Visualizing heart beats

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Abstract

Our tool's purpose is to represent a visual representation of six dancers' heartbeats, recorded during a professional 10-minute ballet performance.
The user needs to be able to view the data in a cohesive and understandable manner and furthermore, be able to alter the input parameters for different output.

1 Introduction

The idea of our project is to create a visual representation of the recorded heartbeats of six dancers during a ballet performance.
The project our data stems from focused on recording the heartbeats of six professional dancers during a 10-minute ballet performance. That means that the data we have consists of a few thousand timestamps (each representing a single heartbeat) and a corresponding index (A - F) implying which dancer the heartbeat belongs to.
Our goal is to take those lines of data and represent them in a visual and easy-to-grasp manner. That is achieved by various means, such as displaying the total amount of heartbeats as bar charts or the frequency of a user's heartbeat as a line chart.
Ultimately, it should be possible for the user viewing the data to first and foremost understand it and then alter it with the filters given (e.g. displaying the data for a specific user only). Questions such as "Which user had the most heartbeats?" or "During what part of the performance did a heartbeat frequency rise?" should be answered by using our visualization tool.

2 Theory

"The Shadows We Cast" [5] consisted of a team of researchers working together with professional ballet dancers in order to visualize the latter's heartbeats during a live performance. The data was collected by strapping recording devices on each dancer that would measure every heartbeat.
The resulting data was then saved in the following manner.

2017-05-07 20:24:46.292: C

The left part (from 2017 through 292) represents a particular timestamp on the millisecond while the right part (C) represents a certain dancer; the indices ranging from A through F.
Our team would then work with the data, analyze and process it, and finally, create an easily understood visual representation a layman could grasp and interact with.

2.1 Assessing and solving problems

As our initial data consisted of the two previously described values, we had to come up with various visual solutions; different ways to look at the data at hand.
One of these creative approaches was to look at the data that wasn't there. That means, we measured the time between heartbeats (i.e. timestamps) to get a value for the period. And by looking at that value, it is possible to determine how fast a heart is beating; the bigger the period, the slower the heartbeat and vice versa.
Another approach was to display the frequency of a dancer. Namely, we measured the heartbeats of each dancer per given time unit and displayed them as such.

2.2 Target audience

Our project's goal is to provide meaningful insight into the data for both laymen and experts. The former shall be able to satisfy their curiosity while the latter group shall be able to answer specific questions that may arise (for example, after having seen the live performance).
Hence, we decided to create a simple introductory design that, while easy to understand, would also offer means of selection and filtering. See Figure 1 for a visual example.

2.3 Processing the data

As our tool of choice was Tableau [1], we had to combine all the necessary data in one processable file. That means, we had to take the two initial data columns and combine them with our custom values (i.e. frequency and period) by utilizing Microsoft Excel.

Figure 1: An overview of our tool.

3 Related work

While our goal was clear from the beginning, we nonetheless tried to draw additional inspiration from different papers and approaches to the idea of visualization. Our source data may be fairly unique in what it does but the general concept of visualizing dance performances has been tackled before.

ActionPlot [6], for example, focuses on illustrating contemporary dance through means of movement analysis amongst other things. And while their primary focus may differ from ours, we both share similar motivation and data analysis approaches in that we want to offer a tool for both experts and laymen, and use direct data mapping techniques while incorporating a time factor respectively. Concerning the mapping of data variables, ActionPlot utilizes a more detailed approach, dividing its data in subcategories and assigning value scores in different ranges.

To be more precise, ActionPlot divided its data analysis in three main categories – interpretation and meaning (Level 1), structural and performative information (Level 2), and technical movement information (Level 3). Each of those levels would then be assigned variables (e.g. intention, number of performers, and body balance, respectively) which would then in turn receive values based on a scale designed by the project team. Due to such intricate data collecting the subsequent data analysis was eased as well.

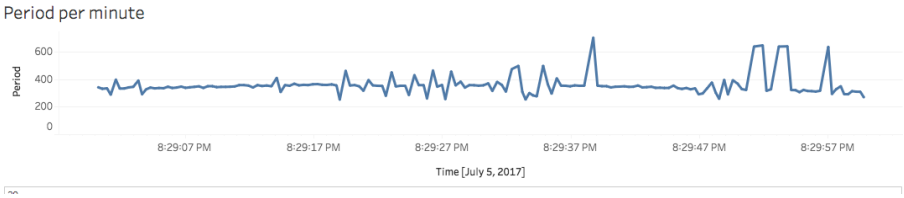
A different approach to the subject, and one that was very close to ours, was provided by the Dance.Draw tool [7]. Their idea was to create a low-cost and portable system for interactive dance performances which created real-time projections of the dancers' movements on a big screen. It was implemented by providing the dancers with two wireless computer mice, one for each hand, that would track the dancers' body movements and use that data as real-time input.

Dance.Draw itself was based on a similar tool (symDrawEI) that allows multiple artists to simultaneously draw on the same canvas hence the former's motivation being the same idea, only with dancers.

As for recording the data itself, Dance.Draw is provided the dancers' motion data from various pointing devices as spatial input streams and visualizes those.

The performance itself is split in three phases which utilize single and group modes:

1. The first phase has each dancer controlling two objects with their respective hands.
2. It then switches to the group mode with the dancers combining and coordinating their movements to display and control a complex object on the screen.
3. The third and final phase reverts back to the single mode, this time however, each dancer controls one object each, utilizing both hands to do so.



(a) Period value for given minute

(b) Filtered period value for entirety of play

Figure 2: Period per minute and over whole play

4 Approach

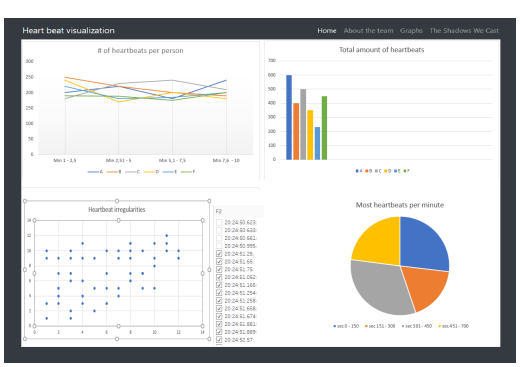
During the design phase, we contemplated what framework to use and what tools would best suit our needs. Ultimately, it came down to using either Tableau or JavaScript and its D3 library.
In the end, we decided to use Tableau, as its features and its basic idea (i.e. offering means to visualize raw data stored in a range of file types) complemented our problem at hand best.

4.1 Description of the design

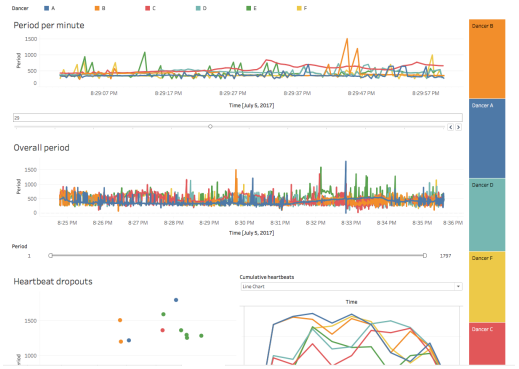
To provide you with an overview of our dashboard, please refer to Figure 1. It consists of five different views and two filters. As for the detailed version, we take a look at the following figures:

- Figure 2a is supposed to act as the visual introduction to our dashboard. The user sees the heartbeat periods of all dancers for a particular minute (ranging from 24 to 35). Immediately, we offer a filter option for the user to interact with (i.e. a minute filter).
- As for filtering a certain dancer, figure 8a, we implemented a color map with each color representing a dancer and those colors mapping to the other graphs' color schemes as well. That way, one uniform color theme is used per dancer for the whole dashboard. And just in case, we also spell out the dancer's name on the respective color field.
- Similar to the first one, figure 2b too displays the heartbeats of the dancers but here the data is applied to the entirety of the play (and not just a minute). What's different as well is the type of filter we use. As one of the ideas of this chart is to spot heartbeat dropouts for a given dancer, the user can adjust the size of the filter to something in the range $>$1200 to possibly find values that can be not explained 'normally'. The conclusion would then be that the high value was caused by a fault in the machinery used for recording said heartbeats.
- Next, we look at the cumulative heartbeats represented by either a bar or line-chart (fig. 6). As there exist advantages to both bar- [2] and line [3] charts, we decided to offer the user an option to pick either by using a filter.
- As for the last picture, we take a look at a scatterplot graph displaying heartbeat anomalies or rather, dropouts caused by outside factors (fig. 5b). Here, we determined that a period value needs to be $<$200 or $>$1200 to be considered out of the norm.
  By applying the following formula, we were able to determine the above period boundaries.

$$Period = \frac{60000}{Frequency}$$

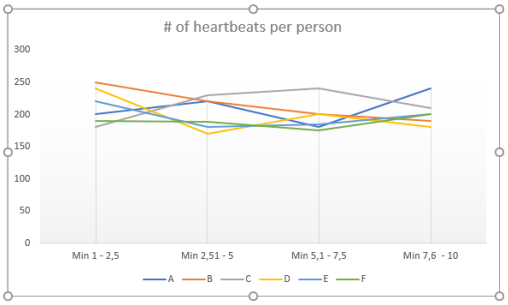


(a) Version 1

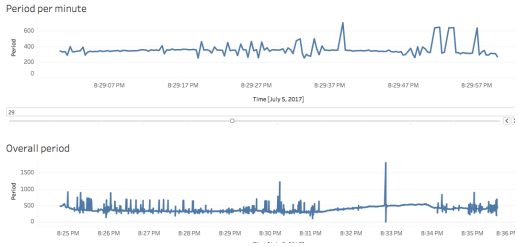


(b) Version 2

Figure 3: Dashboard design changes



(a) Version 1



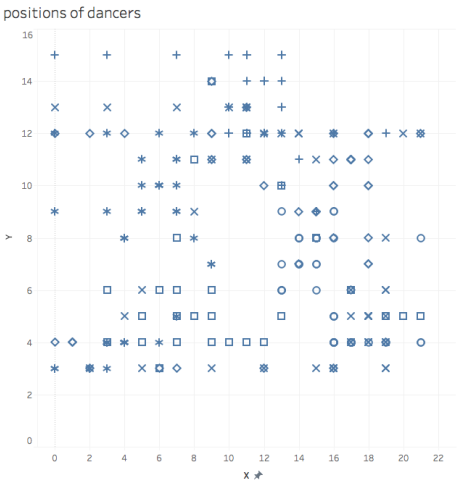
(b) Version 2

Figure 4: Period design changes

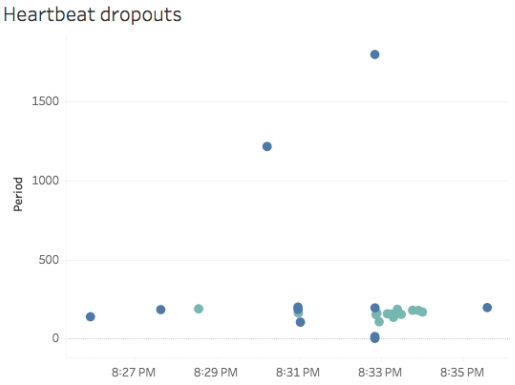
4.2 Design choices and reasons

- Fig. 3 Here, you can see the initial mock-up design we went with for M2 and the final dashboard version we designed for M3. While the basic design ideas were upheld, some major changes took place. Examining those, we look at the following:
- Fig. 4 Our initial idea for the introductory graph (i.e. the view that is supposed to capture the user's attention) consisted of the number of heartbeats per person over a 10-minute time span. And while we did stick with that approach, the actual graph now displays the heartbeat periods of the respective users (i.e. the time that passes between each single heartbeat). The first version wasn't feasible the way we intended as there was no distinction between a user's heartbeats (basically, it would've amounted to six straight lines). Going with the period approach, though, we could create visual distinctions that are easy to trace and that convey very useful information (i.e. the higher the value in the right graph, the slower a dancer's heartbeat is and vice versa).
- Fig. 5 The very first concept for the scatterplot graph was about displaying movement coordinates for a certain dancer but soon we discarded that idea due to insufficient amounts of data and instead focused on using that plot to display heartbeat anomalies (dropouts caused by the technical component used for recording). Dropouts we defined to be in a certain value range (see previously mentioned formula for period).

Generally speaking, I believe we managed to incorporate most of the initial design ideas while modifying our dashboard as the situation demanded it (i.e. missing data, design choices, etc.).

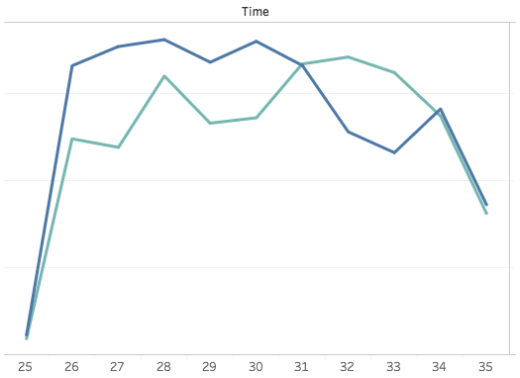


(a) Version 1

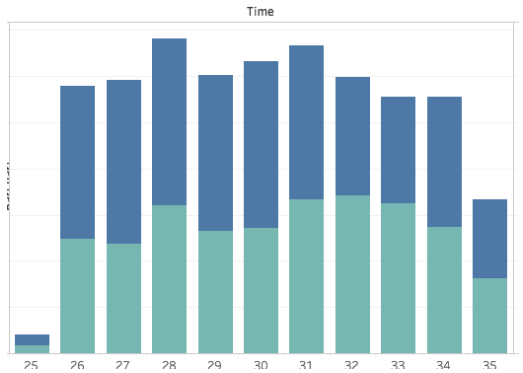


(b) Version 2

Figure 5: Heartbeat irregularities design changes

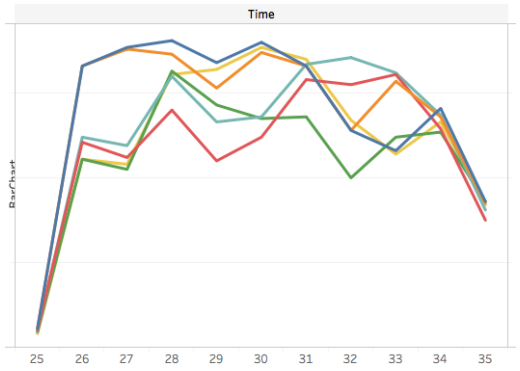


(a) Line chart

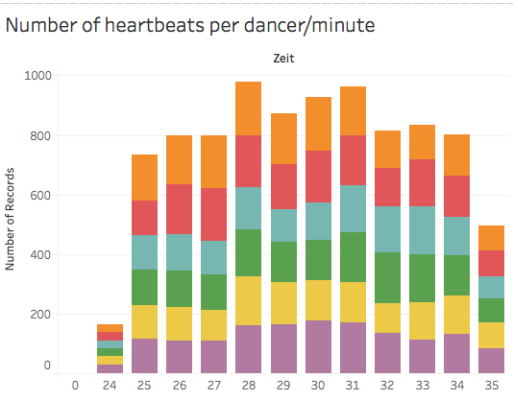


(b) Bar chart

Figure 6: Cumulative heartbeats



(a) Cumulative line chart



(b) Cumulative bar chart

Figure 7: Cumulative heartbeats (use case)

(a) User selection filter

(b) Cumul. heartbeat filter

Figure 8: User selection and cumul. heartbeat filter

4.3 Design chronology and -changes

During the creative design process we came up with various ideas and charts that had to be omitted for some reason or another. A few of the most significant ones include:

- The initial chart for the cumulative heartbeats of a dancer was supposed to display the data for the entirety of the play. We then switched it to a filtered version (i.e. data per minute) as it offers more variety; for the same reason, a line chart option was added [6].
- Our scatterplot chart displaying heartbeat dropouts, too, was supposed to display the dancers' movements as coordinates and while the first drafts were satisfactory, we soon realized that the data provided to us was not sufficient to offer a dynamic and adaptable representation to the user.
- One significant visual change was represented by removing a frequency pie chart in favor of a user selection one.
  The initial pie chart used bins of fixed values (i.e. frequency ranging from 400-600 or from 600-900, etc.) and would be applicable to one or more dancers. As we tried to take the general dashboard design into account, though, we realized that the filter options we provided for the dancers were not user-friendly. Therefore, we went with bigger and more intuitive buttons (as can be seen on the right-hand side in Figure 1).
  We did contemplate keeping both charts, but ultimately the tool would've become too cluttered and possibly distracting.

5 Implementation

Our project was realized by utilizing the Tableau tool for visualizing raw data [1]. As for presenting it to the user, we implemented it on our website which was created using the Bootstrap HTML framework [4].

5.1 Challenges

When talking about challenges concerning the implementation, it can be said that working with Tableau proved to be a smooth experience due to its well-designed range of features.
Likewise, implementing Tableau on our website and designing the latter in general proved no problem whatsoever.

6 Results

Given our initial goal laid out at the beginning of the paper, we were able to meet it (i.e. displaying data in a coherent manner while simultaneously finding interesting data aspects). But more on that in the following section.

6.1 Use Case scenario

1. After witnessing "The Shadows We Cast", Dr. Miller, a heart surgeon by occupation, would like to know more about the data collected during the play.

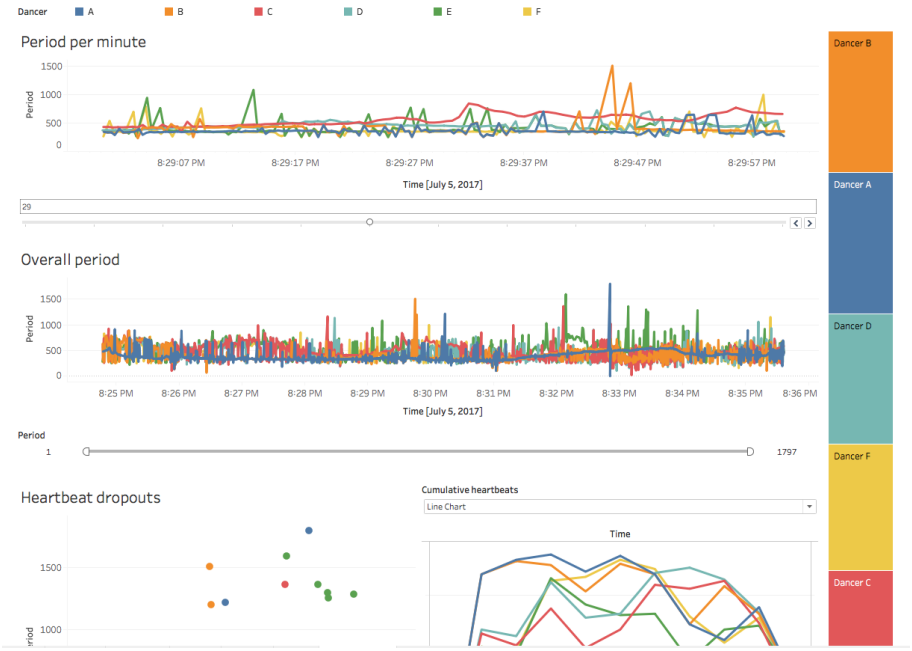


Figure 9: Overview of the system

He's in luck as the team behind the project offers a website for interested audience members to look at the data and explore it to their heart's content. [9]

2. There's a variety of different views Dr. Miller is presented with and as tempting as they may be to play with, he would like to know at what minute the dancers' heartbeats spiked (i.e. during what minute there were the most cumulative heartbeats). For finding that out, Dr. Miller will look at the view displaying the number of heartbeats per minute. [7a]

3. Dr. Miller will be presented with a line chart displaying the cumulative heartbeats of all dancers. Unfortunately, he prefers bar charts. Fortunately, there's a filter option to achieve just that. [8b]

4. There he can choose to click on a different option and be presented with the following bar chart. [7b]

5. Here, Dr. Miller will be looking at the stacked bar chart and see almost immediately that the most cumulative heartbeats occurred in the twenty-eighth minute. Therefore his gaze will turn towards the stacked line charts in the upper half of the dashboard. [10]

6. As luck has it, the first of the two charts offers a filter to pick out a certain minute. [11]

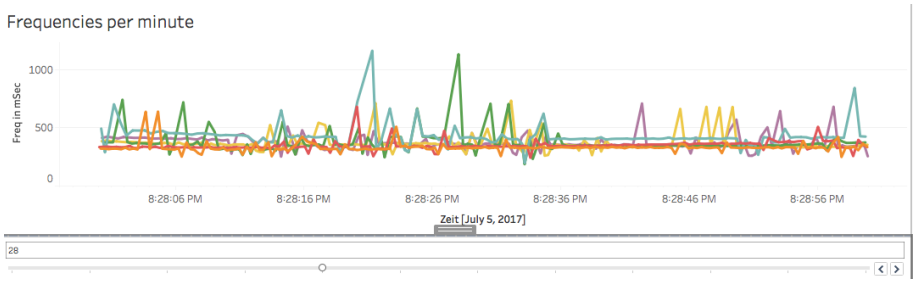
7. Dr. Miller found out earlier that the desired heartbeat spike occurred in the twenty-eight minute thus he navigates to said minute is presented with the following view. [12a]

8. Normally, Dr. Miller would be satisfied by now as he found what he was looking for, but seeing the actual graph, something bothers him. [12b]

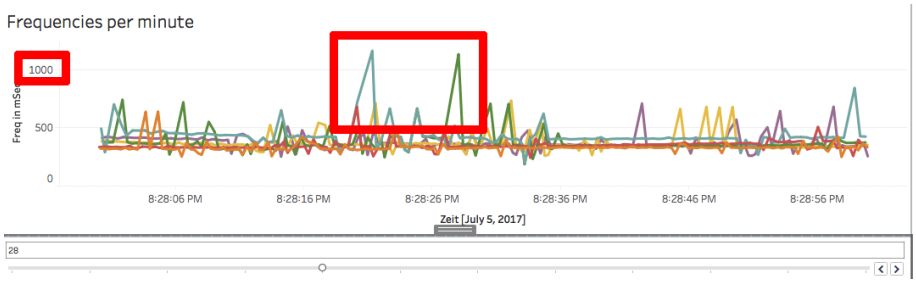
9. The dancers' general heartbeat frequency values seem to conform to the norm but two particular values stand out with almost no time in-between. As those values are >1200, a fact shown by the graph's tooltip function, Dr. Miller knows that it couldn't have happened conventionally hence he concludes that the fault lies with the device used for recording the heartbeats.
   While it may not have been the user's initial intention, he not only found an answer to the actual question he had, but also got to play with the dashboard's features by spotting an anomaly in the data and deciding to pursue it.

Figure 10: Period values overview

Figure 11: Minute filter for period



(a) Period per minute



(b) Period value anomalies

Figure 12: Period per minute and heartbeat anomalies

6.2 Feedback evaluation

6.2.1 Overview of the testing process

In order to get a better evaluation of our work, we asked people both related and unrelated to informatics to test our system and provide us with feedback.
Looking at the testing group, we tried to create a mix of both old and young, male and female, and, as mentioned before, people both unrelated and related to the subjects of informatics and computer science. To be more precise, our testers' age ranged from 22 to 39 and the male to female ratio was roughly 60:40. Most of them had either finished university or were in the process of doing so; generally speaking, the education level was rather high. When taking familiarity with the subject at hand into account, we focused on creating a healthy mix between people related to informatics and those who are not; here, a slight overload was created on the side of the latter group.
As for the testing process itself, it consisted of three major phases – explaining the general idea and background of our project to the user, asking them to perform a few simple but important tasks with our tool, and asking them a few questions in regards to design and possible improvements.

6.2.2 Evaluation of results

When evaluating the results, we did it based on the respective phases (explanation of project, tasks to perform, and questions).

1. The explanation we provided the testers with was essential as it acted as a gateway to our tool yet at the same time it was not allowed to give away too much information without the users having seen the tool itself.
   Generally speaking, the reaction we received during that phase was generally positive as the vast majority of users understood the concept very fast.

2. Next, we showed the tool to our users and gave them a few minutes to understand the different views and to get used to the tool. It needs to be stressed that we did not answer any questions during that phase as it might have affected the test results.
   The tasks we asked our testers to perform consisted mostly of filtering options in order to display a given result (i.e. display only two of six dancers, show the period value for dancer A in minute so an so, etc.).
   We are very pleased to say that all of our testers were able to complete all of the given task very easily.

3. As for the last phase, we asked the testers questions about the design itself and how well they understood our concept. Additionally, we provided the testers with the option of giving general feedback.

   In terms of design and general understandability, we mostly received the answers we had hoped for. All the testers confirmed that they had understood the general idea and that they liked our overall dashboard design. It needs to be mentioned, however, that the testers had problems understanding the scatterplot chart displaying heartbeat dropouts. That chart was the only one that required additional explanation from our side.
   We did offer the option for additional feedback and fortunately, it was used quite frequently. Its main focus was on small design choices (i.e. slightly enlarge chart titles, possibly move user selection chart to left side, etc.).
   And while we did try to incorporate user feedback, we were pleased to see that the general testing consensus was a positive one.

7 Discussion

Dancers	B	C	D	E	F
# in percent	0.33	0.33	0.33	0	0
# of dropouts	1	1	1	0	0

Table 1: Dropouts Dancer A

Dancers	A	C	D	E	F
# in percent	0.125	0.375	0.25	0.125	0.125
# of dropouts	1	3	2	1	1

Table 2: Dropouts Dancer B

Dancers	A	B	D	E	F
# in percent	0.05	0.15	0.4	0.2	0.2
# of dropouts	1	3	8	4	4

Table 3: Dropouts Dancer C

Dancers	A	B	C	E	F
# in percent	0.06	0.06	0.53	0.12	0.2
# of dropouts	1	1	8	2	3

Table 4: Dropouts Dancer D

Dancers	A	B	C	D	F
# in percent	0	0.14	0.57	0.28	0
# of dropouts	0	1	4	2	0

Table 5: Dropouts Dancer E

Dancers	A	B	C	D	E
# in percent	0	0.125	0.5	0.375	0
# of dropouts	0	1	4	3	0

Table 6: Dropouts Dancer F

This section focuses on analyzing our data using our tool and highlighting interesting aspects. To be more precise, we concentrated on heartbeat dropouts and possible reasons thereof.
In previous meetings we had with the team behind our source data , [5], ideas regarding the reasons for dropouts were brought up. Namely, whenever the vicinity between two dancers was reduced to a very small margin, the suggestion was that it could lead to the technical devices responsible for recording the heartbeats to literally skip a beat (i.e. fail to record the owner's heartbeat in that moment). Interested in that thought, we decided to pursue it.
For the thesis to be true, we stated the rule that a dropout had to have occurred for both of the parties involved, not just one dancer. Therefore, our data analysis focused primarily on:

1. Building pairs of dancers covering every possible combination
2. Finding dropouts for one dancer
3. Checking whether a dropout occurred for the respective partner during a time frame chosen by us

As for the time frame, we set the value to be 30 milliseconds or less. There was no explicit reason behind that decision as we tested it with different time frames, but it's a good number to display just how fast those successive dropouts occurred.
As for the number of dropouts, please refer to Tables 1 through 6. There, we detailed the total amount of dropouts that fulfill our criteria for the entirety of the stage play; the respective percentage in relation to the total number of dropouts is provided as well.
In conclusion and by looking at the results, we can confidently say that the initial thesis is very likely to be true (it cannot be confirmed to be 100% true unless we examine the devices used for the recording themselves).

7.1 Strengths and weaknesses of the system

As we were able to meet our initial goals and provide both laymen and experts with a tool good enough to analyze data in the context of the "The Shadows We Cast" stage play, we like to view that as a major strength. Another one is the variability we offer and the adaptability our system provides. Furthermore, the simplicity of our concept stands out in that it is easy to grasp even for users unacquainted with the field of informatics or design concepts.
On the other hand, context can also cause a weakness in our system as the user testing it needs to have seen the stage play and/or needs to be well-read on the subject. We did manage to arouse some interest in users during our testing phase but ultimately we believe that the full immersion would be complete when watching or having watched the original stage play. And while our concept may be pleasing to the eye, even that fact cannot make our design stand on its own without proper context.

7.2 Lessons learned

For this section, we'd like to branch out for a moment and talk about lessons we learned during the work on this project.
All of us had previously worked with charts and basic visualization tools, but over the course of this lecture we were presented with intricate techniques, reasons behind the usage of certain charts, and what constitutes good visualization.
Looking at our source data, we had to learn to cope with what we had and adapt accordingly. That is, we learned how to extract a lot of information out of two data variables. That in itself is valuable experience and a matter that required efficient team work and coordination.
The project did take a lot of work, admittedly, but at some point we started to develop the feeling that the final tool needed to be great, not just good. We do hope our work reflects these thoughts.

7.3 Future work

Our team will very likely not be working on a continuation of this paper as we regard it as completed but it's possible that working with raw data and/or visualization will see us reunite in the future.

8 Separation of tasks

Table 7: Separation of tasks

Milestone	Work description	Person responsible
M4	Create final report including motivation, related work et al	Aldin, Gledion
M4	Create images for report and write up corresponding text	Aldin, Mahmoud
M4	Incorporate any feedback received for M3	Aldin, Gledion, Mahmoud
M4	Work on final PowerPoint presentation	Aldin, Gledion, Mahmoud
M4	Analyze the data and summarize results	Aldin, Gledion, Mahmoud

References

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