Towards a systematic understanding of graphical cues in communication through statistical graphs

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Abstract. Statistical graphs—in particular, line graphs and bar graphs—are efficient means of communication in a wide range of non-expert settings. In communication settings, statistical graphs do not only serve as visualizations of individual data points but also provide visual access to various aspects of the information contained in data. Moreover, specific types of graphs are better means for providing visual access to certain aspects of data. For instance, trend information is visually conveyed through line graphs and bar graphs in the time domain. The interpretation of the information content in a graph is influenced by several factors, such as perceptual salience of line segments in a line graph. In addition, the presence of graphical cues substantially influences the interpretation of graph readers. Graphical cues are visual elements, usually in the form of point markers, non-directional lines, curves and arrows. They play a communicative role in communication through graphs. The present study reports an experimental investigation, in which the participants provided verbal descriptions of a set of graphs with/without graphical cues. The stimuli involved line graphs and bar graphs that represented the same data. The analyses of eye movements and verbal protocols reveal that the interpretations of the participants are systematically influenced by the presence or absence of a graphical cue, the type of the graphical cue (i.e., a point marker vs. an arrow), as well as the type of the graph (i.e., a line graph vs. a bar graph).
Keywords. Statistical graphs, line graphs, bar graphs, graphical cues, verbal protocols, eye movements

1. Introduction

From the perspective of data visualization, statistical graphs (e.g., line graphs, bar graphs, pie charts, histograms) are efficient means for providing visual access to relations between data points, e.g. *trends*, in addition to being depictive representations of specific data points. Statistical graphs are abundant in daily-life communication settings, such as newspapers and in web blogs, as well as in educational settings and academic settings, such as lecture notes and scientific articles. Line graphs and bar graphs are the most frequently used graph types in non-expert communication settings through graphs [1]. They are also the most frequently used graph types that convey trend information.

Statistical graphs (henceforth, graphs) comprise a specific type of representational modality that exhibits non-iconic, abstract characteristics. Graphs are different than iconic representations (i.e., pictorial illustrations, photographs, cartoons) in the sense that a graph and its referents do not share spatial similarity of the layout [2]. Instead, graphs have an internal syntax (cf. representational formats, [3], p. 31), which provides the basis for a systematic analysis at semantic and pragmatic levels [4] [5]. In particular, Kosslyn offered a structural, analytical scheme that identified 'basic level graphical constituents' at syntactic, semantic and pragmatic levels. Kosslyn conducted those analyses to develop a set of design guidelines by providing acceptability principles for graph design. According to Kosslyn, the basic level graphical constituents of graphs involve the following components: the *background*, on which all the components of a graph (or a chart) are presented. Background is often blank and it does not have a crucial role in information communication. The second basic level graphical constituent is the *framework*. In graphs, the domain variables are represented by the framework. The third component is the *specifier*. The mapping between the parts of the framework, thus the relation between the domain variables is represented by the specifier. In a line graph, the specifier is the graph line (proper)[1], whereas in a bar graph, the specifier is the set of bars. The final basic level graphical constituent are the *labels*. The labels involve alphanumeric elements, such as axis labels, as well as depictive elements, such as graphical cues. An analysis at the syntactic-level conceives the basic level graphical constituents as syntactic entities, without taking into account their referents. The semantic-level analysis, however, investigates spatial configurations of the constituents, as well as their referents. The pragmatic-level analysis is concerned with the message conveyed by the graphical constituents. Accordingly, different graph types convey different messages by providing visual access to different aspects of the information content in graphs. Moreover, graphical cues may be conceived as visual entities that contribute to the interpretation of the message conveyed by end-users [6].

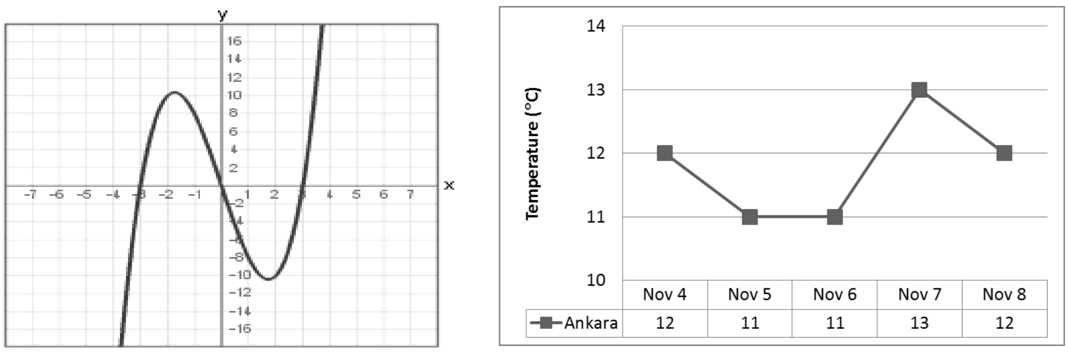
The following section introduces specific graphs types and their characteristics that are at the focus of the present study. Section 3 introduces graphical cues as complementary visual elements in graphs. Section 4 presents a theoretical framework for the analysis of verbal descriptions of graphs. The experiment was reported in Section 5. Finally, Section 6 discusses the results and Section 7 concludes the article.

2. Data graphs in the time domain

From a mathematical perspective, a function graph—as long as it is a graph of a continuous function—represents a veridical mapping between two variables: each and every point on the graph line (proper) in a line graph represents a value of the function, given its domain value (Figure 1a). In a data graph, however, the lines usually serve for connecting data points. For example, the line graph in Figure (1b)

[1] The term "graph line (proper)" is used for the line segments in a line graph, which represent (or connect) data points by means of the construction of a mapping between a dependent variable and an independent variable.

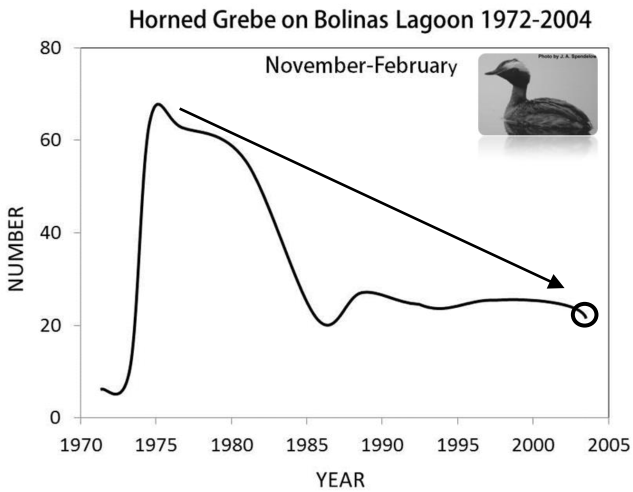
shows the average temperature in Ankara for five consecutive days in November. The data points are shown by squares. The lines that connect the data points do not represent the data; instead, they provide the perceptual continuum that aims at facilitating the interpretation of the graph by the reader.



(a) (b)

Fig. 1. (a) A line graph as a representation of a mathematical function, $y = x^3 - 9x$. (b) A line graph as a representation of data points (the average temperature in Ankara, °C).

Software tools for designing and generating graphs provide various methods for specifying how the data points are connected. Those methods are provided by the software tools for professional graph designers, as well as the ones for non-expert users, such as web blog authors. For example, consider the population graph of birds in a lagoon, accompanied by a sentence in Figure 2.



Bolinas Lagoon Population Trends

From a peak of about 60 wintering birds in 1976, numbers have declined to about 20 birds currently.

Fig. 2. A line graph (left) that represents the population of horned grebe on Bolinas Lagoon [7]. The graph was redrawn based on the original. The graphical cues (the arrow and the circle) were added by the author for demonstration. The text (right) was excerpted from the accompanying text in the original source.

The line graph in Figure 2 exemplifies a method of *smoothing*, a method that aims at facilitating perceptual continuum. In particular, as a means for identifying the trends in the data with high variability, a local regression method called *Loess Smooth* was applied during the production of the graph line for *smoothing* census data [7], thus resulting in a line graph with a smooth graph line.

Another major characteristics of frequently-used data graphs in communication settings is that they usually represent data in the time domain. When represented in the time domain, a line graph provides visual access to states, processes and events that unfold in time, such as peaks, increases, decreases, and stable periods of the value of the domain variable. Therefore, the graph in Figure 2 is not only a visualization of data points but also a representation of a set of states, processes and events in the domain of discourse, such as a peak or a decline in population.

Conceptualization of states, processes and events by means of graphs depends on the characteristics of the visual access provided by graphical constituents. Human perception is largely directed by visual/perceptual salience of visual elements, such as size, color and brightness, and being an unusual shape in various respects [8]. In closed contours, perceptual salience is determined by a set of factors that are defined in terms of geometrically critical points, including maxima, minima, inflection points, discontinuities in curvature and endpoints [9] [10] [11]. In graphs, those critical points have the potential for influencing visual attention and eye movements, thus leading influences on conceptualization processes. Therefore, when providing visual access to trend information, choosing alternative design decisions—such as using smooth lines or angled lines for perceptual continuum, or using a bar graph instead of a line graph to convey trend information—may lead to changes in conceptualization of the situations that are represented by the graph. Those conceptualization differences may involve changes in interpretations of temporal aspects of events [12] and causal relations in the domain of discourse [13]. Previous research on visualizations has shown that visualizations promote both coherence and inference by mapping abstract concepts to space [14]. Accordingly, statistical graphs present a specific instance of a more general relationship between human conceptualization and visualizations [15].

In addition to the graphical entities under Kosslyn's [4] *specifier* category, which was one of the basic level graphical constituents, designers make decisions about graphical cues. For example, Figure 2 involves two graphical cues: an arrow and a point marker in the form of a circle dot, at the end point of the graph line. Section 3 introduces graphical cues as complementary visual elements in graph design.

3. Graphical Cues and Relevant Work

Graphical cues are visual elements that introduce emphasis on a whole graphical entity, a part of it, and/or entities in the domain of discourse. Graphical cues guide the attention of the graph reader or the interlocutor in a communication setting (e.g., the arrow and the point marker in Figure 2; [16] [6]). A review of the literature on graphical cues reveals that research disciplines investigate different aspects of graphical cues on various types of representations (e.g., static figures such as mechanical diagrams, animations). For instance, computer science research focuses on the design of visual elements from a graphical design perspective (e.g., [17]). The instructional science research literature employs the terminology 'signaling' and 'scaffolding', by focusing largely on the role of graphical cues in multimedia learning. Within the framework of the multimedia learning theory [18] [19], signaling has been conceived as a technique to reduce the cognitive load on the learner. By signaling, cues are provided to the learner so that he/she selects and organizes the instructional material, e.g. [20] [21] [22]. In particular, graphical cues are used for updating the "natural perceptual profile" of the display by providing a better alignment between perceptibility and thematic relevance [23].

In research on communication through diagrams, the term 'schematic figures' has been used for visual elements, such as arrows in mechanical diagrams, [24] [25]. Graphical cues also exhibit functional similarities to gestures in spoken communication settings. For example, in a spoken communication setting, such as a classroom presentation, a presenter points at a peak on the graph and then drags her hand diagonally to show the decrease that follows the peak. Those aspects of graphical cues are compatible with deictic pointing [26] in the sense that the act of pointing is a part of the use of visualizations in spoken communication settings. It is a form of referring act, which can take different forms in communication settings [27] [28] [29] [30]. In written communication settings, it is the graphical cues that carry the role of a communicative means in similar ways [31]. The production of graphical cues by non-expert end-users reveals systematic patterns in line graphs and bar graphs that convey trend information. In particular, under linguistic context (e.g., a verbal description that emphasizes a peak or the one that emphasizes an increase process), humans produce graphical cues of certain types [6].

Graph comprehension research has covered investigations from various perspectives, such as the study of perceptual processes of graph comprehension (e.g., [32]), psychology and usability analyses (e.g., [4]), the development of cognitive models [33] [34], studies within the framework of educational psychology and instructional design [21] [35]). Graphical cues on statistical graphs, however, have not been systematically investigated in the recent study of the art. The present study aims at filling this gap by providing analyses of graphical cues in a specific type of depictive representation, i.e. statistical graphs, in interaction with linguistic context.

One method of classification of graphical cues, which reveals systematic differences in the production can be a classification in terms of geometric characteristics of graphical cues, as shown below [6].

- 0-D graphical cues: Point-like markings, such as asterisks, stars, dot circles and dash lines.
- 1-D nondirectional/bidirectional graphical cues: Straight lines or curved lines without arrow heads or lines with double-arrowheads (i.e. left right arrows).
- 1-D directional graphical cues: Straight lines or curved lines with a single arrowhead.
- 2-D graphical cues: Region-shapes such as ellipses, circles, rectangles and squares

Figure 3 shows a schematic representation of 0-D graphical cues (left), and 1-D graphical cues (right) that were produced by the participants of the experimental investigation of graphical cue production reported in [6].

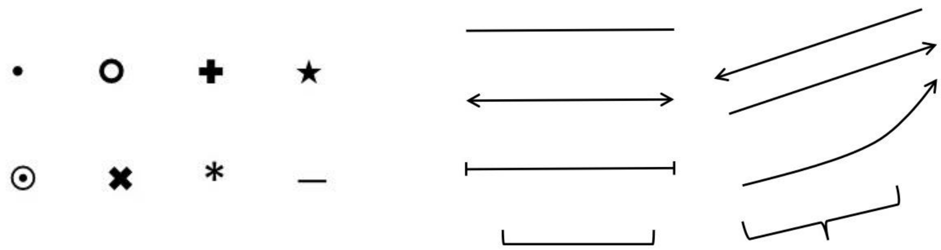


Fig. 3. A schematic representation of 0-D graphical cues (left) and 1-D graphical cues (right) that were produced by the participants as reported in [6].

As reported by [6], human participants show a tendency to produce 0-D graphical cues on graphs to convey punctual state information, as stated in the example sentence ‘*the maximum temperature was 16 ℃ in November*’. They show a tendency to produce 1-D nondirectional/bidirectional graphical cues on graphs to convey durative state information (usually conceived as process information), as stated in ‘*the temperature remained stable between July and August*’. On the other hand, 1-D directional graphical cues are produced under the context of process sentences, such as ‘*the temperature increased after May*’. They produce graphical cues not only on the graph lines (proper) but also on the framework (i.e., the axes), in particular when trends are represented by bar graphs. They also produce horizontal and vertical projection lines that facilitate mapping the correspondence between a specific point on the graph and the corresponding value on the framework. Finally, they produce verbal annotations to graphical cues, such as ‘*max. temperature*’ near a peak.

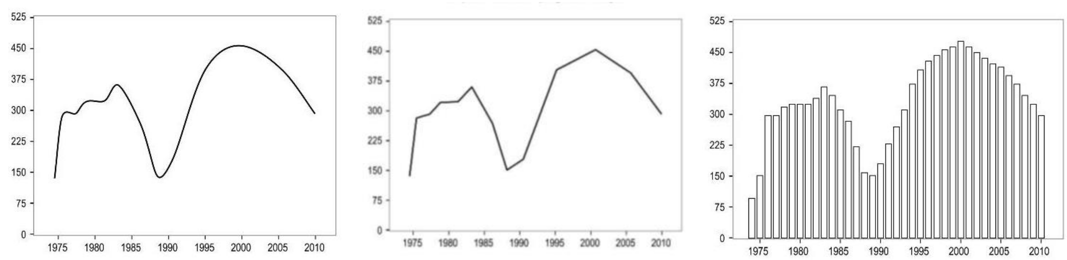
In summary, the previous research on graphical cues from different disciplinary perspectives suggests that graphical cues have the potential to promote learning and comprehension and to facilitate communication. On the other hand, a review of the available software tools in the recent state of the art reveals that, despite offering ample ways for generating graphs of various types, limited methods are provided for designing and generating graphical cues. Given its importance in emphasizing a certain aspect of the visualization over other aspects in learning and communication settings, a systematic understanding of graphical cues is necessary for the design and generation of graphical cues, as well as for the development of software tools that are used for designing graphical cues. The following section will present a theoretical framework, which will be analyzed for the investigation of the role of graphical cues by means of verbal protocols.

4. A Theoretical Framework for the Analysis of Verbal Descriptions of Graphs

Communication through line graphs is a specific case of communication about physical space, where a set of abstract structures constructs the building blocks of conceptual representations. Those abstract structures are necessary not only for communication about space but also for figurative language [36] [37] [38] [39]. More recently, the research on psycholinguistics revealed a closer interaction between visual and linguistics processes than thought before (cf. embodied language) [40] [41] [42]. The relationship between language and graphs can be analyzed in terms of the relationship between linguistic terms, graphical entities and their systematic analysis at a conceptual level [16]. In communication through line graphs, the conceptualization of information represented by the graph leads to a vocabulary that consists of shape nouns, spatial prepositions, adverbial modifiers, and verbs of change cf. the representational modularity hypothesis [43] [44] [45]. For example, the term "decline" in Figure 2 refers to a decline of population in the domain of discourse. The entity in the domain of discourse is also referred to by the diagonal line in the graph, which is, from the perspective of topology, a directed geometric entity. In topology, directed, linear, and bounded entities are called PATH [46]. Accordingly, the concept of DECREASE, which is referred to by the line segment in the line graph and by the term "decline" in the text (Figure 2), is part of the PATH concept that is represented by the line (proper) in line graphs.

More generally, in line graphs or bar graphs that depict trends, spatial verbs such as "fall", "decline" and "decrease" involve the PATH concept in their conceptual structure, in a more specialized form, as exemplified in the process concept DECREASE_OF_VALUE($\_{TEMP}$, $\_{VALUE}$), where *TEMP* and *VALUE* are path arguments. In particular, the *TEMP* argument stands for the duration of the process, the *VALUE* argument stands for the amount of decrease. The geometric specification of the DECREASE concept holds the necessary conditions *VALUE(BEGIN(DECREASE)) > VALUE(END(DECREASE))* (cf. Geometric Concept Specification, [46] [16]). Within this framework, communication through line graphs can be interpreted as a specific case of communication about physical space, where the abstract structures involve process concepts such as DECREASE, based on the concept of PATH OF MOTION, represented by the graphical entities that depict trend information.

The ways that a graph represents the PATH are specified by a set of assumptions—mostly, involuntarily—made by the graph designer. For instance, the designer may or may not use a smoothing algorithm. It is also likely that the designer uses a bar graph, instead of a line graph to convey the trend information. The three graphs in Figure 4 exemplify the three ways that a graph may represent the population data of a bird species. Each graph, at a conceptual level, exemplifies a means of conveying the concept of PATH OF MOTION.



(a) (b) (c)

Fig. 4. (a) A smooth-line graph that represents the population of a bird species in a lagoon, between 1970 and 2010. (b) An angled-line graph that represents the same data points (c) A bar graph that represents the same data points.

The relationship between the three exemplified graphs in Figure 4 is sometimes called ‘information equivalence’ [47]. On the other hand, although the graphs represent the same data points, each graph may lead to a different perceptual interpretation, thus leading to different conceptualizations and verbal descriptions. Those differences in verbal descriptions can be analyzed in terms of a set of semantic notions that specify process concepts, state concepts and event concepts in verbal descriptions. Two major semantic notions that have been traditionally used for this purpose are *dynamicity* and *telicity* [48] [49] [50]. Telicity is an aspectual property that emphasizes completeness of the action that is represented by a verb or a verb phrase. The most frequently used diagnostics for telicity is to modify the verb or the verb phrase by a phrase such as “in an hour, within an hour” (e.g., *to prepare a sandwich in one minute*). When this phrase is applied to telic verbs, they return acceptable phrases, whereas atelic verbs are more acceptable with phrases, such as “for an hour” *(e.g. to run for an hour*). Dynamicity is another aspectual property, which emphasizes *change*, such as change of state or motion [51] [52] [53]. Telicity can be used in combination with dynamicity for identifying different ontological types for states, events and processes. In particular, when verbal descriptions are classified according to their telicity aspect (i.e., telic vs. atelic) and their dynamicity aspect (i.e., dynamic vs. non-dynamic), the classification leads to the abstractness hierarchy, i.e. the ontological categories that depend on time and space, as shown in Table 1.

Table 1: The abstractness hierarchy identified by the two semantic notions (dynamicity and telicity). The ‘+’ sign means having a feature whereas the ‘-’ means lacking a feature.

	Dynamicity	**Telicity**
States	-	-
Processes	+	-
Events	+	+

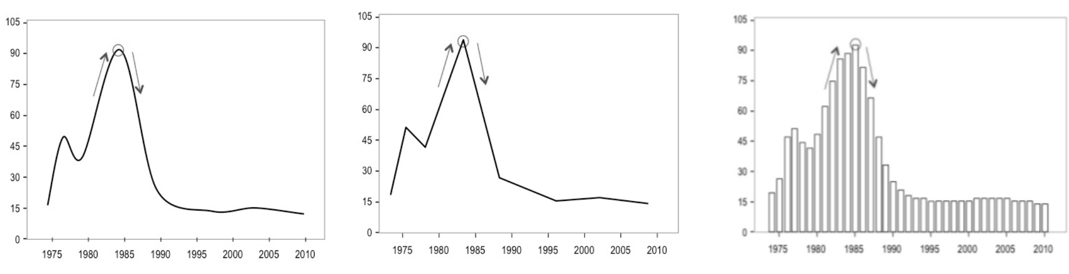
The analysis of verbal protocols in the present study employs this abstractness hierarchy.[2]

5. Experiment

The present study reports an experimental investigation of the production of single-sentence verbal descriptions by human participants under a set of experimental conditions. The specific research objective is to investigate how absence or presence of graphical cues, as well as the type of the graph, influence conceptualization of graphical entities. For this, a between-subject experiment was designed with two conditions. The first between-subject condition was the absence of a graphical cue (Group 1) or the presence of a graphical cue (Group 2).[3] The second between-subject condition was the type of the trend graph: smooth-line graphs, angled-line graphs and bar graphs. Based on a corpus of recorded verbalizations, the analyses were performed in terms of the abstractness characteristics of the sentences produced by the participants.

5.1. Participants, Materials and Procedure

In two groups, 125 participants (*mean age* = 22.4, *SD* = 4.2, 68 female and 57 male) from various departments at the Middle East Technical University (METU, Turkey) produced verbal descriptions of eight trend graphs of three different types. All the graphs were in population-time domain, as exemplified by the graphs in Figure 4. In Group 1, 57 participants produced verbal descriptions of graphs that involved no graphical cues (henceforth, *noncued graphs*). In Group 2, 68 participants produced verbal descriptions of graphs that involved graphical cues of different forms (henceforth *cued graphs*). Figure 5 below exemplifies cued-versions of the graphs shown in Figure 4.



(a) (b) (c)

Fig. 5. Graphs with a graphical cue set composed of two arrows and a circle dot at a peak. (a) A smooth-line graph that represents the population of a bird species in a lagoon, between 1970 and 2010. (b) A straight-line graph that represents the same data points (c) A bar graph that represents the same data points.

[2] The semantic notions that underlie aspectual characteristics of verbs have been a debate in lexical semantics since the past several decades [48] [51] [52] [53]. The present study follows a relatively coarse-grained hierarchy [49] [50], leaving the investigation of finer-grained analysis to future work.

[3] The focus of the present study is graphical cues on the graph (proper), therefore graphical cues on the framework, projection lines, and verbal annotations to graphical cues are beyond the scope of the present study (see [12] for the role of verbal annotations in text-graphics documents).

The only difference between the stimuli presented to Group 1 and Group 2 was the presence of graphical cues in Group 2. Each group was divided further into three sub-groups in approximately equal numbers (19 participants per sub-group in Group 1; 22 or 23 participants per sub-group in Group 2). The participants were randomly assigned to each sub-group. Each sub-group was presented one of the three graph types: (i) Smooth-line graphs (exemplified in Figure 4a and Figure 5a), (ii) Angled-line graphs (Figure 4b and Figure 5b), (iii) Bar graphs (Figure 4c and and Figure 5c).

The stimuli involved eight graphs of different visual properties (e.g., a continuous increase, a decrease followed by a stable state, a stable state followed by an increase, etc.). Accordingly, each participant was presented eight graph stimuli of a single graph type, in a random order. All the graph stimuli were excerpted from [7] and redrawn based on the experimental conditions.

The experiment was conducted in single sessions. The graphs were presented on a Tobii T120, a non-intrusive, 120 Hz eye tracker, integrated into a 17” TFT monitor with 1024x768 pixels. Spatial resolution and accuracy of the eye tracker was about 0.30° and 0.50° degrees respectively. The I-VT filter was used to extract eye movement data. The parameters were set by the eye tracker software, Tobii Studio such that the gap fill-in threshold was set to 75 ms, a velocity threshold was set to 30 degrees/second; adjacent fixations were merged when the time between fixations was less than 75 ms and the angle between fixations was less than 0.5°; short fixations below 60 ms were discarded.

After inspecting each graph, the participants wrote down a single-sentence verbal description of the presented stimuli. The participants were asked to imagine themselves in a seminar environment where the presenter tells a single sentence for each graph. They were asked to predict and to write down the sentences. The following section presents the results of the experiment.

5.2 Results

5.2.1. The Analysis of Eye Movements

Eye movements of the participants were recorded during the course of inspection, before the participants started verbalization of the stimuli. After the inspection of the graph, the participants wrote down verbal descriptions on paper. Therefore, the eye movement analyses reflected offline inspection of the graphs before verbalization. The purpose of recording participants’ eye movements was to evaluate the influence of the presence of graphical cues on graphs. A qualitative analysis of eye movement patterns reveal that, during participants’ inspection phase of the graphs, the presence of graphical cues (Group 2) exhibited a strong influence, by attracting attention of the readers. This influence was observed in both 0-D graphical cues and 1-D graphical cues investigated in this study. The eye movement patterns of the participants in Group 1 (noncued graphs), however, were influenced by the visual salience of the line segments only. In particular, the critical points (see Section 2), such as peak or a bottom were at the focus of attention in Group 1 participants.

For further analysis of eye movement data, three Areas of Interest (AOIs) were identified on the graphs: (1) GraphAOI: This AOI included the graph specifier (i.e., the lines or the bars), (2) xAOI: This AOI included the horizontal x-axis line and the numerical values on the axis, (3) yAOI: This AOI included the vertical y-axis line and the numerical values on the axis.

A comparative analysis between the mean inspection times on cued graphs and the mean inspection times on noncued graphs revealed significant differences in ANOVA, $F(1, 124) = 16.7$, $p < 0.01$, univariate $\eta^2 = .12$. The participants who were presented cued graphs (Group 2) spent less time inspecting the graph, compared to the participants who were presented noncued graphs (Group 1).

The analysis also revealed significant differences in inspection time between the three graph types, $F(2, 124) = 4.95$, $p < 0.01$, univariate $\eta^2 = .07$. Before they started verbalization, the participants spent similar amounts of time inspecting both smooth-line graphs and angled-line graphs, whereas both were longer than the inspection times on bar graphs. Finally, the participants spent different time on the three AOIs, $F(2, 124) = 66.4$, $p < 0.01$, univariate $\eta^2 = .52$. They spent longer time inspecting the specifier AOI (i.e., the GraphAOI) compared to the x-axis AOI (i.e., the xAOI). The inspection time on the xAOI was longer than the inspection time on the yAOI.

The results also revealed an association between graph inspection time and the length of the verbal descriptions in terms of the number of words. A positive correlation was obtained between the total inspection time (on all the three AOIs) and the length of the verbal descriptions, $r = .375$, $n = 48$, $p = 0.009$, independently from the presence or absence of graphical cues. Accordingly, the participants in Group 1 (noncued graphs) produced longer verbal descriptions that the participants in Group 2 (cued graphs). Table 2 below shows the mean number of words produced by the participants in each verbal description.[4]

Table 2: The mean number of words produced by the participants. The numbers in parenthesis show standard deviation.

	Graph Type	**Sample**	**Mean number of words**
Group 1 (noncued)	Smooth line graph	Figure 4a	12.2 (1.83)
	Angled line graph	Figure 4b	13.8 (2.19)
	Bar graph	Figure 4c	12.3 (1.52)
Group 2 (cued)	Smooth line graph	Figure 5a	11.4 (1.95)
	Angled line graph	Figure 5b	11.0 (2.63)
	Bar graph	Figure 5c	11.4 (2.42)

To sum up, the analysis of eye movements revealed that the presence of graphical cues influenced graph inspection patterns of the participants. In particular, the

[4] A detailed analysis of the verbal descriptions that were produced by the participants can be seen in [54], with a particular focus on the analysis of Turkish referring expressions.

participants spent less time before they started verbalization. The type of the graph also influenced inspection times: the two line graph types (i.e, the smooth-line graph and the angled-line graph) took longer to inspect before the participants started verbalizations, compared to bar graphs. In the following section, the results for the verbal protocol analysis are presented.

5.2.2. The Analysis of Verbal Protocols

The participants provided a total of 1,000 verbal protocols (125 participants x 8 graph stimuli per participant). The verbal descriptions were classified according to their telicity and dynamicity characteristics, as described in Section 4. The classifications were then used for the identification of the sentences as *processes*, *events* or *states*, in the abstractness hierarchy. Two coders, who were blind to the goals of the experiment aimed at the present study, performed the classification. The interrater reliability between coders, which was calculated by Cohen's kappa, was tested by using randomly selected 25% of the recordings. The calculations revealed an initial agreement value of 0.55. According to [55], a value of Kappa from 0.40 to 0.59 are considered moderate interrater agreement.[5]

The verbalizations below are excerpted from the recorded data. The sentence (1) is a sample process description, (2) is an event description and (3) is a state description.

(1) 'The black bellied plover exhibited a decrease after 1985 until 1990 and then increase again, whereas it increased from 1975 to 1980s.'

(2) 'The number of black bellied plover reached the lowest [level] in 1989 and the highest [level] in 2000.'

(3) 'The population of black bellied plover is about 300 in the year 2010.'[6]

A Kruskal-Wallis test was conducted to evaluate differences between Group 1 (the participants who were presented noncued graphs) and Group 2 (the participants who were presented cued graphs) on median change in the type of verbal description (i.e., process description, event description, and state description). The test revealed a significant effect of the presence of a graphical cue on verbal descriptions, χ^2 (1, N = 908) = 34.08, p = 0.000. The test also revealed a significant effect of graph type on verbal descriptions, χ^2 (2, N = 908) = 6.97, p = 0.03. Follow-up tests, which were conducted to evaluate pairwise differences among the three graph types, indicated an overall significant difference in verbal descriptions between smooth graphs and bar graphs. However, since the cued graph stimuli involved graphical cues of different types, a more detailed case-by-case, comparative analysis is presented for specific graphical cue types below.

[5] The low value of the Kappa was due to the difficulty of identifying telicity and dynamicity in the verbal descriptions by multiple syntactic diagnostics. After the initial coding, the discordance between the two coders was handled by mutual agreement upon face-to-face discussion and the coding was updated throughout all verbal descriptions.

[6] The sample sentences reported in this article were translated from Turkish (the language of the experiment) into English by the author, following a literal translation for emphasizing the lexical content in the verbal descriptions produced by the participants.

5.2.2.1. 0-D Graphical Cues

In two of the eight graph stimuli, Group 2 participants provided verbal descriptions for graphs that involved 0-D graphical cues in the form of point markers, as shown in Figure 6. The participants in Group 1 provided verbal descriptions for noncued graphs of the same form.

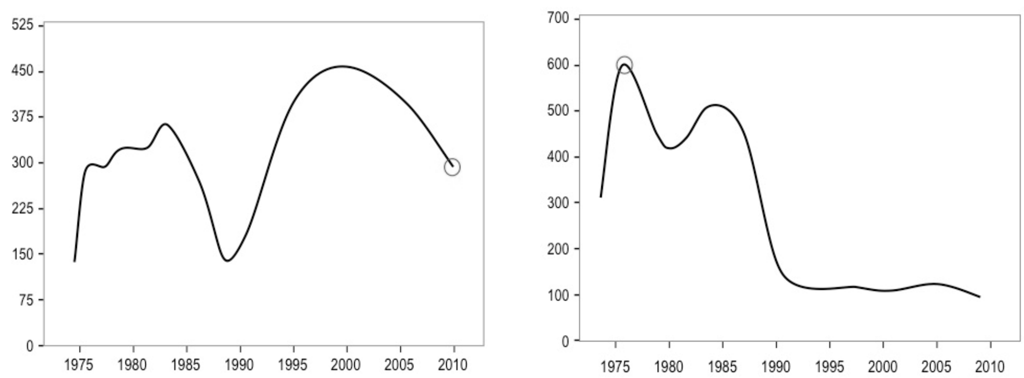


Fig. 6. The two graph stimuli that involved 0-D graphical cues in the form of point markers (Group 2). The participants in Group 1 were presented the same graphs but without the graphical cues.

In Figure 6, the graph stimuli are shown as sample stimuli for the smooth-line graph condition. The experiment stimuli involved angled-line graphs and bar graphs, as well (see Figure 4 and Figure 5). Significant differences were obtained in verbal descriptions (i.e., process description, event description, and state description), showing an influence of both the presence of a graphical cue, χ^2 (1, N = 225) = 68.2, p = 0.000, and the type of the graph (smooth line graph, angled line graph, and bar graph), χ^2 (2, N = 225) = 5.90, p = 0.05. In particular, the results of the analysis revealed that, Group 1 participants verbalized noncued graphs mostly by employing process concepts in all graph types (Figure 7, left), whereas the dominant types of description were event descriptions and state descriptions in Group 2 participants, who provided verbal descriptions for cued graphs (Figure 7, right).

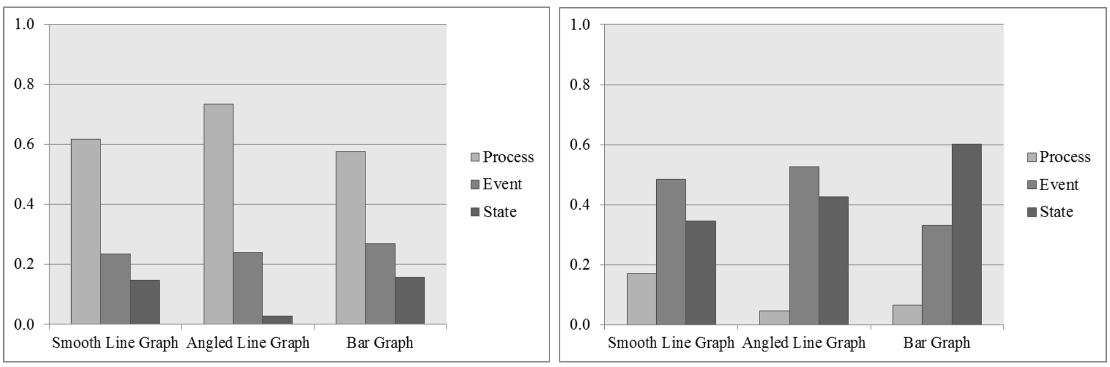


Fig. 7. The percentage distribution of the sentences in the abstractness hierarchy for the two stimuli shown in Figure 6. Group 1 verbalized noncued graphs (left), whereas Group 2 verbalized cued graphs (right).

A closer look at the verbal descriptions of the cued graphs showed that state descriptions (e.g., the ones that emphasized a punctual value at a certain year) were more frequently observed in bar graphs compared to both smooth-line graphs and angled-line graphs, whereas no statistically significant difference was obtained between the two.

To sum up, the results showed that the presence of a graphical cue (such as a dot circle) led to a suppression of process descriptions. Moreover, the effect of 0-D graphical cue on state descriptions was larger in bar graphs than both line-graph types. This finding indicates that despite that bar graphs may convey trend information, the presence of a 0-D graphical cue on a bar graph leads to a stronger influence in favor of state interpretation compared to line graphs.

5.2.2.2. 1-D Graphical Cues

In four of the eight graph stimuli, 1-D graphical cues were used, in the form of a directional graphical cue (i.e., a one-sided arrow) and a non-directional graphical cue (i.e., a left right arrow), as shown in Figure 8.

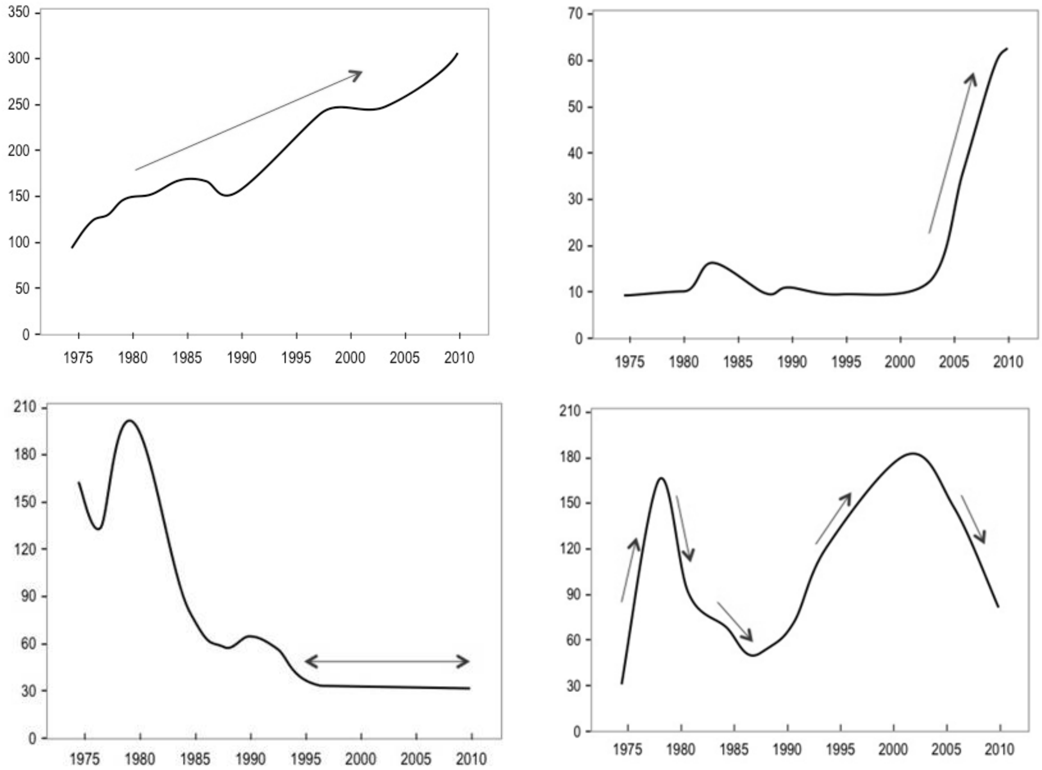


Fig. 8. The four graph stimuli that involved 1-D graphical cues of different forms (Group 2). The participants in Group 1 were presented the same graphs but without the graphical cues.

The analysis of the verbal descriptions provided by the participants in Group 1 (Figure 9, left) revealed an overall similar pattern to the verbal descriptions in Figure 7 (left), including some variability in specific graph types. An overall similarity is expected because in both cases, the participants verbalized noncued graphs. On the other hand, the verbal descriptions of Group 2 for the four cued-graph stimuli (Figure 9, right) differs than the verbal descriptions presented in Figure 7 (right). This difference reflects the difference between the influence of 1-D and 0-D graphical cues on verbalizations.

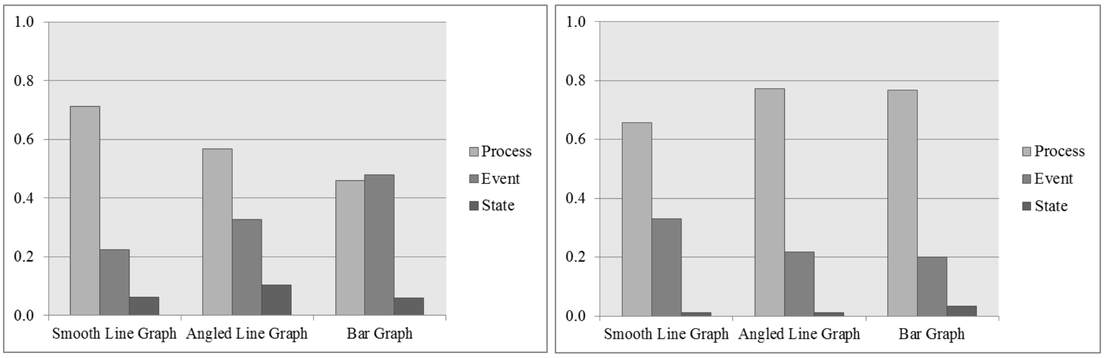


Fig. 9. The distribution of the sentences in the abstractness hierarchy for the stimuli shown in Figure 8. Group 1 verbalized non-cued graphs (left), whereas Group 2 verbalized cued graphs (right).

The analysis of the results revealed a significant difference for the presence of a graphical cue (i.e., a significant difference between Group 1 and Group 2) on verbal descriptions, χ^2 (1, N = 458) = 12.5, p = 0.000, for the stimuli shown in Figure 8. In particular, 1-D graphical cues introduced a higher emphasis on process descriptions, in contrast to the presence of 0-D graphical cues (which suppressed process description by giving higher emphasis on state description, as described in the previous section). On the other hand, the process-emphasis effect was not significant for all graph types: the proportion of process descriptions was similar between cued smooth line graphs and noncued smooth-line graphs. In other words, the process-emphasis effect was observed in both angled-line graphs and in bar graphs.

5.2.2.3. Combinations of 0-D and 1-D Graphical Cues

In two of the eight graph stimuli, a combination of 0-D graphical cues and 1-D graphical cues was used, as shown in Figure 10.

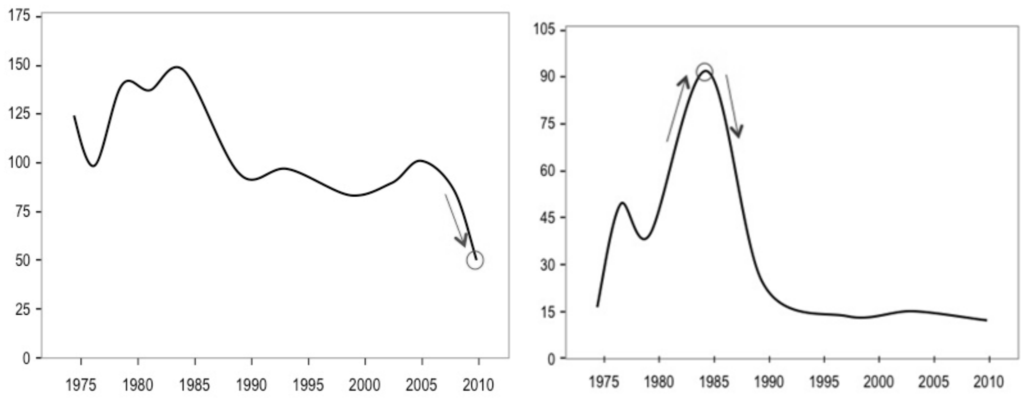


Fig. 10. The two graph stimuli that involved a combination of 0-D graphical cues and 1-D graphical cues (Group 2). The participants in Group 1 were presented the same graphs but without the graphical cues.

The analysis of the sentences revealed a pattern that is different than the influence of both 0-D graphical cues which introduced emphasis on states (Figure 7, right) and 1-D graphical cues which introduced emphasis on processes (Figure 9, right). Instead, the presence of a graphical cue led to a significant difference in verbal descriptions for the stimuli shown in Figure 10, χ^2 (1, N = 225) = 52.8, p = 0.000, showing that the combined use of 0-D and 1-D graphical cues led to the dominance of event interpretations (e.g., reaching the peak or reaching the end, both carrying telicity, as well as dynamicity, as the underlying semantic notions), as shown in Figure 11. The event-description effect was significant between Group 1 and Group 2 in all three graph types.

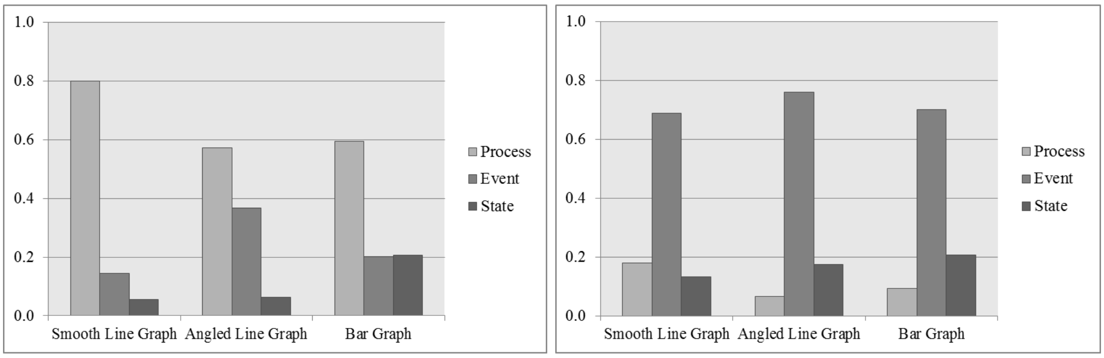


Fig. 11. The distribution of the sentences in the abstractness hierarchy for the stimuli shown in Figure 10. Group 1 verbalized non-cued graphs (left), whereas Group 2 verbalized cued graphs (right).

In summary, different graphical cues led to different influences depending on the type of the graph, as identified by the analysis of verbal descriptions. In particular, 0-D graphical cues led to a suppression of process descriptions and a larger increase in state descriptions in bar graph; 1-D cues lead increase process emphasis in angled-line graphs and in bar graphs. The combination of 0-D and 1-D graphical cues led to an increase in event descriptions in all three graph types.

5.2.3. The Analysis of Numerical Phrases

The verbal protocols that were provided by the participants involved numerical time phrases that conveyed information about a specific year of mention (e.g., *1970*) and numerical value phrases that conveyed information about the domain value (i.e., the population of birds, such as *300*). The numerical phrases for the time were present in the majority of the verbal descriptions (Figure 12, left), whereas the numerical phrases for the domain values (in this case, the values for the population of birds) were much less frequently used in verbal descriptions.

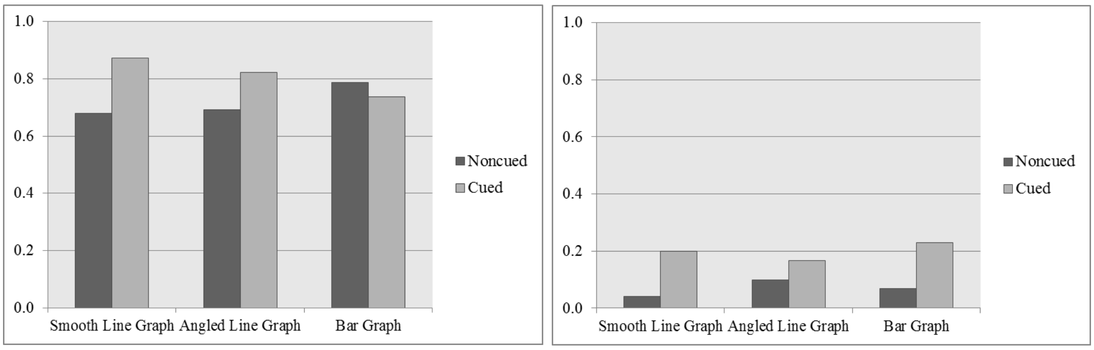


Fig. 12. The distribution of numerical phrases for time (left) and for value (right).

An analysis of the use of numerical phrases for the time revealed a significant difference between Group 1 and Group 2, χ^2 (1, N = 935) = 10.4, p = 0.001. Further pairwise comparisons showed that the difference between Group 1 and Group 2 was significant for smooth-line graphs and for angled-line graphs, but not for bar graphs. In other words, the presence of a graphical cue led to an increase in the use of time-value numerical phrases in both line graph types, whereas no effect was observed in bar graphs.

The results also showed that the presence of graphical cues resulted in a more frequent use of the domain value phrases in verbal descriptions (Figure 12, right), as indicated by a significant difference between Group 1 and Group 2 in their use of numerical phrases for value in verbal descriptions, χ^2 (1, N = 935) = 29.9, p = 0.000. Further analysis revealed that this effect was observed in smooth line graphs and in bar graphs, but not in angled line graphs. Finally, the influence of graphical cues on the use of value phrases in verbalizations was stronger, in particular, when the graphical cue was a 0-D cue. The presence of 1-D graphical cues exhibited less influence on the use of value phrases.

6. Discussion

The present study investigated communicative use of graphical cues on different types of graphs. In an experimental study, the participants provided verbal descriptions of smooth-line graphs, angled-line graphs and bar graphs in the time domain. The same data sets were represented by the three graph types. The graphs were presented with or without graphical cues. This study focused on the investigation of two types of graphical cues: point markers (0-D graphical cues) and arrows (1-D graphical cues). The combinations of point markers and arrows were also investigated.

A comparative analysis of eye movement data was conducted for the inspection of the graphs that involved graphical cues and the inspection of the graphs with no graphical cues. The results revealed that the presence of a graphical cue led to shorter inspection times of the graphs, compared to the noncued graphs. This finding shows that the participants were faster in preparing for their verbal descriptions in the presence of graphical cues on graphs. This may be related to a relatively *specific* description of cued graphs, which usually emphasizes one aspect of the graph (or the domain information represented by the graph) over the others. The verbal descriptions of noncued graphs, however, are more *global* in the sense that they usually describe an overall pattern of change in the domain value in time. The results also showed that the presence of a graphical cue led to shorter verbal descriptions compared to the verbal descriptions of non-cued graphs. The eye movement analyses also showed that, independent of the presence or absence of a graphical cue, the participants spent the longest time inspecting the specifier (i.e., lines in a line graph, bars in a bar graph). It was followed by the inspection of the horizontal axis (in this case, it was the axis that represented the time) and then by the inspection of the vertical axis.

In addition, the presence of numerical phrases for the time and numerical phrases for the domain value were analyzed by means of the analysis of verbal protocols. The results of the verbal protocol analyses revealed that the participants produced numerical phrases for the x-axis (in this case, for time values, i.e., the years) more frequently than the numerical phrases for the y-axis (in this case, domain values, i.e., the population). This finding may provide supporting evidence that time information, which was represented in the horizontal axis may play a more crucial role in conceptualizations compared to the domain value information, which was represented in the vertical axis. The time domain may be conceived as the major driving engine of conceptualizations due to its major role in the conceptualization of trend information. On the other hand, whether this finding is specific to time values or it is an instance of a more general finding of the mapping from the x-axis to the y-axis is now known at this stage. A comparative study between time-domain graphs and no-time-domain graphs is necessary to answer this question.

A comparative analysis of verbal protocols was conducted by employing an abstractness hierarchy, which was based on two semantic notions: telicity and dynamicity. These semantic notions have been traditionally employed for identifying processes, events and (punctual) states in literature on semantics [48] [49] [50]. The results revealed that the verbal descriptions, as members of the categories that were identified by the abstractness hierarchy, were influenced by the presence or absence of graphical cues, as well as the graph type. Further case-by-case analyses revealed that the presence of 0-D graphical cues, which were point markers in the form of a circle-dot in the present study, led to a suppression of process descriptions. This effect was observed in all graph types, whereas the strongest effect was observed in bar graphs. This finding is in line with the previous work reported in the literature in the sense that bar graphs usually lead to conceptualization of discrete comparisons between data points, whereas line graphs are usually associated by trends [56]. In the present study, all the three graph types represented trend information. On the other hand, the stronger effect in bar graphs indicates that different conceptualizations may be employed by the readers when they inspect bar graphs than the conceptualization when they inspect line graphs.

In non-cued graphs, process descriptions were mostly the canonical description type for trend graphs compared to both event descriptions and state descriptions. The analysis of 1-D graphical cues—in the form of arrows in the present study—showed that the presence of 1-D graphical cues introduced an even higher emphasis, in particular, in angled-line graphs and in bar graphs. The presence of 1-D graphical cues, however, did not have a significant impact on process descriptions in smooth line graphs. This finding reveals different conceptualizations between the two specific types of line graphs (in this case angled-line graphs and smooth-line graphs).

Finally, the analysis of the combinations of 0-D graphical cues and 1-D graphical cues reveled a different picture. When both graphical cues were present on the graph, the participants produced more event descriptions, compared to both process descriptions and the state descriptions, in all three graph types. This finding may be due to the telicity aspect (cf. completeness of the action, such as a decline to a certain population) introduced by the 0-D graphical cue, which in turn, transforms the process interpretation into an event interpretation.

7. Conclusion

The role of visualizations in communication settings is not only to convey information about specific data points. Instead, visualizations provide visual access to information contained in the data, such as trends. When used in the time domain, trend graphs convey information about states, processes and events in the domain of discourse. Graphical cues introduce emphasis to certain aspects of the presented information, such as introducing emphasis on a punctual state, on a process or an event. The experimental investigation reported in the present study shows that the interpretations of human readers are systematically influenced by the presence or absence of graphical cue on the graph, as well as by the type of the graph (i.e., line graph vs. bar graph). The findings reveal a potential facilitating role of graphical cues in communication. Compared to the rich variety of graph types offered by most graphical design software in the recent state of the art, however, limited means are provided for designing and generating graphical cues. The present study, therefore, offers the design and generation of graphical cues as a potential domain for software development. A further research topic is the implementation of graphical cues as complementary visual elements on trend graphs.

The analysis of verbal protocols revealed some variability between graph types. For instance, the presence of an arrow led to a higher increase in frequency of process descriptions in angled line graphs and in bar graphs but not in smooth line graphs. Despite that all those three graph types convey trend information, the finding shows that perceptual differences among specific graph types, even between specific types of line graphs may lead to different conceptualization of the represented information.

The verbal protocols revealed variability within specific graph types, as well. It is likely that the visual shape of the trend influenced the ways the participants produced verbal descriptions. In the present study, the visual shape was not among the controlled parameters due to the stronger focus on the influence of the graphical cues and the graph types. Instead, different visual shapes were used as graph stimuli, thus leading to a between-subject experiment in which each participant produced verbal descriptions for eight graph stimuli with different visual shapes. Further analyses should address the role of graph type in more detail and the role of visual shape on both eye movement data and verbal descriptions.

Finally, the focus of the present study was an investigation of graphical cues on lines in a line graph and the ones on bars in a bar graph. Humans also produce graphical cues on the axes, vertical and horizontal projection lines to connect data points to axes, they produce numerical and verbal annotations during the course of communication. Further study should address extending the analysis to those graphical and alphanumerical entities so that a broader range of communicative graphical entities are covered in the analysis.

Acknowledgments. Thanks Özge Alaçam and Nihan Ocak from the METU HCI Research and Application Laboratory for technical support, Emine Eren and Semra Küçük for transcriptions and coding, and Christopher Habel for his valuable comments and suggestions.

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