Representational Form and Communicative Use

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Abstract

The form of representations is typically considered to be conditioned by three things: the nature and availability of domain regularities, the perceptual and cognitive abilities of individuals, and the properties of the medium used to construct a representation. This paper reports on an experimental investigation of a fourth constraint on representational form; communicative use. Subjects were given a graphical interaction task in which they produced drawings of pieces of music. The results demonstrate that both level of interaction and communicative context have a marked influence on the form of the representations produced. The results parallel findings for dialogue and indicate that communicative use may be a key constraint on representational form.

Background

In order to be effective in communication, a representation must address, in some reliable way, regularities in the represented world or domain. This intuition naturally suggests a focus on characterising the relationship between the form of representations and the form of a particular domain. For example, between the elements of a picture and the scene or object it represents, or between the structure of a sentence and a mathematical model of the domain. Of course, this relationship may be indirect and arbitrary but where it can be characterised it provides a basis for comparing representations according to properties such as: abstraction, conventionalisation, expressiveness, iconicity, schematisation, and specificity. In cognitive science, three factors are typically cited as moderating these properties. Firstly, the domain to be represented must be sufficiently regular or structured. Secondly, individual perceptual and cognitive limitations constrain both the types of regularity that are identified and the form of the representation used to capture them. Thirdly, representational form is conditioned by the properties of the medium used to produce them.

Significant attention has been directed to analysing the importance of cognitive-perceptual factors and the properties of the medium in conditioning the form of graphical representations (see Scaife & Rogers, 1996, for a review). For example, some authors have highlighted how graphical representations can exploit spatial layout to reduce memory load and facilitate reasoning about a domain (e.g., Stenning & Oberlander, 1995; Shimojima, 1996). The influence of conceptual limitations and perceptual processes in normalising and conventionalising the form of graphical representations has also been investigated (Bartlett, 1932; Tversky, 1981, 1989, 1995). The specific physical properties of graphical media have also been cited as a constraint on representational form. For example, clay discourages the fluent use of detailed graphical forms, favouring simplified, reduced symbols or scripts instead. Historical transitions from pictographic to more abstract scripts have been attributed, in part, to the introduction of clay tablets as the principal writing medium (Tversky, 1995).

These considerations overlook what we take to be the primary function of graphical and linguistic representations: use in communication. Evidence is accumulating to indicate that distinctively interactional or communicative factors constrain the form of descriptions used in dialogue. For example, Garrod and Doherty (1994) showed experimentally that choice between alternative forms of spatial description is primarily influenced by pressure to establish conventions within a sub-community. Importantly, these effects arise independently of domain structure and independently of cognitive-perceptual factors such as individual task expertise (Healey, 1997, 2001). Schwartz (1995) also provides evidence of significant communicative constraints on the form of graphical representations. He studied the differences between the graphical representations produced during problem solving by pairs or individuals. Dyads produced abstract problem representations, such as matrices and graphs, significantly more often than individuals working alone.

This paper reports two experiments that investigate the influence of domain structure, media type, and communicative use on representational form. Our task was designed to meet three basic requirements. Firstly, the precondition that the task domain should exhibit a number of basic regularities which could be captured in a representation. Secondly, that there should be no strong pre-existing representational conventions for carrying out the task. The rationale for this is that our focus on changes in representational form requires a domain for which participants can, in principle, deploy a variety of possible representations and which does not encourage them (or us) to suppose there is a particular 'correct' representation. Existing experimental studies of graphical representation have focussed almost exclusively on tasks and materials, such as maps, Euler circles, circuit diagrams

and program flow charts, which have standard interpretations and which individuals must learn to read in the intended way (cf. Scaife & Rogers, 1996). Thirdly, we wanted a task that is accomplished by exclusively graphical means. This facilitates comparison with other communicative modalities, especially language and is more likely to promote the development of novel conventions. To this end we developed a music communication task. This task involves people producing pictures of pieces of music so that a second person can use them to identify the piece drawn. Music provides a highly structured task domain because of the availability of parameters such as: tempo, intensity, texture, scale and mode. It also provides a domain for which, with the exception of formal notations used by musicians, participants have no pre-existing representational conventions to call on.

Experiment 1

Experiment 1 investigated the effects of domain structure on the form of drawings produced. Musical genre (Jazz vs. Classical) was used as the basic manipulation of domain structure. Two quantitative dependent measures were selected: accuracy of identification of the music from the drawings and time to respond.

Materials 36 pieces of piano solo music were chosen; 18 Jazz pieces and 18 Classical pieces. Each piece was by a different composer or artist and easily recognisable pieces were avoided. The Jazz pieces all included some improvisation and used non-diatonic chord progressions or tones whereas the Classical pieces did not.

All drawing was carried out and captured on a shared virtual whiteboard written specially for the task. The whiteboard was displayed on two LCD tablets (combined graphics tablet and screen) connected to two desktop computers. The whiteboard consisted of a shared drawing area, a strip palette of eight colours and a set of buttons for controlling playback and indicating selections at the top. Subjects could draw using a stylus and lines could be erased by using the reverse end of the stylus.

Subjects 24 participants were recruited from local universities and divided into 12 pairs. They were paid an honorarium for taking part.

Procedure On each trial one participant, the Giver, drew a picture of a target piece of piano music. Givers were free to draw anything they like, subject to the restriction than no letters or numbers should be used. The other member of the pair, the Follower, saw the Giver's drawing developing on the whiteboard and their task was to use this picture to select which of two pieces; the target and a distractor, it corresponded to. Playback and selection of the target and distractor pieces, controlled by buttons at the top of the screen, was self-paced. Followers were asked to make their choice as quickly and as accurately as possible. If a two minute time limit expired before the Follower decided then further drawing by the Giver was blocked and a dialogue window appeared to prompt a final choice. After each trial subjects received feedback about whether the choice was correct. This was repeated for 24 trials with the roles of Giver and Follower alternating between the members of a pair. Music was randomly assigned subject to the constraints that no individual heard the same piece of music twice (as target or distractor), each piece of music occurred equally often as target and distractor, choice of pieces was counterbalanced across pairs and conditions, and order of presentation was randomised for each pair.

Results

Despite some initial hesitation, participants found the task intelligible and engaging. They were able to perform consistently above chance getting, on average, 68% correct ($t_{(44)} = 6.38$, p (two tailed) = 0.00.)[1]. To evaluate effects of the manipulation of genre, two analyses were carried out. Firstly the type of target drawn by the Giver; Classical vs. Jazz. Secondly, the type of discrimination performed by the Follower; same genre (Jazz vs. Jazz and Classical vs. Classical) or different genre (Jazz vs. Classical). The average proportion of correct responses for each pair were analysed in a 2 factor analysis of variance: There was no simple main effect of target type ($F_{(1,11)} = 2.10$, p = 0.17) or discrimination type ($F_{(1,11)} = 2.10$, p = 0.66) and no interaction ($F_{(1,11)} = 0.58$, p = 0.46). The corresponding analysis for average response times also showed no simple main effect of either target type ($F_{(1,11)} = 0.84$, p = 0.38) or discrimination type ($F_{(1,11)} = 2.92$, p = 0.12) and no interaction ($F_{(1,11)} = 2.87$, p = 0.12).

Informal inspection suggested that some of the drawings appeared to be coding emotional affect (e.g., sad vs. happy faces). It was hypothesised that this might reflect the influence of a second aspect of musical form; mode (Major or Minor). To test for this the mode of each target and distractor piece was coded. Analysis of variance with Target type (Major/Minor) crossed with Discrimination type (Same/Different mode) again showed no evidence of a main effect on proportion correct of either target type ($F_{(1,11)} = 0.32$, p=0.58) or discrimination type ($F_{(1,11)} = 2.87$, p=0.12) and no interaction. The analysis for average response times also provided no evidence of an effect of either target type ($F_{(1,11)} = 1.312$, p=0.28) or discrimination type ($F_{(1,11)} = 0.87$,p=0.37) and no interaction.

Drawing Types The drawings produced fell into two broad categories. The first category of drawings, 'Abstract' (illustrated in Figure 1), involve some representation of musical form, e.g., intensity, pitch, melody, rhythm or tempo, typically represented as a contour. Attempts to use formal music notation were also coded as Abstract. It was notable, however, that use of formal notation was rare and, except in once case, subjects did not

[1] An alpha level of .05 was used for all statistical tests.

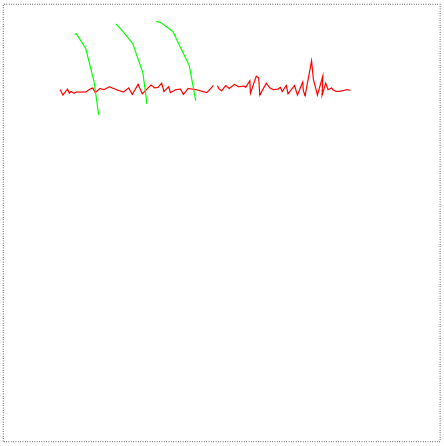

Figure 1: Example Abstract Drawing

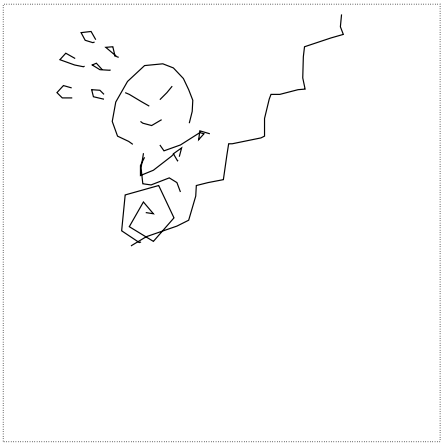

Figure 2: Example Figurative Drawing

persist with it. This was probably attributable to the difficulty of real-time transcription and the fact that it is only useful if both members of a pair are sufficiently expert with it. The second category of drawings, 'Figurative' (illustrated in Figure 2), is a more heterogeneous category involving depictions of e.g., faces, figures, objects or situations. A third, smaller category of Composite drawings was noted in which some abstract and figurative elements had been combined.

Two of the authors independently coded 287 drawings as either Abstract, Figurative or Composite. Inter-judge agreement on the coding was high (Kappa = 0.9, N = 287, k= 2).

It was initially hypothesised that the use of Abstract or Figurative drawings types might be influenced by the manipulation of genre. Jazz is often considered a more abstract form than Classical music and this might be reflected in the use of Abstract representations. Conversely, the selection of non-diatonic Jazz pieces containing some improvisation ensured that, relative to the Classical pieces, they had a less regular structure. On these grounds the form of Classical targets might be more easily detected and drawn. However, as Table 1 indicates, there appears to be no pattern in the distribution of drawing types according to the genre of the pieces. An analysis of the frequency of Abstract and Figurative drawings for Jazz and Classical pieces respectively suggests no reliable difference in pattern of use ($Chi_{(1)}$= 0.45, p=0.50).

Table 1: Frequency of Drawing Types According to Musical Form

	Drawing Type		
	Abstract	Figurative	Composite
Classical	37	94	12
Jazz	42	89	12

To test for effects of communicative context on choice of drawing type, measures of entrainment or matching were used (see Garrod & Anderson, 1987). This is the number of drawings produced by an individual that are of the same type (in this case Abstract, Figurative or Composite) as the immediately preceding drawing produced by their partner. It indexes the degree to which the members of a pair are tending to coordinate their choice of drawing type over and above what would be expected by chance given the frequency of use across the population as a whole. The average score for pairs in experiment 1 was 0.71 compared with a chance level of 0.49 (chance is calculated as the sum of the squared proportions of each drawing type in the corpus as a whole). These were reliably different ($t_{(11)}$=4.03, p (2 tailed) = 0.00).

Discussion of Experiment 1

Although the results show that subjects are able to carry out the task they provide no evidence of an effect of domain structure on task performance. Neither musical genre nor mode, as operationalised here, influenced the effectiveness with which pairs could perform the communication task. The difficulty of producing a drawing, as assessed by the effects of target type, was unaffected by musical form. The difficulty of distinguishing between pieces, as assessed by the effects of discrimination type, was also unaffected. Of course, it is possible that the experiments were insufficiently sensitive to detect an effect or that other aspects of musical form be influencing performance. Nonetheless, two intuitively salient aspects of form; genre and mode, did not affect the difficulty of the task.

More importantly, although the drawings can be reliably classified as Abstract or Figurative, the distribution of these representation types shows no influence of musical form, Jazz and Classical pieces are equally likely to be drawn in a Figurative or Abstract style. The form of the drawings is, however, predicted by communicative context. Pairs tend to entrain to one another, producing

matching drawing types more frequently than would occur by chance. These findings are consistent with our proposal that communicative coordination provides one of the principal influences on choice of representation type. However, the level of communication possible in experiment 1 was very limited. The interaction consisted only in the alternation between the roles of Giver and Drawer and the feedback about whether the last drawing had been correctly identified at the end of each trial. In effect, each trial is analogous to a single conversational turn. If communicative use constrains representational form then manipulation of the level of interaction should affect choice of representation type.

Experiment 2 was designed to address two issues. Firstly to investigate whether altering the richness of the communicative exchange would affect use of drawing types. Secondly to investigate the prediction that a medium which tended to discourage fluent production of graphics would favour more reduced, abstract, forms.

Experiment 2

In experiment 2 the richness of the communicative interaction was increased by allowing both participants to draw and erase freely on the shared whiteboard at any time. The manipulation of medium was introduced by contrasting two conditions, one with the same stylus based interaction as experiment 1, in which subjects draw directly onto the screen, and one with mouse based input. This served to reduce fluency of movement and introduced a spatial separation between input and the screen.

Materials A total of 112, 30 second, piano solo pieces, were used. This included the pieces used in experiment 1 as a subset. The pieces were selected according to the same criteria as in experiment 1 with the exception that each composer was used twice.

Subjects 24 participants, (16 male and 8 female, average age 19) were recruited from a variety of disciplines at local colleges and universities. They were paid an honorarium for taking part.

Procedure Broadly the same procedure as experiment 1 was followed. However, because the restriction to a single person drawing on the whiteboard was removed, subjects were shown a demonstration of simultaneous drawing on the whiteboard. Two versions of the interactive experimental task were used. In the 'matching' version both members of a pair had one piece of piano music each and the task was for them to determine whether these pieces were the same or different. In the 'discrimination' version each member of the pair had two pieces of music and the task was for them to decide which of the two pieces was the same. Although we do not discuss the task manipulation here, the analysis reported below is based on data from both tasks to preserve the balance of conditions and materials.

Design Experiment 2 employed a within-subjects, factorial design with task (Matching vs. Discrimination) crossed with Media (Mouse vs. Stylus). Selection of music was constrained so that the combinations of form (Jazz, Classical) and Mode (Major vs. Minor) were counterbalanced across conditions. Each piece was also classified according to its tempo with selection of tempo randomised across conditions. As before, no one heard the same piece of music twice. This design resulted in a total of 68 trials per pair with order of conditions and materials counterbalanced.

Results

The effects of media and experience on task performance were assessed in two analyses of variance. To index experience, the trials were divided into four blocks. For each quarter of the experiment, and each pair, the proportion of correct responses and the average time to respond were calculated. Analysis of variance on the proportion of correct responses, with media and experience as within subjects factors, showed a reliable main effect of experience ($F_{(3,24)} = 4.84$, p=0.01) but no effect of media ($F_{(1,24)} = 0.04$, p=0.84) and no interactions. Linear trend analysis confirmed that participants became more accurate with experience ($t_{(33)} = 3.48$, p(one tailed) = 0.00) . The parallel analysis for time to respond also showed a main effect of experience ($F_{(3,47)} = 4.07$, p=0.18) and again, no effect of media ($F_{(1,47)} = 0.01$, p=0.92). Linear trend analysis confirmed that participants were becoming faster at the task with experience ($t_{(33)} = 2.38$, p(one tailed) = 0.01). The results suggest that the manipulation of medium does not affect participants' ability to carry out the task.

Drawing Types The drawing activity of each member of a pair was separated into two files and independently coded, as before, for the categories Abstract, Figurative or Composite. An additional category of 'None' was introduced to deal with a small number of cases (3%) where one or both of the partners had not drawn a picture of a piece on a given trial. The distribution of each drawing type across all trials is given in Table 2.

The prediction that medium should affect distribution of drawing types was assessed by scoring, for each pair, the proportion of drawings that were classified as Abstract. This was analysed in an analysis of variance with medium, task and experience as within subjects factors. There was no simple main effect of media ($F_{(1,24)} = 2.22$, p= 0.15) and no reliable interactions.

Table 2: Distribution of Drawings, Experiment 2.

	Drawing Type		
	Abstract	Figurative	Composite
Frequency	970	345	257
Proportion	59%	21%	16%

Entrainment scores were calculated, as before, to provide an indication of the extent to which the members of a pair were coordinating their choice of representation

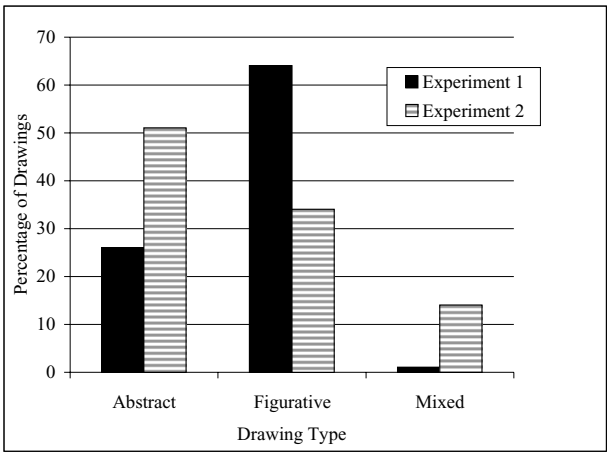

Figure 3: Choice of Drawing Types in Experiments 1 and 2

type. In this case scores were calculated as the proportion of trials in which drawings of the same type were produced, excluding trials in which one or both participants produced no drawing. The average entrainment score was 0.79, reliably above the chance level of 0.42 ($t_{(11)} = 6.75$, $p = 0.00$).

Comparison of Experiments 1 and 2

To test for effects of the difference in level of interactivity between experiments 1 and 2 only data from the first 12 trials of experiment 2 were used. This was in order to restrict comparisons to the situation in which participants had completed the same number of drawings of different pieces.

To compare level of coordination in choice of drawing type a t-test was performed on the average entrainment scores for each pair with experiment (1 vs. 2) as a between subjects factor. This indicated that levels of matching were not reliably different ($t_{(22)} = 0.74$, p (2 tailed) = 0.46). The ability to interact directly did not affect the extent to which pairs tended to match their choice of representation type.

Although degree of matching did not differ between experiments 1 and 2, a reversal in patterns of choice in drawing types was observed. As Figure 3 illustrates, during the first 12 trials of experiment 2 almost twice as many Abstract drawings were produced than in experiment 1. The contrast in relative frequency of Abstract and Figurative drawings confirmed the reliability of this pattern ($Chi^2_{(1)} = 50.7$, $p = 0.00$). The results indicate that the ability to interact directly has a substantial effect on the use of drawing types leading, in particular, to a much greater use of Abstract drawings.

General Discussion

Considered together, the results provide evidence that communicative use has a strong effect on representational form. Although intuitively genre and mode are important elements musical form, they had no effect on task performance or on choice of representation type in the present study. Additionally, although the manipulation of medium between mouse-based and stylus based input provides a contrast in levels of control and fluency it had no demonstrable effect on either performance or representational form. In particular, no evidence was found for the prediction that the simpler contours of Abstract drawings would be favoured when subjects used a mouse. In contrast to medium and domain, two effects of communicative use were noted. Firstly, subjects' choice between Abstract and Figurative representations was sensitive to their partner's choice of representation. People were much more likely to produce a drawing of a similar type to the one last produced by their partner than could be expected by chance. This pattern of entrainment parallels findings for dialogue. Garrod and Anderson (1987) found that, while domain structure favours some types of verbal description over others, the main constraint on choice of representation type is the pressure to coordinate with an interlocutor. Secondly, the pattern of use of drawing types between experiment 1 and 2 effectively reverses with approximately twice as many Abstract drawings and half as many Figurative drawings used in experiment 2. This suggests that level of interaction has an especially marked effect on choice of drawing type and this occurs even though the level of entrainment or matching in the two experiments is not reliably different.

One potential issue with this interpretation is that additional pieces of music were used in the second experiment, raising the possibility that these pieces particularly favoured Abstract drawings. However, the selection criteria for pieces were the same across both experiments and it seems unlikely that a specific bias was introduced. A second issue is that the difference in level of interaction is not the only difference between the tasks in experiments 1 and 2. Although number of pieces drawn and taken into account in the analysis, other task differences might have contributed to the observed effect on drawing types. Arguably, the interactive versions of the task are more comparative because more than one piece is drawn on each trial. This would not explain the tendency to entrain but it could contribute to choice of drawing type. This possibility is being investigated in further work.

The issues raised above notwithstanding, the results provide evidence of a substantial influence of communicative constraints on representational form. This does not necessarily undermine the claim that domain structure and media type influence representational form. Amongst other things, it is possible that genre and mode are relatively unimportant aspects of musical form and other aspects of domain structure would have a more marked effect. Similarly, the difference in ease of execution between a mouse and a stylus, although significant, may be insufficient to affect representational form. These questions can only be resolved by further empirical work. However, the present study suggests that constraints deriving from communicative use can have a strong, per-

haps key, influence on representational form.

The interpretation of these results depends on providing an account of what the difference between Abstract and Figurative drawings consist in. The Abstract category consisted of drawings that appeared to pick up on formal aspects of the music. Contour lines and blobs were used to represent a potentially wide variety of possible regularities, e.g., pitch, stress, harmonic structure, chord structure, rhythm, tempo, texture and intensity. For each of these possibilities a further number of variations are possible including choice of axes, choice of scale, and level of granularity (whole piece, first few bars etc.). A specific type of Abstract drawing imposes a systematic interpretation. It generalises to any piece of music and can sustain internal structural inferences for a piece, e.g., one chord is twice as long or intense as another. Relative to Abstract drawings, Figurative drawings, are highly heterogeneous. They employ a range of ad hoc devices such as visual emblems (city skylines for Jazz) symbols of emotive affect (sad faces, graves), pictures of rabbits or cars to indicate tempo, pictures of landscapes to suggest moods and so on. In contrast to Abstract drawings they provide only weak support for generalisations. There is not a street scene or landscape for every piece and they provide almost no information about the internal structure of a piece.

The present proposal is that the key constraint on the use of Abstract or Figurative drawings in the present task is the degree of coordination they require. In particular, successful use of Abstract drawings demands a higher degree of semantic coordination. To use Abstract drawings successfully subjects must attempt to coordinate on which aspect of musical form is being used, on which axes, at what level of granularity. Figurative drawings, by contrast, can be used in a more ad hoc manner. They can exploit different interpretations in each case and do not impose a particular structure on the music. We propose that direct interaction sustains the use of Abstract drawings by providing mechanisms that facilitate the coordination of interpretation. For example, in experiment 2 subjects were seen to circle and underline parts of each other's representations. This could function as a means of isolating and repairing problems with particular elements of a drawing. Lines and arrows between different contours were also used to indicate possible alignments or changes of scale. In experiment 1 such exchanges were impossible even though, in principle, the same types of representation could have been used.

The implication of these considerations is that properties of representations, such as abstraction, may depend more on the character of the interactions in which they are used than on the character of the represented domain. This is not to suggest that effective representations do not address regularities in the represented domain but rather that representational form is conditioned, first and foremost, by the structure of interaction and the kinds of coordination that it makes possible, and only contingently by the structure of the domain.

Acknowledgments

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References

Bartlett, F. (1932). Remembering: A study in experimental and social psychology. *CUP*.

Garrod, S., & Anderson, A. (1987). Saying what you mean in dialogue: A study in conceptual and semantic co-ordination. *Cognition, 27*, 181-218.

Garrod, S., & Doherty, G. (1994). Conversation, coordination and convention: An emprirical investigation of how groups establish linguistic conventions. *Cognition, 53*, 181-215.

Healey, P. G. (1997). Expertise or expert-ese: The emergence of task-oriented sub-languages. In M. Shafto & P. Langley (Eds.), *Proceedings of the ninteenth annual conference of the cognitive science society* (pp. 301–306). Stanford University, CA.

Healey, P. G. (2001). *Semantic coordination in dialogue.* (Manuscript in preparation)

Scaife, M., & Rogers, Y. (1996). External cognition: How do graphical representations work? *International Journal of Human-Computer Studies, 45*, 185-213.

Schwartz, D. L. (1995). The emergence of abstract representations in dyad problem solving. *The Journal of the Learning Sciences, 4*(3), 321–354.

Shimojima, A. (1996). Operational constraints in diagrammatic reasoning. In G. Allwein & J. Barwise (Eds.), *Logical reasoning with diagrams* (pp. 27–48). Oxford.

Stenning, K., & Oberlander, J. (1995). A cognitive theory of graphical and linguistic reasoning: Logic and implementation. *Cognitive Science, 19*, 97–140.

Tversky, B. (1981). Distortions in memory for maps. *Cognitive Psychology, 13*, 407–433.

Tversky, B. (1989). Perceptual and conceptual factors in distortions in memory for graphs and maps. *Journal of Experimental Psychology: General, 118*(4), 387–398.

Tversky, B. (1995). Cognitive origins of graphic conventions. In F. Marchese (Ed.), *Understanding images* (pp. 29–53). New York: Springer-Verlag.