The Impact of Design in Diagrams on Reading Behavior and Learning

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Preface

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I want to thank my supervisors, Dr. Jan van der Meij and Dr. Hans van der Meij, for their lots of great suggestions, priceless help and energetic support in providing all the essential conditions in carrying out this study.

Abstract

Diagram's superiority compared to written descriptions lies in its ability to structure and summarize information, and to make relations between concepts and ideas readily clear. Expanded by perceptual cues like arrows, boxes or lines diagrams serve both thinking and communicating. Unfortunately, research on effects of such specific design elements like arrows in (matrix) diagrams is rare and all too often are practitioners forced to rely on their intuition and experience while making layout decisions to promote learning and convey meaning in the way intended.

The purpose of this study is twofold. First, it is going to be examined if learners do follow arrows while studying a matrix diagram. Second, it is going to be investigated if the way in which learners study a matrix diagram has any impact on recall. For this purpose, eye-tracking technique will be used combined with a knowledge test and a short interview.

The results showed that participants did not follow the arrows in their traversal of the diagram. If anything, arrows served initial orientation. Participants which read the diagram per category also performed better on the post-test questions focusing on categories, corroborating prior research that reading order can have influence on learning performance (i.e. recall).

1. Introduction

A diagram is a powerful tool to organize and summarize information, making it possible to infer facts and relations at a glance (Tversky & Kessell, 2006). To communicate meaning, diagrams make use of spatial relations and commonly much of the information needed to make a certain conclusion is present and explicit at a single place (Larkin & Simon, 1987). Typically, diagrams are expanded by words and cues or elements like arrows, lines, boxes, and brackets so that users can go on through a smooth traversal of the diagram. In that way, diagrams serve as an aid for both thinking and communicating, especially for problems with large working memory demands (Tversky & Kessell, 2006).

A common type of diagram which will also be used in this research is a matrix diagram. A matrix diagram is a two-dimensional cross-classification table where content elements are typically represented with text, enclosed in boxes or circles, and often augmented by perceptual cues like color or arrows (see Figure 1). Such text-based matrix diagrams make it readily possible to look especially across multiple categories and compare different topics (Kauffman & Kiewra, 2010).

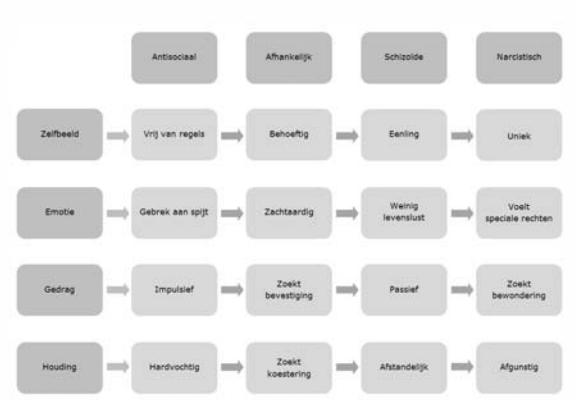

Figure 1. One version of a matrix diagram used in this research.

Unfortunately, with regard to the designation of diagrams it has to be stated that there is no standard classification system. As a consequence, the same terms are used for diagrams with different characteristics. For example, Winn (1987) refers to such matrix diagrams just described as *charts*, whereas Hegarty et al. (1991) call 'organization' and 'flow charts' *diagrams* (Vekiri, 2002). Throughout this research article the term *diagram* will refer to such a matrix diagram just depicted.

1.1. Processing and learning from (matrix) diagrams

To get a better understanding of why matrix diagrams are such powerful and popular tools, it is useful to compare them with other kinds of representations. According to Larkin and Simon (1987), when representations contain the same information (i.e. when they are informationally equivalent), diagrams are advantageous in comparison with written descriptions because they offer a computational benefit. This means that diagrams aid search and inference processes and allow an easier recognition of information (Larkin & Simon, 1987). Likewise, Lohse, Biolski, Walker, and Rueter (1994) stress that diagrams can assist problem-solving and detection by providing an efficient structure for expressing data.

Based on the assumption that diagrams are more “computational efficient” (Larkin & Simon, 1987) than other representations, Kauffman and Kiewra (2010) set out to investigate what accounts for this efficiency. The researchers theorized that computational efficiency is the sum of a representation’s ability to cue information (*signaling*), the degree to which the representation takes out information (*extraction*), and *localization*, which refers to how close together similar information is placed. Localization can be further divided in *topical* and *categorical localization*. A representation which presents all information about one topic followed by information about the next topic possesses topical localization, and a representation which places categorical information closely together possesses categorical localization. Kauffman et al. (2010) therefore examined the independent and relative effects of signaling, extraction, and localization on learning. To accomplish this, the researchers compared the learning potential of a standard text, a signaled text which cues the reader’s attention to the text’s underlying structure in the form of boldface type, italics, and underlining, a text with key ideas extracted, an outline localizing ideas topically, and a matrix diagram which localizes both topic and category information using its two-dimensional arrangement. They found that both, highlighting vital topics, categories, or facts and extraction alone are not enough for learning to take place. Only localization proved to be an important factor in determining a representations’ benefit. Localizing information about a topic might help the reader to learn the facts or relationships pertaining to that topic, whereas categorical localization allows the reader to compare the topics effortlessly across a single or multiple categories.

Recent research confirmed that the advantage of matrix diagrams over text or outlines relies mainly on the way the information is presented. Although matrix diagrams may express the same information as textual or linear representations do, matrix diagrams are more valuable than text because they help readers to make complex inferences and integrate the information provided in a more efficient way (Vekiri, 2002).

Starting from the research of Kauffman et al. (2010), in our research it is going to be examined if learning from matrix diagrams can be further facilitated with the addition of arrows pointing either from left to right or from top to bottom, thereby guiding the readers attention in the direction of the topics or in the direction of the categories, respectively (Tversky & Kessell, 2006).

Whereas lines usually suggest connectors and crosses suggest points where paths interconnect, arrows usually suggest direction in space, time, motion, and in causality (Tversky, Zacks, Lee, & Heiser, 2000), with the arrowhead indicating the direction of the relation (Heiser & Tversky, 2006). The meanings of arrows are indicated by their geometric forms, meanings that are universal but can also be more refined and interpretable in different contexts (Tversky et al., 2000). For example, Heiser and Tversky (2006) found that when arrows were added to structural diagrams, people tended to interpret the diagrams functionally. But arrows can also readily indicate the chain of steps in the operation of a system. Arrows can illustrate the path of motion, the direction of the consequences of mechanics or specify the direction of force. The uses of arrows have clearly not been limited to direction in space and time and for example Horn (1998) counted in his comprehensive survey of diagrams 250 different meanings for arrows, including increases and decreases (Tversky et al., 2000).

The idea behind such cueing is thus that cues can serve three functions. (1) *selection* contains that cues guide reader’s attention directly to certain aspects of an object (Fischer & Schwan, 2010), (2) *organizational*, cueing the content’s structural organization, and (3) *integration*, explicating relations between two (or more) elements within a single representation, or cueing to draw attention to related elements in different representations (de Koning et al., 2009), so increasing their probability of being detected and integrated into the reader’s developing mental model (Boucheix & Lowe, 2010). In our research, the proposed main function of the arrows is an organizational one, intended to guide the reader primarily either in the direction of the topics or in the direction of the categories, thereby cueing the structure of the presented content.

Studies in cognitive psychology substantiate that readers process diagrams in two phases. In the first, the preattentive phase, graphical elements like arrows, color and circles are detected and serve as an initial guidance. In the second, the attentive phase, reader’s attention is directed towards these graphical and also towards textual elements presented in the diagram. It is in this attentive phase where processing of information is taking place. However, it is in the preattentive phase where perceptual cues like arrows may have the most influence on where and how to start reading (Treisman & Gelade, 1980).

Furthermore, research has shown that the bottom-up perceptual organization of information can in fact exert an important influence on how the information will be stored in memory (Woodman, Vecera, & Luck, 2003).

Unfortunately, the research on effects of such specific design elements like arrows in matrix diagrams, especially on their organizational function, is rare. Numerous studies that have used memory performance (i.e. recall) as an indicator of attentional processing have focused primarily on color as a means of selective cueing, showing that it can be effective in both, text and illustrations (de Koning, Tabbers, Rikers & Paas, 2009). The use of arrows as organizational cues is hence rather based on personal taste than on scientific evidence of cue functioning and of how people may process such cues in static, matrix-like diagrams (Lowe & Boucheix, 2010).

One purpose of this study is therefore to investigate whether arrows in a matrix diagram, cueing the structural organization of the content, do influence how a viewer processes such a diagram, thus influencing reading direction and subsequent recall. For practical reasons, only two informationally equivalent diagrams will be examined instead of using a 2 x 2 between-subjects design, with arrows pointing from left to right and from top to bottom, respectively.

Summarizing, although research has well focused on the impact of specific design elements in diagrams, it must be stated that studies have explored some functions of cueing more comprehensively (e.g., attention-directing function (selection)) than others (e.g., organizing function) and did not always provide clear-cut explanations of the effects of the functions of cueing (de Koning et al., 2009). The majority of studies were directed at the use of color, and nearly solely concentrating on rather complex graphical diagrams than on non-graphical matrix diagrams or other chart-like representations. Likewise, research focusing specifically on the role of arrows was rather concentrated on graphical diagrams and animations, than on matrix-like diagrams, putting emphasis on the selection and integration function of arrows, rather than on cueing content’s structural organization (ibid.). To my knowledge, no single study exists where the direct impact of arrows on reading textual information in a matrix diagram has been investigated. Furthermore, no study could be found which examined the impact of arrows as organizational cues in a matrix diagram on learning performance.

The goal of this study is therefore to examine whether perceptual cues like arrows in a matrix diagram do influence how a viewer *processes* such a diagram and the subsequent *learning* performance.

To that end, eye-tracking technique will be used as eye fixations are seen as being at the boundary of perception and cognition; in that they are an overt indicator that information is being cognitively represented. When we read, look at scenes, or search for an object, we constantly make rapid movements with our eyes with velocities as high as 500° per second, called *saccades.* Between the saccades, during *fixations,* the eyes stay relatively still during for about 200-300 ms. In simple discrimination tasks, the locus of attention and eye location can easily be uncoupled, but in complex information processing tasks such as reading, the link between the two is probably quite tight (Rayner, 1998). Considerable data have been collected indicating that eye movements are in fact closely linked to real-time cognitive processing activities of readers and that the time spent looking at a figure reflected both, the time to encode that figure as well as the time to operate on the encoded symbol; thus reflecting the ongoing mental processes related to the present information. While processing the most recently encoded information, there is no reason to direct the eye to seek other information, thereby probably initiating an encoding activity that could interrupt the ongoing processing (Just & Carpenter, 1975). Real-time cognitive processing measures which can be used are the locus of the eye-fixation, the (average) fixation duration (Rayner, 1998), and the total fixation time (i.e. cumulative duration of fixations within a region), considered as an indication of the amount of total cognitive processing engaged with the fixated information (Ozcelik et al., 2009), with greater amount leading to better learning (Mayer, 2010). Mayer (2010) summarized evidence on the link between eye-fixation measures and learning outcomes, thereby supporting the notion that increases in the total fixation time of a relevant section involve improvements in measures of learner understanding of the corresponding material.

In short, eye-tracking is a good measure to study attention guidance, as eye fixation patterns represent an on-line record of cognitive processing by providing information about *where* learners visually attend in a matrix diagram and for *how long* they inspect the different sections (Hannus & Hyönä, 1999; Hyönä, 2010). In order to overcome the limitations of the eye-tracking data and to find out not only how and for how long, but also *why* participants have inspected the diagram as they did, we have supplemented the eye-tracking data with a short interview. Self-reports given by the participants reduce the amount of inferences and serve as an aid to obtain a more comprehensive picture of the performance processes (van Gog, 2010). The influence of the reading direction on learning performance will be investigated on the basis of a post-test, which can be divided in sub questions focusing either on the topics or on the categories presented in the diagram.

1.2. Research questions

In accordance with the above made remarks, it is going to be investigated whether perceptual cues like arrows pointing either from left to right or from top to bottom in a matrix diagram do guide reader in their reading behavior. On the one side, eye-tracking data will be used to check where and for how long readers visually attend in a matrix diagram. On the other side, self-report data will be used to supplement the eye-tracking records and to find out why readers inspected the diagram as they did. On the basis of a post-test it is going to be investigated whether the reading direction has an influence on subsequent learning performance (i.e. recall).

The following research questions are going to be addressed in this study:

1: Do perceptual cues (arrows) in een matrix diagram guide learners' reading behavior?
2: Does the way in which learners read a matrix diagram influence their learning performance?

Based on the remarks of Treisman et al. (1980) and Heiser et al. (2006), indicating that the presence of arrows should in fact encourage their following, it is expected that the learners will follow the arrows when reading the information in the presented matrix diagram with probably the greatest influence during an initial orientation phase, thus in the beginning of the studying process. It is hence not only expected that readers will *initially* follow the arrows, but also that readers will orient themselves by the arrows *throughout* the reading session.

Furthermore, it is expected that the way in which learners study the information in the matrix diagram will exert an influence on how the information will be recalled later on. In particular, we expect that participants will follow the arrows and thus recall the information in the way the arrows connect the single elements in the matrix. Readers which dominantly studied the diagram from left to right should perform better on the topic sub questions of the post-test. Respectively, readers which dominantly studied the diagram from top to bottom should perform better on the category sub questions.

But there are other relevant factors besides cues which can exert an influence on reading behavior in a given situation, namely the conventional format of a diagram (e.g. matrix, tree, hierarchy) and the conventions of language. In the case of matrix diagrams, it is according to Winn (1993) the column headings which are looked at first, as reading from top to bottom unfolds, and are taken as designating superior categories, thereby providing a framework into which objects can be placed. Likewise, without other guidance, readers of English and many other languages, search for information in diagrams beginning at the top left-hand corner, working across and down the page. People whose languages are written from right to left process diagrams also form right to left, which is convincing evidence on the influence of language on how diagrams are inspected. Thus, factors like the diagram format and learned conventions should therefore be kept in mind when investigating the impact of design elements on reading behavior.

2. Method

2.1. Participants - design

A total of forty-three students (29 female, 14 male) from the University of Twente in the Netherlands took part in the study for the granting of either money or one credit point. As an initial step, two participants had to be removed from the data set because in one case it was not possible to define the look zones unambiguously the participant looked at. In the other case, the participant had a remarkable low tracking time value. Participants were between ages of 19 and 29 (M = 21.74, SD = 1.90) and were randomly assigned to one of the two conditions (arrows from left to right or from top to bottom).

A between-subjects design was used with the orientation of cues (arrows from left to right or from top to bottom) as independent variables and reading behavior and learning performance as dependent variables. Reading behavior was measured with the help of eye-tracking, and learning performance was measured with a post-test.

2.2. Materials

2.2.1. Diagrams

The matrix diagram used in this study consists of four header cells on top and four on the left, thereby organizing the content in the sixteen body cells around four distinct personality disorders as the main categories and four distinct topics, respectively. The two versions of the diagram were informationally equivalent and contained as categories (top header cells) information on the following four personality disorders: *antisocial*, *dependent*, *schizoid* and *narcissistic*. The topics (left header cells) consist of the following characteristics: *self-image*, *emotion*, *behavior*, and *attitude*. The perceptual cues in the diagrams were computationally non-equivalent and were oriented either from left to right (first condition) or from top to bottom (second condition). Figure 2 shows the two versions of the matrix diagram used. In a related research study the same diagrams were used with the only difference of placing the categories on the left and the topics on top, in sum thus creating a 2 x 2 between-subjects design with *diagram orientation* (categories on top or on the left) and *cues orientation* (arrows pointing from top-down or from left-right) as independent variables, which could not be accomplished within the scope of this research study.

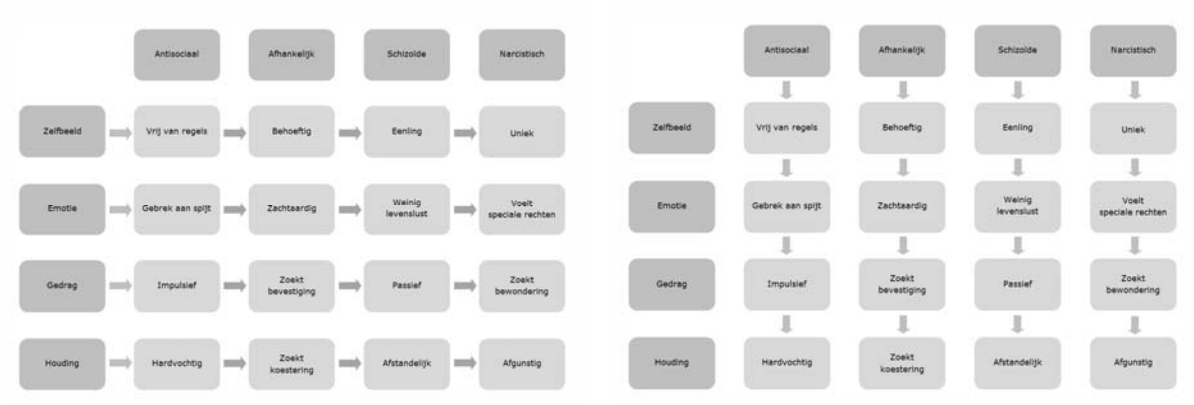

Figure 2. The two Dutch versions of the diagrams used in this study.

2.2.2. Demographics questionnaire

Participants were given a demographic questionnaire asking to give information on their age, gender, education, academic year and their existing knowledge on personality disorders on a visual analog scale (VAS).

2.2.3. Post-test

The post-test contained ten questions to assess what participants recalled from the content of the diagram. Five questions consisting of one open question and four multiple choice questions required an orientation on the categories (personality disorders), the other five questions, one open and four multiple choice questions, required an orientation on the topics (self-image, emotion, behavior, and attitude). In addition, question eleven showed both matrix diagrams and asked the participants to indicate which one they had studied and to draw in which order and direction they had studied this diagram.

2.2.4. Interview

In a short interview, the researcher asked the participants to specify how they studied the diagram, and why so and the answers were recorded with a standard digital voice recorder.

2.3. Procedure

Each participant was tested individually in a single session lasting about forty-five minutes.

On arrival, participants were asked to fill in the informed consent and the questionnaire, and were then familiarized with the eye-tracker and the process in general. Afterwards, every subject underwent an eye-tracking calibration and the quality of the calibration was checked by examining the calibration plot. Recalibration took place only if the calibration data was insufficient. The participants were asked to follow the instructions presented on the screen and were informed that they would be given a post-test after the study session to assess their learning performance. The matrix diagram was presented for a total duration of 300 seconds. After studying the diagram, each participant was instructed by a screen to ask the instructor for the post-test. Participants answered the questions on the post-test. After completing the post-test the interview took place.

2.4. Analysis

2.4.1. Eye-tracking data

The diagram was divided in 24 look zones, one for each header and body cell (see Figure 3). For each look zone the following variables were included in the analyses: average fixation duration, cumulative fixation duration, and sequence. *Fixation duration* was defined as the time of relative stability of the eye between two eye movements (saccades). We counted a time of minimal 100 ms within a 30 pixel diameter as one fixation. All fixation durations in a specific look zone (cell) were defined as *cumulative fixation duration*.

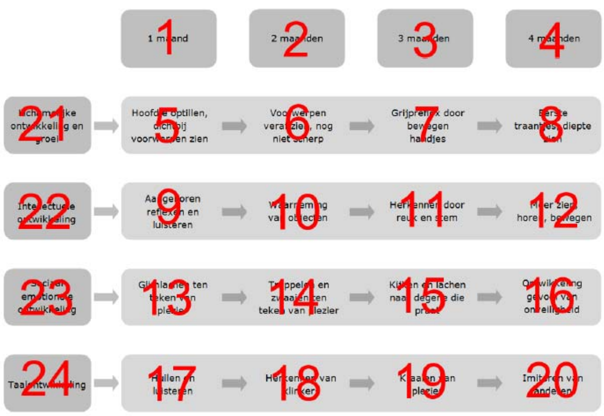

Figure 3. Definition of look zones

We were especially interested in the *sequence*; i.e., the reading order in which the participants studied the diagram. In other words, did the participants study the diagram from top to bottom or from left to right and was the sequence based on perceptual cues? To our knowledge, there is no ready-made method available to analyze a reading pattern or sequence in diagrams. Therefore, we constructed an *Eye Movement Sequence model* (EMS-model). Based on the fixations in the look zones, the EMS-model tries to find a sequence from left to right (e.g., 5, 6, 7) and top-down (e.g., 5, 9, 13). As long as the time spent in look zones belonging to the sequence are larger than the time spent in look zones not fitting the sequence, the sequence is intact. When the time spent in look zones not fitting the sequence becomes too long, the sequence is terminated and the EMS-model looks for a new sequence. For the analysis of eye movement patterns in the current study, minimally three subsequent row or column look zones had to be present to count as a sequence. In the EMS-model we had to take into account that participants sometimes temporarily deviate from a strict order. For example, when studying the body cells, a participant may temporarily look at a header cell to integrate the information (see Peebles & Cheng, 2001). The sequence < 5, 6, 7, 8 > counts as a strict left-to-right sequence in the same row. However, should the sequence < 5, 6, 2, 7 > also count as a left-to-right sequence? We argue that this depends on the fixation duration in the look zones, and we included fixation duration as a variable in the EMS-model.

The algorithm basically has to decide whether, given a current sequence, the next look zone fixation is added to this sequence or not. We denote the score of the current sequence after i fixations as S_i and the duration of the ith look zone fixation in the current sequence as d_i. The empty sequence has $S_0 = 0.0$. There are now two cases:

1. The next fixation is compatible with the current sequence (e.g., current is < 5, 6 > and next is < 7 >). In this case the score is updated with: $S_{i+1} = \max(S_i, d_{i+1})$.

2. The next fixation deviates from the current sequence (e.g., current is < 5, 6 > and next is < 2 >). In this case the score is updated with: $S_{i+1} = \max(S_i, d_{i+1})$. C is an experimentally validated constant which determines how quickly a sequence is broken if a fixation is not in the correct row or column. In this study C equals 2.0 which means that the fixation duration outside the sequence can be at most half (1/C) of the longest fixation duration inside the sequence[1]. If S_{i+1} becomes negative the sequence terminates.

The algorithm is illustrated using the following example:

fixation (i)	1	2	3	4	5
look zone	5	6	2	7	3
duration (di)	0.4	0.5	0.1	0.5	0.3
score (Si)	0.4	0.5	0.3	0.5	-0.1

0. Each empty sequence has $S_0 = 0.0$.

1. Look zone 5 is a body cell, so it can start a sequence < 5 >, $S1 = \max(S0, d1) = 0.4$.
2. Adding 6 results in < 5, 6 >. A sequence is initiated when two subsequent look zone fixations are adjacent left-to-right (in the same row) or top-to-bottom (in the same column). < 5, 6 > fits these criteria. The score is updated to $S2 = \max(S1, d2) = 0.5$.
3. Look zone 2 is not in the left-to-right row of the current sequence. The score is updated as follows S3= S2 – (C* d3) = 0.2.
4. Look zone 7 is in the correct left-to-right row: $S4 = \max(S3, d4) = 0.5$.
5. Look zone 3 is not in the row: S5= S4 – (C * d5)= -0.1. The score is now negative and we reject adding 3. The complete sequence is then <5,6,2,7>.

2.4.2. Post-test

On the post-test, participants could get one point for every correct answer on the multiple-choice questions, thus, receiving a minimum of 0 points and a maximum of 8 points. For the open questions, participants received one point for every correct answer, thus receiving a minimum of 0 points and a maximum of 4 points on each open question, thus 8 points for both open questions. The range of the total score lies hence between 0 and 16 points. Calculated scores include an overall score and a score for the category-related (focused on disorders) and topic-related (focused on characteristics) questions separately.

3. Results

3.1. Do perceptual cues in een matrix diagram guide learners’ reading behavior?

3.1.1. Eye-tracking measures

In total, 94.3% of all eye movements were tracked and a one-way ANOVA revealed no differences between the two conditions in this regard. In all, 98% of all fixations were to be found in one of the look zones. The average fixation time was 241 milliseconds.

One-way ANOVA showed significant differences between the conditions in total fixation duration for the body $F(42) = 4,86$, $p = 0.033$, the top-header $F(42) = 5,97$, $p = 0.019$, and the left-header $F(42) = 5,29$, $p = 0,027$.

Participants spend significantly more time looking at the body when the arrows pointed from top to bottom than from left to right. But the duration of fixations was significantly longer for both, the top- and the left-header when participants studied the diagram with arrows pointing from left to right than from top to bottom (see Table 1).

Table 1. Total fixation duration for the body, the top-header and left header per condition.

	Condition			
	Arrows left-right		Arrows top-bottom	
	M	SD	M	SD
Total fixation duration body	111.93	23.93	131.39	33.36
Total fixation duration top-header	38.19	15.63	28.19	10.58
Total fixation duration left-header	26.23	14.17	17.03	11.8

3.1.2. Initial reading

An analysis of the fixations showed that 34 out of 43 participants first looked at the header cells before looking at the body cells of the diagram.

To determine whether participants initially followed the arrows, the direction of the first sequence was examined. The analysis showed that in the diagram with the arrows pointing from left to right, 22.7% of all participants' first reading sequence was also from left to right. In the diagram where the arrows pointed from top to bottom, 76.2% of all participants' first reading sequence was also from top to bottom, $\chi 2 = 0.007$, $p = 0.933$. The results indicate that with respect to an initial reading direction participants had a from top to bottom reading preference.

3.1.3.Time in sequence for body cells

To check whether participants studied the diagram in a certain reading order depending on the condition they were in, an ANOVA on mean time in left-to-right and top-to-bottom sequence in the body was executed. The results showed no differences between the conditions, $F(1,42) = 1.44$, $p = 0.236$ and $F(1,42) = 1.19$, $p = 0.28$ respectively.

But, irrespective of the direction of the arrows, a repeated measures ANOVA revealed that the average time in top-to-bottom sequence was longer than in left-to-right sequence, thereby confirming the findings with regard to initial reading, that participants had a top to bottom reading order preference (see Table 2). The results indicated that the mean time in body sequence differed significantly, $F(1,41) = 6.98$, $p = 0.01$.

Table 2. Means and standard deviations for time in sequence per condition.

	Condition			
	Arrows left-right		Arrows top-bottom	
Time in sequence	M	SD	M	SD
Left to right	16.19	17.85	24.27	25.71
Top to bottom	30.18	19.60	37.74	25.46

3.2. Does the way in which a matrix-diagram is read influence recall?

3.2.1. Learning outcomes

In general, participants answered about 70% of the post-test questions correctly, M = 7, 86, SD = 2,61. A paired-sample t-test revealed no differences between the questions focused on categories and on topics $t(42) = 0{,}868$, $p = 0{,}391$, with a mean of 4,13 (SD = 1,20) for the questions focused on categories and a mean of 3,93 (SD = 1,56) for the questions focused on topics.

A one-way ANOVA was accomplished to check whether there were differences in answering the questions depending on the condition. Results indicated that the two groups did not differ, $F(1,42) = 0.34$, $p = 0.56$.

Furthermore, a one-way ANOVA showed no differences between the conditions on questions focusing on categories and questions focusing on topics, $F(1,42) = 0.23$, $p = 0.63$ and $F(1,42) = 0.24$, $p = 0.62$ respectively.

3.2.2. Reported dominant reading order

In all, self reports indicated that participants had three different dominant ways of studying the diagram. Participants stated either that they read it from top to bottom (N= 20), from left to right (N= 8) or in both ways either simultaneously, thus making combinations of the categories and topics, or in succession, thus reading it first in one direction and then in other (N= 15).

A one-way ANOVA revealed significant differences between the three different dominant reading orders on the total test score, $F(2,42)= 5.49$, $p= 0.008$. Looking at the test scores for the category and topic sub questions separately, one-way ANOVA likewise revealed that the reported dominant reading orders differed significantly, $F(2,42)= 3.34$, $p= 0.04$ and $F(2,42)= 3.98$, $p= 0.02$ respectively.

On the total and topic test scores, the group which studied the diagram in both ways, from left to right and top to bottom, outperformed both the from-left-to-right and from-top-to-bottom readers. The from-top-to-bottom readers reached the highest test score on the disorder sub questions, whereas the from-left-to-right readers reached the lowest test score on all three measures (see Table 3).

Table 3. Means and standard deviations for the total test score, and the test scores for the disorder and characteristic sub questions per reported dominant reading order.

	Reported dominant reading order					
	left-right		top-bottom		both	
	M	SD	M	SD	M	SD
Total test score	5.87	1.12	8.45	2.30	8.73	2.15
Disorder sub questions	3.12	0.64	4.40	1.31	4.33	1.04
Characteristics sub questions	2.75	1.03	4.05	1.46	4.40	1.68

3.3. Self-reports

41 out of 43 participants indicated the diagram they studied correctly. Irrespectively of the experimental condition, there appears to be a general top to bottom reading order preference.

When looking at the different experimental conditions in particular, the following picture emerges: against the odds, only 3 out of 22 participants in the left to right condition indicated they read the diagram accordingly, whereas 12 participants reported they studied it from top to bottom. Likewise, only 8 out of 21 participants in the top to bottom condition reported they studied the diagram accordingly, whereas 8 participants reported they studied it in both ways (see Table 4).

Table 4. Reported dominant reading order per condition.

	Condition	
Reported dominant reading order	Left-right	Top-bottom
Left to right	3	5
Top to bottom	12	8
Both ways	7	8

Most participants reported that they read the diagram from top to bottom because they believed the disorder header represented the main categories and they tried to anchor the information accordingly. Some reported it "made more sense" to orient oneself by the categories and some found it also "easier to memorize" the material.

Participants who studied the diagram from left to right mainly reported doing so “out of habit”, thereby confirming the influence of language convention (Winn, 1993). Others told that they found it “easier to memorize” the material.

Participants who studied the matrix diagram in both ways did so because they found it to be the wisest learning strategy or the “best way to memorize the material”.

In all, only 4 out 43 participants declared to have used the arrows as a reading guidance and 33 reported that they consciously did not follow them. 5 participants reported that they were guided by the arrows either only at the beginning or at the end, but not continuously.

The influence of the arrows on reading seemed to have the greatest influence only at the beginning of the reading process. In sum, 15 out of 43 participants indicated that they consciously followed the arrows at the beginning, but then switched either to their favourite reading order or kept follow them, thus corroborating the earlier mentioned findings from the examination of the direction of the first sequence. As already indicated, the most did not follow the arrows consistently. As reasons for not following the arrows (consistently), participants reported that the arrows “appeared not to be logical”, especially in the from left to right condition where participants studied the diagram from top to bottom, the arrows were felt as “disturbing”, or of “no value”. In general, participants found the arrows to be “not very use- or helpful” and sometimes “disturbing”. One participant reported that the arrows seemed to represent a certain relation between the boxes, which was disturbing because there was no such relation.

4. Discussion

In our study, a matrix diagram was supplemented by arrows as organizational cues, intended to guide the reading of the information presented in the diagram either from left to right or from top to bottom.

Irrespectively of the experimental condition, there appeared to be a from top to bottom reading order preference. Both, with respect to the initial reading sequence and the average time in a body sequence, eye-tracking data indicated that participants had predominantly a from top to bottom reading order tendency. Self-report data corroborated the eye-tracking results. Irrespectively of the experimental condition, most participants (20 out of 43) reported they studied the diagram from top to bottom, orienting oneself by the categories (personality disorders), because for them the disorder header represented the main category. This verifies the importance of the content presented in diagrams.

In all, only 4 out of 43 participants declared to have consciously used the arrows as a reading guidance and 33 participants reported that they consciously did not follow them because they found them of having no additional value. If anything, the influence of the arrows on reading seemed to be the greatest only at the beginning of the reading process. These finding is in accordance with the remarks of Treisman et al. (1980), who indicate that graphical elements may have the most influence on reading behavior in the beginning. In sum, 15 out of 43 participants indicated that they followed the arrows at the beginning, but then switched either to their favourite reading order or kept follow them. Those who switched did so because they found the arrows either not helpful or running in an non-logical direction, especially when the arrows pointed form left to right and when participants studied the diagram from top to bottom, thereby further confirming the importance of the content. Other found the arrows simply disturbing, because they seemed to indicate a special relation between the boxes connected through the arrows, where in fact there is no such special relation. This can be seen as an unwanted side effect of the many meanings arrows are able to serve, which are mainly universal but can also be more refined and interpreted differently (Tversky et al., 2000).

It appears that in the case of matrix diagrams where there is no special connection between the information, arrows as cueing devices seem not to be of special relevance with respect to organizational guidance and to be overruled by the conventional format and by the content presented in the diagram. In accordance with Winn (1993), most participants declared that they first looked at the header cells before looking at the body cells of the diagram, which provide a framework into which items can be placed as organization of the content unfolds. Eye-tracking data revealed that 34 out of 43 participants first looked at the header before looking at the body of the diagram and most participants also reported that they guided oneself by either the categories or the topics in order to learn the material. This two-dimensional organization of the matrix diagram and the type of content presented (categories and topics) seem so powerful that the additional inclusion of arrows as organizational cues seems either futile or having even adverse effects.

With respect to the influence of the reading order on learning performance it can be stated that the condition the participants were in had no remarkable influence on their learning performance. Results indicated that the two groups did not differ on answering the test questions in general, and the category- and topic-questions in particular. Thus, whether the arrows pointed from left to right or from top to bottom made no difference for learning. But, this is only part the story.

Looking at the *reported* dominant reading order, the results appear different. In all, self reports indicated that participants had three different central ways of studying the diagram. Participants stated either that they read it from top to bottom, from left to right or in both ways either simultaneously, thus making combinations of the categories and topics, or in succession, thus reading it first in one direction and then in other. In accordance with the stated expectations, the from-top-to-bottom reader reached the highest test scores on the disorder sub questions. However, the from-left-to-right readers reached the lowest test score on the characteristics sub questions. A possible explanation for the poorer performance of the from-left-to-right readers on the topic sub questions can possibly be found in the eye-tracking data. Eye-tracking studies suggest that a better understanding of diagrams is associated with more time spent in relevant regions of the diagram and less time spent in irrelevant parts (Cromley, Snyder-Hogan, & Luciw-Dubas, 2010). Computations of the total fixation duration of participants revealed in fact that participants who were in the condition with arrows pointing from left to right spend significantly more time looking at the header than on the body of the diagram, thereby neglecting the content in the body cells. The fact that participants who studied the diagram in both ways, making combinations between the categories and topics, reached the highest test scores on both, the whole test and the characteristic sub-questions, underlines the already adequate structure provided by the matrix diagram format and thus the remarks of Kauffman et al. (2010) about the influence of categorical and topical localization.

Summarizing, the question whether arrows in a two-dimensional matrix diagram do guide reading behavior *continuously* can be negated. Most participants found the arrows not helpful, even annoying and it seems that the conventional structure of the matrix diagram and the type of content presented already provide sufficient guidance which overrules the intended effect of the arrows. This is confirmed by the fact that, although some participants did follow the arrows *in the beginning*, most of them did so because at that time participants did not know what the diagram is all about and therefore thought that the arrows must have some special importance. But, as the participants realized the structure of the diagram, most gave up following the arrows.

The question whether reading order does have an influence on learning performance can in turn be affirmed, if not necessarily unequivocal, corroborating findings which have shown that the bottom-up perceptual organization of information do have an important influence on how the information will be stored in memory (Woodman et al., 2003).

Diagrams should be designed to facilitate the use of effective strategies of encoding, the process whereby sensory information is transformed into a representation suitable for storage in memory and subsequent retrieval (Winn, 1990). Self-reports revealed that most participants were rather ‘active’ in their way to deal with the two-dimensional structure of the matrix diagram, making combinations and reading it in many ways, thereby integrating the content dynamically. Arrows pointing in a certain direction seem not to be helpful in this regard and even to work against this self-motivated and individual process.

Designer of matrix diagrams should thus refrain from ‘overloading’ the matrix diagram with additional organizational cues like arrows, which can have no influence at best, and be frustrating at worst, or at least not expect that the arrows will automatically be followed, especially when the content presented seems to be organized in itself (in categories and related topics).

What seems to be crucial for the following of cues is their function and the content to be presented. Rather than arbitrarily grafting cues onto such diagrams, the use of cues should be tailored for the specific processing demands the diagram poses (Lowe & Boucheix, 2010). Thus, where the task is to guide reader’s attention to certain aspects of a diagram (selection), to explicate relations between elements within a single diagram or to show the route and sequence of events (integration), arrows seem to be well planned, to be followed and even to encourage different interpretations (causal or functional) of diagrams (Heiser & Tversky, 2006). In the case of matrix diagrams, however, where in addition to the pre-structured format, the presented content already offers a certain hierarchy in relevance (categories and related topics), the supplementary use of arrows as *organizational* cueing seems redundant. The content and structure provided by the diagram format overrule the function of the arrows, thereby winning the contest for the viewer’s attention. But, further research is surely needed to verify this finding.

Limitations of the study revolve primarily around language aspects. 26 out of 43 participants were no native Dutch speaker and occasionally participants mentioned spontaneously that they did not understand some of the information presented in the diagram. This surely will have influenced the test-scores, mostly the open questions where participants have to recall the information from memory. This should be kept in mind when results are interpreted and conclusions are drawn.

Further research on cue design and usage should systematically consider the content being presented by the diagram, the graphical elements implemented and surely the task that the reader is to perform with that material.

Our results entail that even with such pre-structured learning material like the one used in this study, readers work actively with the presented information. Instead of simply following the implemented design elements, readers make combinations, compare and anchor information accordingly to *their* main point of reference. This should by no means discourage designers of learning materials but should simply remind them of the importance of the input of learners and direct the focus to the needs of the learner and the task she or he is to perform.

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