Investigation of Haptic Line-Graph Comprehension Through Co-Production of Gesture and Language

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Abstract

In communication settings, statistical graphs accompany language by providing visual access to various aspects of domain entities, such as conveying information about trends. A similar and comparable means for providing perceptual access is to provide haptic graphs for blind people. In this study, we present the results of an experimental study that aimed to investigate visual line graphs and haptic line graphs in time domain by means of gesture production as an indicator of event conceptualization. The participants were asked to produce single sentence summaries of visual graphs and haptic graphs. The gestures that were produced during the course of verbal descriptions were analyzed. The results showed that directional gestures accompanied verbal descriptions of both visual graphs and haptic graphs. Further analyses revealed differences between visual graphs and haptic graphs in terms of type of gestures, as well as the production rates.

Keywords: Gesture production; haptic graph comprehension; line graphs; multimodal communication

Introduction

Documents combining text and pictorial (re-)presentations, such as graphs, diagrams, drawings or maps (covered in the following by the term *depiction*), are wide-spread in print media and in electronic media. Such multimodal documents cover newspaper articles, educational material as well as scientific papers. In addition to text-graphics documents, in many communication settings—e.g., conference presentations or classroom settings—spoken language, depictions and often also gestures, accompany each other forming multimodal communication acts.

In the present paper we focus on depictions that visualize data, such as by line graphs or bar 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 (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 newspapers; 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 graph types. Haptic presentations of graphs (henceforth, haptic graphs) provide suitable means for blind and visually impaired people to acquire knowledge about data sets (Abu Doush, Pontelli, Son, Simon & Ma, 2010). Whereas visual perception supports comprehension processes which switch between global and local aspects of a graphical representation, haptic perception has a more local and in particular a more sequential character. Thus, compared to visual graphs, one drawback of haptic graphs is the restriction of the haptic sense regarding the possibility of simultaneous perception of information (Loomis, Klatzky & Lederman, 1991). Comprehension of haptic line graphs is based on explorations processes, i.e. hand movements following the lines with the goal to summarize information of geometrical properties of the line explored; in particular, the detection of shape properties—as concavities and convexities, as well as maxima and minima—is of major importance, see Figure 1 exemplifying a haptic line graph and Phantom Omni Haptic Device. It is relatively unproblematic to detect haptically the shape of simple graph line with only a single global maximum, whereas graphs with several local maxima require—depending on their complexity—additional assistance for most users of haptic graphs. For resolving some difficulties in haptic exploration of graphs, providing additional information, such as auditory assistance through the auditory channel, has been proved to be helpful (Yu & Brewster 2003). Sonification or speech can support—for example—the detection of local and global extrema of graph lines.

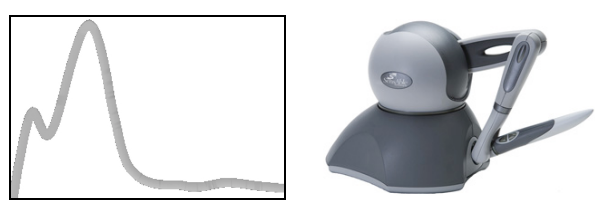

Figure 1: Sample haptic graph (left) and Phantom Omni® Haptic Device (right)

For designing haptic graphs augmented by audio assistance (sonification or speech) it is necessary to determine, which information depicted by the graph or by segments of the graph, are appreciated as important (Habel & Acartürk, 2012). The analysis of verbal descriptions and of gestures seems as effective tools 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.

Communicating about Graphs: Gesture and Language

The interaction between language and gesture has been investigated for the past several decades in a variety of domains from different frameworks (e.g., Goldin-Meadow, 2003; Hostetter & Alibali, 2008; McNeill, 2005; Kita & Özyürek, 2003). All of the frameworks agree on that gestures rely on spatial representations. According to Tversky (2011), gestures and graphical communication are visuo-spatial modalities, and they share similar perceptual visuo-spatial features to convey meaning such as quantity, and relations. Therefore the resemblance between two modalities yields the idea that the vocabularies of gestures, speech and diagrams can be considered as parallel (Tversky, 2011). For instance, 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) indicated that in order to emphasize processes (e.g., *increase*, *decrease*) more vertical and diagonal gestures were produced during the course of verbal descriptions, 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 conceptualizes events represented by a line graph. Towards designing haptic graphs for visually impaired people, we believe that the investigation of gestures, eye movements, language and haptic exploration in interaction has the potential to provide insights for human interpretation of the represented information (Alaçam, Habel & Acartürk, 2013). We also believe that as well as conducting experiments with visually impaired people, having insight about which information is relevant for sighted graph readers is highly crucial. Our goal in this study is to investigate the salient aspects of the event which is highlighted by sighted graph readers not only in their verbal description but also in their gestures for the graphs represented in different modalities; haptic versus visual in order to localize the information that is candidate for verbal/audio assistance for haptic representations.

Experiment

This experiment was conducted in two conditions in a within subject design employing a total of twenty participants. In the first condition, the participants explored line graphs verbally. In the second condition, the graphs were presented on the computer screen and the participants had visual access to the graphs. In both conditions, after the participants explored the graph, they were asked to produce single sentence summaries of bird population graphs.

Condition 1: Haptic Line Graphs

Participants, Materials and Design. Nine participants (students at the University of Hamburg, 4 female, Mean age = 25, SD = 6.3) were employed for this condition. The experiment was conducted in German, the native language of all participants. Before starting haptic graph exploration, all participants completed a warm-up session that aimed to familiarize the participants with Phantom Omni® Haptic Device (Figure 1). In this warm-up session, the participants explored the character set consisting of two letters (L and G) and two digits (2 and 3). Those characters were chosen because of their resemblance to graphs by having edges and curves. Additionally, in order to assess participants' comprehension, the characters were presented in different rotation (normal, left rotated, right rotated and upside down), and then they were asked to tell what the character and its direction were. The experiment session started only if the participants succeeded in at least 9 trials. In the experiment session, each participant was presented five haptic line graphs with smooth edges. In the instructions session, the participants were informed that the graphs represented populations of bird species in a lagoon, see Figure 1 (two additional graphs were employed for the familiarization part). Haptic graph exploration was performed by moving the handle of the haptic device, which can be moved in all three spatial dimensions (with six degree-of-freedom). In haptic graph representation, the graph (the line of the line graph) was represented by engraved concavities on a horizontal plane; therefore the graph readers perceived the line as deeper with respect to other area on the surface. Due to restriction of haptic graph representations, the numerical labels were not presented. After they completed the haptic exploration without time limitation, the participants were asked to present single-sentence verbal descriptions of the graphs to a hypothetical audience. Participants' gestures for five population-graphs of bird species were video-recorded. The participants were asked to produce verbal descriptions. This is exemplified by

(1) It is similar to the one before with the difference that it was a bit deeper. Then it had a small peak, than a large peak and somewhere in the midfield it levels off.

a translation of a German description, given for the graph depicted in Figure 1. Description (1) was accompanied by a gesture sequence depicted in Figure 2. Since gesturing was not mentioned in the instructions, the gestures produced by the participants were spontaneous gestures.

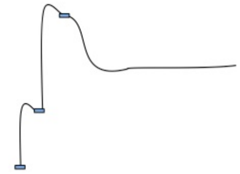

Figure 2: Trajectories of the gestures accompanying the verbal description *(the rectangles indicate pauses on the gestural movement)*

Gesture Annotation. The experiment session consisted of five haptic line graphs for nine participants, leading to 45 sentences in verbal descriptions, and 88 representational gestures.

The coding scheme was based on both McNeill's (2005) semantic 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. Directional gestures were also classified into two categories; (i) single direction, and (ii) multiple directions. The gestures that contained movement in only one direction (such as upward) were classified under the "single direction" category, while category of "multiple directions" covers the gestures formed with the combinations of one-directional gestures. Two coders analyzed and classified the data. Interrater reliability was calculated by Cohen's kappa. The results revealed a value of .70 that indicates substantial interrater agreement.

Results. Gesture data that belong to eight of the nine participants was evaluated since one of the participants had a misconception about the time domain, comprehending the x axis as months instead of years. All participants produced gesture for at least one stimulus during their session. For 75% of the protocols, speech-accompanying gestures (*N* =88) were observed. The results of a chi square test showed that more directional gestures (*N* = 76) were produced than non-directional gestures (*N* = 12), $\chi^2(1) = 46.5$, p<.05. More detailed analysis on directional gestures revealed that the participants produced the same amount of gestures consisting of hand movements with multiple directions (*N* =38) and with single direction (*N* =38).

Condition 2: Visual Line Graphs

Participants, Materials and Design. Eleven participants (students at the University of Hamburg, 4 female, Mean age = 23,4, SD = 1.7) participated in the study. Same data graphs of the previous experiment were used, but they were presented visually in this condition (Figure 3). Each graph was shown for 10 seconds on a computer screen. After the graph disappeared, the participants were asked to present single-sentence verbal descriptions of the graphs to a hypothetical audience. The gestures were categorized according to same annotation scheme used in previous condition. Whereas x and y labels were provided in the visual condition, as it is common, we omitted them in the haptic graphs since their exploration would distract the explorations process (see, *Future Work*, below).

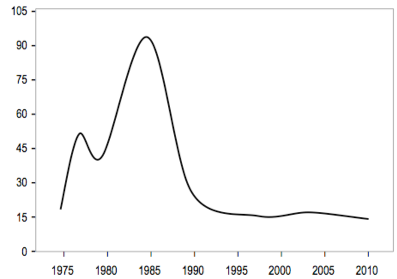

Figure 3: Sample visual graph

Results. The session consisted of five visual line graphs for eleven participants, leading to 55 sentences in verbal descriptions, and 102 representational gestures. Six of eleven participants produced gestures that accompany to their verbal description of the graph. For %44 of the protocols, speech-accompanying gestures (*N* =102) were observed. The results of a chi square test showed that more directional gestures (*N* = 67) were observed than non-directional gestures (*N* = 35), $\chi^2(1) = 10.1$, p<.05. Unlike the pattern in haptic graph comprehension, a significant difference was observed between the directional gestures with multiple directions (*N* = 15) and single directions (*N* = 52), $\chi^2(1) = 20.4$, p<.05, indicating that participants tend to describe the events with simple – one directional hand movements.

Haptic versus Visual Modality

Pearson's chi square test was conducted to investigate the relationship between the modality and the gestures produced by the participants. The results revealed that the number of protocols accompanied by at least one gesture in the haptic exploration (35 of 45 protocols) was higher than that in the visual graph exploration (24 of 55 protocols) $\chi 2 = 11.9$, $p < .05$. However, a Mann-Whitney U test indicated that there was no significant difference in the number of produced gestures across two modalities; haptic graphs (N=88) and visual graph (N=102), U=261, $p > .05$. Additional non-parametric tests were applied in order to investigate the underlying differences for each of the gesture type (non-directional and directional gestures). A Pearson chi square test revealed that the association between modality and variety in the directional gestures is significant, $\chi^2 = 11.6$, $p < .05$, see Figure 4.

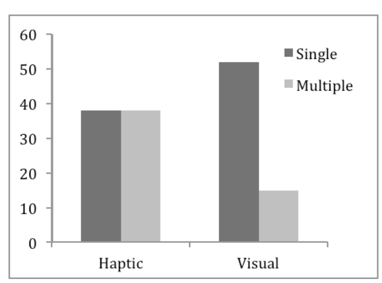

Figure 4: Single and multiple-directional gestures for haptic and visual modalities

This result implies that while there is no difference in terms of directional gesture types for haptic graphs, there is a significant difference in the visual graph exploration. Finally, the results of a Pearson´s chi square also revealed that more non-directional gestures were produced in visual graphs (N=35), compared to haptic graphs (N=12), χ^2 =10.8, $p < .05$.

Discussion

In this experiment, the effect of modality was investigated on the gestures produced by the participants. In both haptic and visual conditions, more directional gestures were produced supporting the idea that line graphs emphasize trend conceptualization (Zacks & Tversky, 1999). Furthermore, in haptic graph comprehension, the production of multiple-directional gestures that highlight the general pattern in the segments or in the entire graph was observed as well as the production of the gestures that point out one directional segment on the graph. This kind of "as-a-whole" comprehension might have been facilitated due to sequential perception of the data. In the visual graph comprehension, still more directional gestures were produced compared to non-directional gestures, but the difference is not as large as in the haptic version. Additionally, the participants tend to produce gestures with single direction (such as only upward or only downward movement) more than multi directional gestures, indicating that visual exploration enhanced the segmentation of the events with respect to visually salient points. The comparison between haptic and visual modality also showed that haptic exploration had an influence on the production of gestures during verbal description, possibly due to the alignment between shared spatial properties of gestures and haptic exploration, a finding we name "multimodal carry-over effect".

Conclusion and Future Work

In the present study, 1-line graph comprehension was investigated by a comparative analysis of gestures that accompany verbal descriptions of visual graphs as well as of haptic graphs. The results showed that the modality of the representation has an influence on the gestures that accompany to descriptions. In particular, the production of more multiple-directional gestures in haptic condition compared to visual graph is worth to elaborate in the further studies. The investigation of the relationship between explanatory gestures during haptic exploration and communicative gestures may shed light on underlying mechanism of this multimodal carry over effect. Moreover, how visually impaired people gesture about events represented by haptic graphs will be in the focus in a future empirical study. Finally, the graphs in both modalities were presented in a natural way as much as possible. However, considering the state-of-art of haptic graphs, providing haptic data labels is a challenge for designing haptic graphs, therefore informational inequivalence is inevitable. Further research should address appropriate means of providing label data in alternative modalities.

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