little increase.

Additionally, the verbal data that belongs to twelve participants (regardless of the accompaniment of the gesture) were also analyzed in order to examine the use of comparatives across the two congruency conditions. For each participant, the number of descriptions that referred to the overall graph at least once was counted for each congruency condition. The analysis showed that the participants tend to refer to the first graph in the graph pair, the overall precipitation graph, more in the description of the incongruent graph (M = 2.4, SD = 1.0) than in the description of congruent graph (M = 1.9, SD = 1.1), $Z = -2.12, p < .05$, indicating that the incongruence between the overall graph and the specific-year graph enhanced the production of the comparative phrases. A similar pattern was observed for the comparatives accompanied by gestures: more comparative phrases in the incongruent graph description (N = 14) were accompanied by a gesture than in the congruent graph description (N = 5), $\chi^2(1) = 4.26, p < .05$. Additionally, the comparative speech parts are mainly accompanied with the non-directional gestures (N=14), $\chi^2(1) = 5.56, p < .05$.

Discussion

The goal of the experimental investigation was to analyze the role of congruency between two graphs in a set of graph pairs in conceptualization of bar graphs. The first graph in the graph pair was always a monthly representation of 30-year average of precipitation data. The second graph was always a monthly representation of precipitation for a specific year. The results were analyzed in terms of the analysis of verbal descriptions of the participants, as well as the gestures produced by the participants. The results of the experimental investigation revealed that, in general, the participants spent similar amount of time to describe the congruent and incongruent situations with respect to overall graph (i.e., the graph which represented monthly precipitation data averaged over 30 years). On the other hand, a more frequent use of comparatives was observed in the incongruent condition during the course of the description of the second graph in the graph pair. This finding indicates that the participants noticed the difference between the overall graph and the specific-year graph and they found this anomaly worth mentioning in their verbal descriptions. Moreover, the comparatives were accompanied by non-directional gestures that aimed at referring to the previous graph in the graph pair.

As for the production of gestures, there was no difference in the type of the gestures that accompanied the speech parts. However, while gestures during congruent graph´s description mainly were correlated with specific time phrases, during incongruent graph´s description, gestures for "specific" and "long term" phrases were similar. This may indicate that unlike congruent graphs´ description, description of two relational but incongruent events represented with bar graphs requires "as-a-whole" comprehension of the events as well as focusing on the specific regions of the graphs. Additionally, the number of gestures produced during incongruent graph description was higher than that during congruent graph description. Furthermore, when the incongruence was presented, differences in the event description between the incongruent graph and the overall graph were observed in the production of directional gestures: the participants produced more directional gestures for the specific-year graph compared to the overall graph, whereas there was no significant difference in the production of non-directional gestures. The increase in the number of directional gestures was considered as a likely indicator of a different conceptualization. Therefore, a more detailed analysis was conducted on the small region in the graph where the incongruence was presented. In the descriptions of those regions, the graph readers tended to use more directional gestures, indicating that those regions were interpreted as a trend, although those regions referred to a specific time period on the bar graph representation.

Conclusion and Future Work

In this study, we investigated the conceptualization of events by focusing on the gesture production and verbal descriptions in the precipitation domain represented by bar graphs. Although the previous research on graph comprehension provides evidence that bar graphs are preferred to emphasize discrete entities, rather than trends, experts in specific domains, in our case meteorology, frequently use them. As the current study demonstrates as well, bar graphs are highly effective to communicate trends. The specific regions, where the incongruence is presented, are conceptualized as trends and the descriptions are accompanied by directional gestures. The perceptual properties of bar graphs that emphasize the entities may be helpful to catch the incongruence, but it also seems that the events are interpreted as "processes", similar to typical comprehension of the events represented by line graphs (Zacks & Tversky, 1999). In order to understand the underlying mechanism in more detail, our future research will address the preference of the terms used to emphasize two different events, "process" *such as increase or fluctuating* and "state" *such as peak, maximum,* and their co-existence with the gestures in the case the congruency was systematically changed. Moreover, applying same experimental design with line graphs will also shed light into the effect of graph type on the conceptualization of the event that requires extrinsically comparison and also requires intrinsically trend evaluation.

Furthermore, the analysis of gestures seems as an effective tool to assess the graph reader`s comprehension and to obtain the important aspects considered as worth to mention in verbal descriptions. In addition to the rich data provided by verbal descriptions, the gestures point out the hard-to-encode information and conceptually salient points, as well as perceptually salient regions and entities of the graph.

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