Exploring Highly Structured Data
A Comparative Study of Stardinates and Parallel Coordinates

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Abstract

Comparing different Information Visualization (InfoVis) techniques is a challenging task and a necessary step to reach the users and their tasks. We evaluated the effectiveness in visualizing psychotherapeutic data of two InfoVis techniques, namely the Stardinates and the Parallel Coordinates by a comparative study with 22 participants. Based on three research questions we interpret the results of our study in order to derive statements on both visualization techniques. We evaluated (1) the time participants were engaged in testing our material, (2) the number of correct answers, (3) subjects' statements, which were categorized by the type of statement, and (4) the subjects' key statements in comparison to those defined by an expert. Our empirical results indicate that the Stardinates are a more appropriate method for interpreting such highly structured data in detail whereas Parallel Coordinates show advantages for gaining information at the first glance.

1. Introduction

Information Visualization (InfoVis) is the use of computer-supported interactive visual representations of heterogeneous data and information to facilitate cognition [2]. In the last couple of years, a considerable number of techniques were developed to support that process. By comparative evaluation we can prove the applicability of InfoVis techniques. In this paper we discuss the evaluation of two InfoVis techniques, namely the Stardinates [5, 6] and the Parallel Coordinates [4, 3]. In particular, we are interested in the effectiveness in visualizing psychotherapeutic data. Domain experts stated both visualization techniques to be convenient for this kind of data derived from a clinical study on anorectic girls. The Stardinates are a hybrid InfoVis technique developed recently combining geometric- and glyph-based features. The data of one patient is represented by a line with its vertices on the axes arranged in a circle (compare Figure 2). Each Stardinate can represent the data of one patient so the data is decomposed into small multiples. The Parallel Coordinates are a well-known InfoVis technique capable of displaying high dimensional and complex data. By uniting the data of all patients in one visualization the user is encouraged to compare the patients' values of single parameters. The goal of our evaluation is to compare the applicability of Parallel Coordinates and the Stardinates. Based on our research questions we interpret the results of our study in order to derive statements on both visualization techniques.

Our user study, which can be categorized as concept testing, was conducted with 22 participants. The tests were carried out by the use of a software tool we implemented for that purpose. We mainly collected qualitative data which we evaluate by categorization. Based on our research questions we analyze our data by quantifying the qualitative data [8].

Concept testing differs form usability testing insofar as it allows for focusing on the concept of the visualization itself. Thus, we reduced the need for extensive preparation of the participants and narrowed the complexity of user interaction processes by restricting interaction to a bare minimum. Namely highlighting data lines was implemented in order to view details, such as date or patient ID. Total elimination of interaction, e.g., by presenting series of views to the user, would have been counterproductive because both visualization techniques are not developed for the purpose of presentation but for exploration and analysis. So, controlled restriction of interaction aspects seemed to be appropriate in order to cope with the characteristics of an explorative visualization technique on the one hand, and receiving informative feedback from the subjects on the other hand. However, when it comes to usability testing of a tool, the full range of interaction needs to be integrated and the tools should be matched with users, tasks and real problems evaluated over

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a long time [7].

We started our study by designing two concrete visualizations—the first using a simple, common data set, the second is based on psychotherapeutic data derived from a clinical study. Thereafter, we formulated our research questions for the study and prepared the testing procedure. In order to improve the testing procedure and check its practical suitability we adopted pretesting. The goal of pretesting was to get first feedback on the visualization techniques and the practicability of our testing procedure. Five people participated in these pretests. Based on the findings of the pretesting we finalized the software, the testing procedure, and the information material for the subjects. This paper discusses the results of our main study with 22 subjects.
In the following section we define our research questions. Thereafter, the participants and the setting of our user study are described. Our evaluation methods are explained in Section 5. In Section 6 we list the results of our study followed by our conclusions.

2. Research questions

In order to compare both visualization techniques, the Stardinates and Parallel Coordinates, we defined the following research questions:

- Are the users able to find information at the first glance?
- Are the users able to find the crucial information?
- Which visualization supports the creation of hypotheses?—characteristic for exploratory information visualization [9].

In the following we describe the participants and the setting of the study in more detail.

3. Participants

The sample we used for our investigation is not homogeneous. The subjects we found are diverse in backgrounds, professions, ages, and gender. Although InfoVis techniques are often developed for a specific user group, we think that concept testing should be characterized by a broader approach. This helps us to test the properties and features more generally.

The evaluation of the Stardinates took place ten month before the evaluation of the Parallel Coordinates. 30 persons tested the Stardinates and 31 the Parallel Coordinates, 22 of these persons took part in both evaluations. Since subjects did not expect to participate in two tests, some participants of the first test were not available for our second test. For our study which is a comparison of the Stardinates and the Parallel Coordinates only the results of these 22 subjects were used. The large time lag between the first and the second test made sure that subjects did not remember the results from the first test when they made the second test. Results from the second test indicate that no learning effect took place, and subjects informally told us that taking part in the first evaluation did not influence their performance in the second evaluation. We assume, therefore, that the results from the first and the second evaluation can reliably be compared. We decided that this approach was more advantageous than using two parallel samples because in this way we can make sure that there are no intervening variables influencing our results (as, for example, previous computer experience or knowledge about graphical representation of data).

Table 1. Participants' age distribution

Age	# of Sub.
- 20	1
21 - 25	6
26 - 30	6
31 - 35	4
36 - 40	1
41 - 45	3
45 -	1
Total	22

Table 1 shows the age distribution of the participants consisting of 12 women and 10 men. 12 among them study Computer Science or Information Systems. In total 14 participants have a background in Computer Science or similar domains. The professions of the others range from nurses to people holding a degree in drama, and from professors to secretaries.

4. Setting

Results of related work [1] on test data sets were not sufficient in our context because our application domain (psychotherapy) show specific criteria not covered by existing approaches. In order to test the relevant aspects of the Stardinates and the Parallel Coordinates we developed two examples based on image maps integrated in HTML[1] code. Simple PHP[2] forms were used to present the questionnaires to the subjects. Combined with automatic time measurements the results are stored in a MySQL[3] database. We observed the time each subject (1) views the first example, (2) answers the corresponding questions, (3) views the second example, and (4) again answers the related questions.

[1] http://www.w3.org/MarkUp/
[2] http://www.php.net
[3] http://www.mysql.com

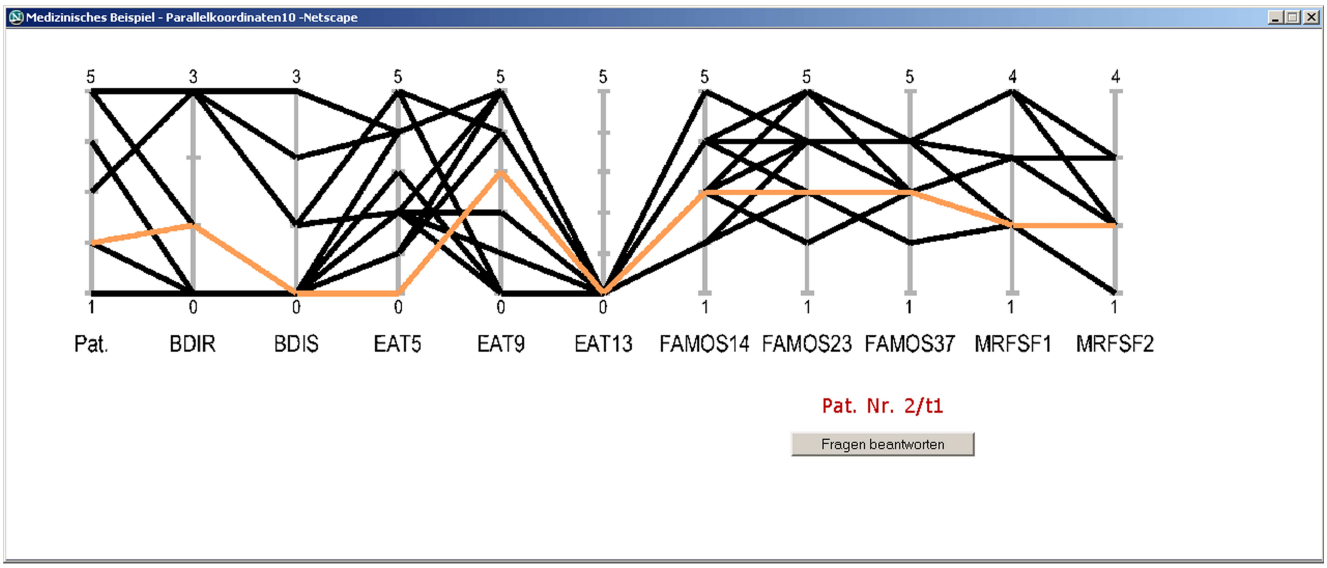

Figure 1. Psychotherapeutic data of five patients at three different times visualized by Parallel Coordinates, the first measurement of patient ID 2 is highlighted.

The questionnaire is in German. Before the test started each subject was provided with a detailed information flyer explaining the procedure, the examples, and the questions. The tests took place in our InfoVis lab, a maximum of five participants tested synchronously.

The testing procedure consisted of the following stages:

First, the starting screen asked for general information on the subject, such as profession, age, and gender. After clicking the start button the subject got the first example and time measurement started.

This example showed position data of airplanes based on the x-, y-, and z-coordinates at different times. The subjects were asked whether a collision of aircraft has occurred. To understand this example the subjects need common knowledge of geometry. This first example gives an overall idea of how the visualization looks like. The Stardinates consist of just three axes and three data lines, each of the four Stardinates shows spatial data of three aircraft at four different times. Parallel Coordinates consist of four axes: the time point on the left hand side, then x-, y-, and z-axes. Although this kind of spatial data are not best suited, since they are very simple and other visualization methods are more appropriate, we chose it as an introduction to the participants because tests of other geometric techniques used the same approach. Particularly, similar data were used for tests of the Parallel Coordinates [4].

Interaction was limited to selection purposes: by moving the mouse cursor over a data line this line is highlighted and the number of the aircraft is shown.

By clicking the button 'Answer Questions' the subject opens an additional window containing the questionnaire. While answering the questions she or he can switch to the example again and examine it in more detail. It was not our goal to test whether the subject remembers the visualization. Therefore, we decided to allow for viewing the example and answering the questions synchronously. This affects time measurements and so their interpretation becomes harder. But it makes the tests more realistic.

The questions related to the first example of both InfoVis techniques are:

- Did a collision occur? If yes, which aircraft were involved?
- Which visualization(s) / properties of the visualization helped you to examine the data? What information did you get there?
- Which problems / challenges occurred while interpreting the visualizations?

So, there is just one correct solution for the first question. The second and the third questions give additional information and help us to understand the answer to the first question.

The second example deals with totally different data. It visualizes (partly fictitious) psychotherapeutic data of five patients at three different times derived from a study on anorectic girls mainly based on questionnaires. Such data is characterized by a high number of dimensions (e.g., up to 1500 per patient). In Parallel Coordinates (compare Figure 1) all data is shown within one visualization, whereas

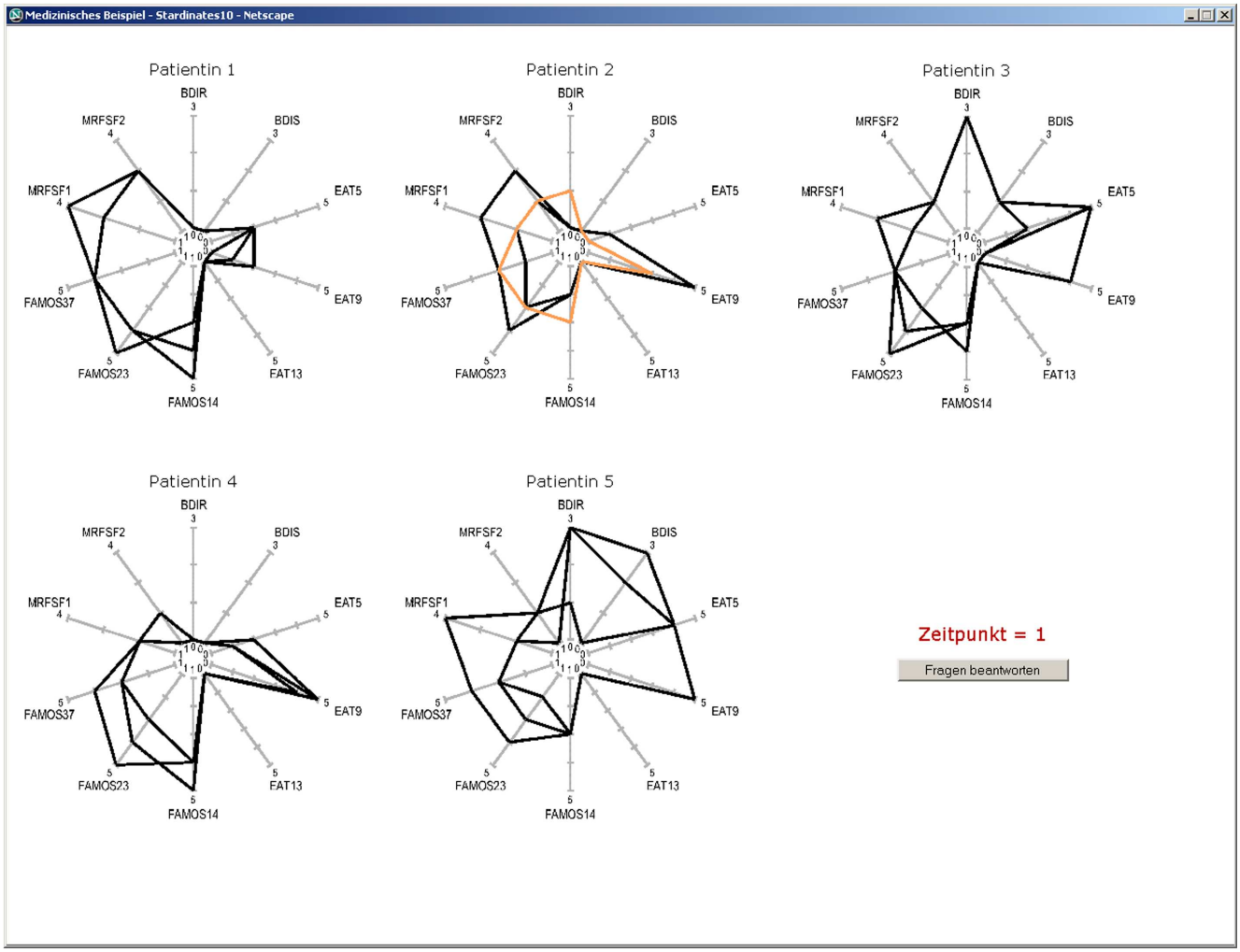

Figure 2. Psychotherapeutic data of five patients at three different times visualized by the Stardinates, the first measurement of patient ID 2 is highlighted.

each Stardinate (compare Figure 2) depicts the data of one patient based on 10 parameters. The labels of the parameters are abbreviations the subjects were unfamiliar with. Moreover, participants had no experience with this kind of data. Subjects were asked to interpret the data by searching for eye-catching similarities or varieties among the patients or significant changes over time. They were provided with information material explaining these acronyms, e.g., 'EAT13' means that the 'Patient does not feel sick after eating'.

The questions related to the second example are:

- Are there any outstanding characteristics of the data?
- Which visualization(s) / properties of the visualization helped you to examine the data? What information did you get there?
- Which problems / challenges occurred while interpreting the visualizations?

These content-specific questions are followed by two more general items. In particular, the subject is asked to describe the first impression of the visualization and convey some feedback about the testing procedure.

5. Method

We used different methods to analyze our data. (1) We analyzed the time participants were engaged in testing our material, (2) the number of correct answers to whether a collision of aircraft happened, (3) the results of the second example are categorized by the type of statement, and (4) whether subjects formulated key statements similar to those

defined by an expert who analyzed the psychotherapeutic data beforehand. For the comparison between the Stardinates and Parallel Coordinates we computed statistical tests to find out whether there was any significant difference between these two approaches. We assumed that both Stardinates and Parallel Coordinates are useful for interpreting highly structured data but that both methods would have significant strengths and weaknesses in the context of visualizing psychotherapeutic data. We thought that the Stardinates would be more valuable for a holistic interpretation of data whereas Parallel Coordinates would be better for the interpretation of single axes. This should lead to significant differences in the number of statements of subjects related to these areas.

For the qualitative analysis we identified the subjects by S1 to S22. Since we translated subjects' statements from their native language, they do not match literally with their answers, but we tried to illustrate the meaning of the statements.

In the evaluation of the first example we counted how many subjects were able to correctly solve the question whether a collision occurred or not. The analysis of the results of the second example is quite different from the first one because there is not one correct solution. We are interested in the question whether participants were able to find characteristic similarities or differences within the data and get information on the states of the patients. Therefore, we applied two evaluation procedures which are described beneath.

5.1. Categorization of statements

We defined groups of statements. These categories of statements enable us to interpret which properties of the visualizations are primarily used by the subjects in order to find information about the patients. We developed these categories because they allow for a clear and comprehensive classification of our material. In particular, we checked whether a participant made a statement associated with a certain category or not.

Comparing patients: such as, patient A is similar to patient B.

Overview: for instance, Patient A seems to be in good condition.

Changes over time: as condition of patient A is rather stable.

Examining single axes: for instance, EAT9 is rather high.

General conclusions: such as, patients with loss in weight and appetite tend to ignore their own well-being.

Causal dependency: for instance, patient A has a high BDIR value (loss of appetite). In combination with a high value in MRFSF2 (I do something just for me) this patient would like to care more about herself but does not realize it.

None: this category refers to subjects who did not make any relevant statement.

These categories represent the way the visualization techniques were used to search for information. In particular, we count whether a subject adopted a certain category or not.

5.2. Key statements

Another approach is defining key statements from an expert's point of view. This was done in cooperation with a psychologist. In particular, we collected five patient-specific statements (one for each patient) and one statement about the whole group of patients, together representing the most significant information found within these data. These key statements outline the information an expert would conclude from these data. So, we use these statements in order to evaluate whether the subjects were able to find crucial insights.

Group: All patients do not feel sick after eating.

Patient 1: good starting basis.

Patient 2: unstable.

Patient 3: contradicting answers.

Patient 4: positive progress in therapy and she cares more about herself.

Patient 5: significantly positive progress in therapy between second and third time point.

6. Results

First, we analyzed whether there are any significant differences in the amount of time subjects needed to study the examples and answer the questions in the tests. Subjects were supposed to work between 30 and 45 minutes but there was a certain flexibility in this. We compared the overall time it took subjects to complete both examples. There was no significant statistical difference in this variable between the Stardinates condition and the Parallel Coordinates condition ($t = -0.947$, $df = 21$). Then we compared the time subjects needed to finish the first example and the second example. The first and the second example are slightly different, so the assumption might be plausible

Table 2. Duration of the testing procedure (HH:MM:SS)

	Stardinates			Parallel Coordinates		
Task	Average	Minimum	Maximum	Average	Minimum	Maximum
Viewing 1.Example	2:28	0:10	7:56	4:17	0:11	11:51
1. Answering	9:29	2:14	18:32	9:09	2:43	22:16
Viewing 1.Example (Correct answer)	2:31	0:10	7:56	3:37	0:11	9:58
1. Answering (Correct answer)	8:57	2:14	18:25	11:32	4:24	22:16
Viewing 1.Example (Incorrect answer)	2:09	0:38	5:01	5:28	0:24	11:51
1. Answering (Incorrect answer)	12:50	8:13	18:32	4:49	2:53	8:30
Total time 1. Example	11:57	5:57	20:31	13:26	3:24	26:40
Viewing 2.Example	4:58	0:14	16:56	3:57	0:08	16:43
2. Answering	20:41	6:47	46:02	16:08	3:03	41:34
Total time 2. Example	25:39	7:46	53:50	20:05	4:43	48:33
Total time (1. + 2. Example)	37:36	16:37	1:14:21	33:31	12:42	1:04:11

that one method was more advantageous for one example and the other method for the other example. There were no statistical differences concerning the time subjects needed to finish the first ($t = 0.862$, $df = 21$) or the second example ($t = -1.615$).

The average duration of the testing procedure was 37:36 minutes for the Stardinates and 33:31 minutes for the Parallel Coordinates. Table 2 shows the details of the test duration. In particular, average time, minimum time, and maximum time is listed for both examples and for the testing procedure in total. We see how long the participants were engaged with (1) viewing the first example, (2) answering the first questionnaire, (3) viewing the second example, and (4) answering the second questionnaire for both visualization techniques. During the answering process the users had the possibility to do further investigation of the visualization.

6.1. Results of example 1

Stardinates: The question if a collision occurred was answered correctly by 16 participants. So, 72.7% solved the first example successfully. 22.7% (5 subjects) gave an incorrect answer and 4.5% (1 subject) could not find any solution. Statements of those subjects who answered the first question correctly show that most of them responded to congruity of areas.

Parallel Coordinates: 14 participants (63.6%) recognized the correct solution, whereas 5 subjects (22.7%) gave the wrong answer, and 3 subjects (13.6%) could not answer the question.

6.2. Results of example 2

Stardinates: 63.6% of the participants (14 subjects) said that they were able to get information at the first glance. After becoming a little more familiar with the data and the visualization, all subjects (100%) found new information about patients' states.

Parallel Coordinates: According to subjects' self-assessment 90.9% of the participants (20 subjects) were able to get information at the first glance. This number of subjects finding new information on patients' states remained unchanged after becoming a little more familiar with the data and the visualization.

Typical findings reported by the subjects using the Stardinates are the following:

S3: Patient 4: Pronounced awareness concerning nutrition, controls calories. Tendency to restrain appetite. Patients would like to treat themselves to something without realizing these wishes. Patient 3: Loss of weight and appetite. Avoids to eat when hungry. Controls calories. Patient 5: Condition improves clearly. Loss of weight and appetite decreases. Patients 1 and 2 are in good condition.

S14: Data of patients 2 and 4 indicates similarity. Patients 1, 2, and 4 quite stable, patients 3 and 5 significant variances.

Subjects using the Parallel Coordinates mentioned the following statements:

S10: None of the patients feels sick after eating. There are significant changes in EAT5 and EAT9.

S18: All patients: EAT13 is 0 in all time points. FAMOS14,23,37 and MRFSF1 never show small values.

These statements give a first impression how subjects examined the data and what their findings were. In order to

evaluate the results more thoroughly we defined categories of statements.

6.3. Results of example 2 by categorization of statements

In general, subjects produced significantly more statements in the defined categories (Comparing patients, Overview, etc.) when they worked with the Stardinates than when they worked with Parallel Coordinates ($t = 3.504$, $df = 21$, level of significance: 5%). The mean number of statements in the defined categories was 3.27 in the Stardinates condition and 2.14 in the Parallel Coordinates condition.

There are two categories which contribute to this result. Subjects produced significantly more statements concerning the category 'Overview' in the Stardinates condition ($\chi^2 = 5$, $df = 1$, level of significance: 5%) and concerning the category 'Causal dependencies' ($\chi^2 = 5.44$, $df = 1$, level of significance: 5%). Contrary to our expectation, they did not produce significantly more statements concerning any category in the Parallel Coordinates condition.

Table 3 shows the frequency scale of the various types of statements. We checked for each subject whether this kind of statement was made or not, e.g. Table 4 shows who made which type of statement using the Stardinates.

6.4. Results of example 2 evaluated by key statements

Table 5 shows how many subjects found information corresponding to our key statements. 72.72% of the subjects using the Parallel Coordinates and 54.55% using the Stardinates found out that patients do not feel sick after eating. 68.18% of the subjects using the Stardinates but only 22.73% of those using the Parallel Coordinates reported about the good starting basis of patient 1. Also noticeable is the high number of subjects (54.55%) who recognized the significant progress of patient 5 and the group statement using the Stardinates.

In general, subjects produced significantly more key statements (as defined by an expert) when they worked with the Stardinates than when they worked with the Parallel Coordinates ($t = 2.687$, $df = 21$, level of significance: 5%). The mean number of key statements was 2.32 in the Stardinates condition and 1.32 in the Parallel Coordinates condition.

There are two categories which contribute to this result. Subjects produced significantly more often a key statement concerning the first patient (good starting basis) in the Stardinates condition ($\chi^2 = 5$, $df = 1$, level of significance: 5%) and concerning the fifth patient (outstanding positive progress) ($\chi^2 = 5.4$, $df = 1$, level of significance: 5%). They did not produce significantly more statements concerning any patient in the Parallel Coordinates condition.

7. Conclusions

Finally, we answer the three research questions and interpret the results.

7.1. Are the users able to find information at the first glance?

90.9% of the participants testing the Parallel Coordinates and 63.6% of the participants testing the Stardinates stated that they were able to get information at the first glance. Obviously, this is just an individual impression of the participants but in combination with our other research questions it is an interesting factor. The outstanding difference between the two visualization techniques might be influenced by the degree of familiarity with the Parallel Coordinates. Nobody was familiar with the Stardinates but 36.4% of the subjects knew the Parallel Coordinates. However, glyph-based visualizations are often confusing at the first glance because it is not obvious which item deserves immediate attention. It seems that the user needs to decide where to start in contrast to more intuitive focusing when confronted with just one visualization. Thus, the Parallel Coordinates are beneficial in this context.

7.2. Are the users able to find the crucial information?

Although the participants were unfamiliar with psychotherapeutic data, they were able to find crucial insights. According to our statistical analysis the Stardinates are significantly better for finding crucial information represented by the key statements defined by an expert. One reason might be that the Stardinates direct users' attention to differences and similarities. Decomposing the data into appropriate chunks of information (typical for glyphs) but keeping a grid of reference at the same time (typical for geometric visualizations) seems promising. The visualizations of the data of patient 1 on the one hand and patient 5 on the other hand are obviously different. Participants were motivated to report this difference. Also the similarity of one parameter, in particular, EAT13, was informative to the participants. Although Parallel Coordinates showed a high result in the group-category, which is based on one dimension (EAT13) only, Parallel Coordinates are not significantly better in this category.

Table 3. Categories of statements

Category	Stardinates		Parallel Coordinates	
	# of Sub.	% of Sub.	# of Sub.	% of Sub.
1: Comparing Patients	15	68.18%	10	45.45%
2: Overview	15	68.18%	5	22.73%
3: Changes over Time	15	68.18%	10	45.45%
4: Examining Single Axes	14	63.64%	19	86.36%
5: General Conclusions	5	22.73%	1	4.55%
6: Causal dependency	8	36.37%	1	4.55%
7: None	0	0%	1	4.55%

Table 4. Categories of statements for each subject: Stardinates

Subject	Comparing	Overview	Time	Singe Axes	Conclusions	Causal Dependency	None	Total
S1	•		•	•				3
S2	•	•						2
S3	•	•	•	•				4
S4	•		•					2
S5		•	•			•		3
S6	•	•		•		•		4
S7	•	•	•	•				4
S8	•	•	•	•		•		5
S9	•	•	•		•	•		5
S10	•	•	•	•		•		5
S11				•				1
S12	•	•	•		•	•		5
S13	•	•	•	•	•			5
S14				•		•		2
S15		•		•	•			3
S16		•			•			2
S17		•	•					2
S18	•	•	•	•				4
S19	•		•	•				3
S20	•			•		•		3
S21			•					1
S22	•	•	•	•				4
Total	15	15	15	14	5	8	0	

7.3. Which visualization supports the creation of hypotheses?

This criteria is an essential aspect of exploratory information visualization [9] and is therefore considered in our evaluation. In general, subjects produced significantly more statements in the defined categories (Comparing patients, Overview, etc.) when they worked with the Stardinates than when they worked with the Parallel Coordinates. Moreover, they did not need significantly more time when using the Stardinates. So, the Stardinates seem more motivating for finding hypotheses in the context of our study although subjects reported more information at the first glance when using Parallel Coordinates. So, Stardinates seem less informative at the first glance according to participants self-assessment but yielded more information because subjects created significantly more hypotheses.

7.4. An interpretation of the results

Our empirical results indicate that the Stardinates are a more appropriate method for interpreting such highly structured data in detail. Subjects produced more statements in the predefined relevant categories (compare Table 3) of interpretation and they produced more statements similar to the key statements (compare Table 5) given by an expert. It seems that the Stardinates are a method which motivates users to process the information presented by the visualization more deeply than the Parallel Coordinates and to create a more detailed interpretation. Parallel Coordinates over the Stardinates enabled the users to find information on the first glance. A combination of an overview visualization on the one hand and small multiples on the other hand could be

Table 5. Key statements

Key Statement	Stardinates # of Sub.	Stardinates % of Sub.	Parallel Coordinates # of Sub.	Parallel Coordinates % of Sub.
Patients do not feel sick after eating.	12	54.55%	16	72.72%
Pat. 1: good starting basis.	15	68.18%	5	22.73%
Pat. 2: unstable.	6	27.27%	2	9.09%
Pat. 3: contradicting answers.	3	13.64%	3	13.64%
Pat. 4: positive progress in therapy. Cares more about herself.	3	13.64%	0	0%
Pat. 5: significantly positive progress in therapy between second and third time point.	12	54.55%	3	13.64%

a promising approach. There is some indication that Stardinates especially support holistic forms of interpretation and interpretation of temporal developments. Nevertheless, it is necessary to check whether these results hold under modified conditions. We tested, for example, the Stardinates using the data of five patients but it seems plausible to assume that only a limited number of Stardinates can be processed simultaneously. Therefore, more research in that area is necessary.

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