Interactive graphics for multidimensional pain assessment – a human-centered design and evaluation study with patients suffering from chronic pain

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ABSTRACT

In clinical contexts, pain is normally assessed by self-report using numeric–rating scales and questionnaires. This practice reduces the possibility of expressing individual pain experience to a few numeric options. Developed by the research groups of Mühlenberend and Willmann at Bauhaus-Universität Weimar and the Team of the Clinic for Interdisciplinary Multimodal Pain Therapy at the University Hospital in Jena, the approach presented here, fosters an alternative form of qualitative pain documentation using interactive and parametric graphics. These allow to express the pain individually through fluidly adjustable visualizations. In this study, a set of prototypical graphics was used to characterize and validate *input combinations, input forms, number of parameters* and, ultimately, *general visualization strategies*. The results indicate that the approach is promising and beneficial in the context of pain therapy, and it could be potentially transferred to mobile and other "smart" applications.

Keywords: Pain Assessment · Human-Centered Design · Design Research · Interactive Pain Assessment · Mobile Apps · Chronic Pain · Medical Informatics

INTRODUCTION

Although adequate assessment of pain is considered as essential of successful pain management (Breivik et al., 2008), concurrent pain assessment methods have significant drawbacks. In clinical contexts, pain is normally assessed using numeric rating scales and self-report questionnaires (Dansie and Turk, 2013). The former reduce the possibilities of expressing the individual pain experience to a few categorial options (Stinson et al., 2006), and questionnaires can be overwhelming for patients due to their inherent semantic complexity (Herr et al., 2011). Overall, the discrete and rigid expressive options currently available contrast sharply with an embodied conception of pain, being inherently dynamic and interferential (Tabor et al., 2017). Nevertheless, the standardized assessment of patients' experienced pain is an undisputed benchmark and defines ultimately the quality and performance of medical interventions (Meißner, 2011). The study presented here attempts therefore to develop a standardized, but, at the same time, highly detailed and intuitive form of qualitative pain assessment, bringing forward a novel form of visual pain documentation through a custom interactive graphical user interface (GUI) being realized for smartphone and other smart and/or mobile applications. For this purpose, current potentials of future health and digital health services, such as individualized and precise care (Albrecht, 2016), are combined with an participatory design procedure. To carry out this approach, a consortium between the Faculty of Art and Design and the Clinic of Anesthesiology and Intensive Care Medicine of the University Hospital of Jena was installed, bringing together expertise in digital design processes, interface design, patient reported outcome measurement and interdisciplinary multimodal pain therapy. In this paper, we will present 1) an brief introduction to current digital solutions and clinical assessment procedures in this field; 2) the design process and respective metrics, including *input combinations, input forms*, *number of parameters* and *general visualization strategies;* 3) a subsequent mixed-methods study with patients, suffering from chronic pain and healthy participants, in which a guideline interview is combined with a grounded theory analysis, to gain deep insights from the users while operating the prototype. Furthermore the graphics were evaluated using a quantitative questionnaire, and aiming at two questions: First, whether there is a general acceptance of the use of the proposed system; and second, how the different graphic parameters *(input combinations, input forms, number of parameters and general visualization strategies)* can be characterized and evaluated to create a viable basis for further explorations. Parallelly, a group of healthy participants evaluated the specific suitability of the graphics on the basis of three standardized (QST) pain stimuli and to explore the consistency between pain experience and selected pain representations. In the last part of the paper, 4) the overall results and next steps for the further development and implementation are outlined.

2 SELF-REPORTED PAIN ASSESSMENT WITH DIGITAL DEVICES

According to the International Association for the Study of Pain, pain is “an unpleasant sensory and emotional experience associated with actual or potential tissue damage or described in terms of such damage” (IASP, 2022). Acute Pain is usually assessed by factors of intensity and location (Breivik et al., 2008). The assessment of chronic and neuropathic pain also includes quality, duration, and the affective component (Fillingim et al., 2016). Although attempts have been made to assess pain passively by behavioral patterns, self-reporting is still considered to be most reliable and practical (Chow et al., 2016). Visual forms of pain assessment are used for patients who have difficulty articulating, such as children e.g. the *Faces Pain Scale Revised* is well validated and widely used (Breivik et al., 2008). Digital applications for pain documentation on mobile devices are mostly analogous to clinical instruments described above. Usually, sliders or scales are used to survey intensity, combined with parameters about quality or free text field. Often a schematic body diagram is used, in which the pain localization can be drawn in. Here, however, standardized stimuli, numerical or low-resolution discrete scales are used, which do not differ in their level of detail from the paper and pencil version[1]. Approaches to assess pain with interactive computer graphics exist since the early 1990s (Swanston et al., 1993), but the expression is considerably limited to very rudimentary icons and symbol systems. Other projects which foster a digital pain assessment focused on the development of a detailed localization (Steingrímsdóttir et al., 2020). A more far-reaching study was carried out at *Center for Behavioral Health and Smart Technology* at the University of Pittsburgh, where eight interactive graphics were developed within a participatory design process, defining pain intensity as variable (Rao, 2015). The study was successful in generally showing how an interactive graphical pain assessment could be intuitively used by patients to foster diagnostic potential (Jonassaint et al., 2018). The challenge, which has not been embraced so far, however, is to develop truly interactive representations of pain quality in accordance to scientific-clinical standards, including a series of digital prototypes and patient

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[1] This estimation is based on a systematic study conducted by the authors in April 2020. From a group of 1151 apps from the categories *health* and *medicine* (from the Google Play Store, the Apple App Store, and publications about *mHealth Apps* from Pubmed), 136 apps were considered in which pain was assessed. In these five different forms of Input Elements were identified: (Slider, Scale, Icons, List, Free Text).

evaluation sequences. On that scope, our approach is targeted towards a fundamental and methodological exploration of an embodied pain assesment, and the characterization of new visual paradigms and interactive design strategies.

3 DESIGN OF TEST GRAPHICS

The challenge in the development lies in the subjective character of the pain experience, which in principle precludes the elaboration of a generally valid, objective representation (Correll, 2007). However, in order to communicate pain, the participants are dependent on a standardized form of notation. This defines, by its medial characteristics, the situationally possible materialization of the experience in expression and therefore – in principle – restricts it (Breuer, 2020). This circumstance has to be taken into account in the development of systems for pain communication. Therefore, the goal was not defined as a discrete selection of defined graphics, but rather a fluid construction kit in which the pain experiences are created by the users themselves. Through the interactive graphics, the patients are elevated to actors who themselves design their pain experience. Instead of a product, a framework for scenes of individual combinatorics are created through and within the design process (Willmann, 2017). Therefore, iterative testing with a variety of different expressions is essential for this development. For obvious practical reasons, however, a restriction has to be made in the available graphics and thus criteria had to be developed according to which the first test iteration was developed.

3.1. Prototype setup

Since conventional screen design applications, such as *Adobe XD*, *Axure RP9* or *Sketch*, turned out to be insufficient (they only allow to prototype linear interactions) the prototypes were development with *VVVV* (VVVV, 2020). This environment was chosen, because it’s easy to use and it’s specialization for visualizations (Barth, 2013). As a test device the *smartphone simulator* was built, in which usual input forms could be simulated. This consists of a 5.5" capacitive touchscreen, and a 3-axis accelerometer, which is connected through a microcontroller (Arduino Uno). This was installed in a custom-designed 3D-printed shell and reduced to a single cable leading into the computer by soldering the components on a USB-C hub. A patch structure was built in *VVVV*, with the controls and renderer included at the highest level of the hierarchy, which activates and deactivates various subpatches where the interactive graphics reside.

3.2. Test graphics and input sets

Based on interviews with pain patients (n=4), as well as an explorative qualitative analysis of entries in online blogs (n=20), in which patients describe their pain, hypotheses were formulated as to which elements should tested in the construction kit for modeling pain. These were built with basic geometric forms and the variable *size, color, motion* and *shape*. These were then systematized into different series of test-graphics and input sets for the exploration. In the first set hypotheses about the variables of the interactive graphics were investigated, this includes the number of variables as well as the kind of variables provided for the users. Various test graphics with one to four different variables were created, as well as a series of graphics in which the different variables were combined in pairs. Different ways of input were examined in another set of graphs. In addition to the various press and swipe operations, the accelerometer (shake and tilt) was also tested as a possible form of pain input with respective graphics. Since it is hypothesized that pain is represented more accurately in a fluid motion than in a static form, all graphics were animated. In order to discuss different forms of pain representation with the users, additional graphics were created, in which pain was represented pictorially (Figure 4).

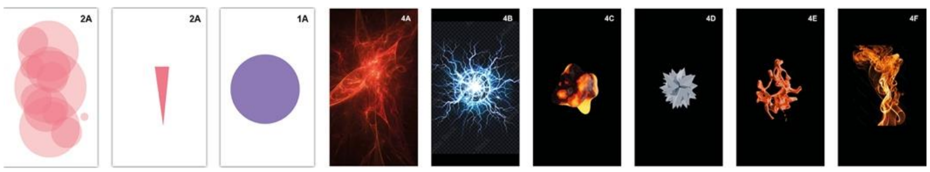

Figure 1: Test Graphics of the series 1, 2 and 4. Pictorial and graphical representations of pain.

The result is four series of test graphs[2] which were tested in the Mixed-Method Study presented in the following section.

4 MIXED METHODS STUDY WITH PATIENTS AND HEALTHY PARTICIPANTS

In the study, the patients were asked whether the parameters provided (and as outlined in Section 3.2.) were suitable and operative for representing their individual pain experience. In turn, different pain stimuli were administered to the healthy subjects to test whether coherence in the selected representation could be found in accordance with the stimuli. In the first study participants suffering from chronic pain were asked and in the second study six healthy subjects receiving QST pain stimuli (as outlined in the following section). Both studies were conducted with the same type of questioning, combining quantitative questionnaires with a guided interview and thinking aloud protocol. The analysis of both studies was pursued by systematizing the statements of the two groups of participants according to themes (as outlined in

[2] **1. Input Combinations (6):** parameters size, color, shape and motion; combined in pairs.
2. Input Forms (4): press and hold, change position, shake and simple tap.
3. Number of Parameters (5): one to four different changeable Parameters.
4. General Visualization (6): animated pictorial representations e.g. lightning, ice, fire.

Section 5.2.).

4.1. Participants: patients and healthy subjects

Patients n=7 Inclusion criteria: a) Adult patients (>18 years of age), b) in treatment for chronic pain, c) proficiency in the German language, d) signed informed consent form. Exclusion Criteria: Physical and cognitive limitations that prevent speech articulation or operation of the device.) Patients were asked to focus on their current pain sensation (main localization). These were to set with the available parameters in the interactive graphics.

Healthy participants n=6 Inclusion criteria: a) Adult patients (>18 years of age), b) Proficiency in the German language, c) Signed informed consent form. Exclusion criteria: a) Chronic pain disorder, b) Physical and cognitive limitations that prevent speech articulation or operation of the device. Were questioned with regard to three predefined, experimental pain stimuli. For that, methods of quantitative sensory testing according to the protocol of the German Research Association for Neuropathic Pain (DFNS) was used. This method is reliable to produce ~~a~~ standardized, comparable pain stimuli (Nothnagel et al., 2017). All stimuli were applied to the right dorsum of the hand (heat and PinPrick) or to the right heel of the hand (Algometer). **Heat pain:** using a thermode (Thermal Sensory Analyzer II, Medoc, Israel), heat stimuli are applied to the dorsum of the right hand. Starting at a base temperature of 32°C, the temperature is increased by 1°C per second in a standardized manner. The subjects are asked to press a button as soon as the thermal stimulus reaches a painful quality. The maximum temperature of 50°C cannot be technically exceeded. **Mechanical pain stimulus (PinPrick, "pricking"):** Pinprick stimulators provide so-called "needle stimuli". The blunted needles can produce various sensations on the back of the right hand through variable weights up to a sharp, pricking pain sensation. The skin is not injured in the process. The maximum force applied is 512mN. **Mechanical pain stimulus (algometer, "pressure pain"):** With the aid of an algometer (Somedic SenseLab, Sweden), a pressure stimulus is applied to the right heel of the hand. The pressure is increased in a standardized manner until the subject experiences a painful sensation. With this procedure, too, there is no risk of injury if the device is used properly.

4.2. Type of assessment

Prototypical test graphics were presented to patients and healthy subjects via the above described *smartphone simulator* (as described in Section 3.1.), allowing the patients to adjust their pain through the various variables provided. In the subsequent 30- and 45-minute interview sections, the patients and healthy subjects were asked to model the graphics with the input methods common for smartphones (swipe, press, position change, physical acceleration) and report their impressions. For that a *Quantitative questionnaire on suitability* was used containing Likert scales for quantitative evaluation of the suitability for visualizing the pain experience.

Additionally, in a *semi-structured interview*, open-ended questions were asked about acceptance and usage experience during and after testing (Reinecke, 2014). Furthermore a *Think-Aloud Protocol* was conducted to record cognitive and affective associations (Konrad, 2010).

5 RESULTS

5.1. Questionnaire

	1A	1B	1C	1D	1E	1F	4A	4B	4C	4D	4E	4F
Patients												
Not suitable				1		1	2	2	3	2	3	1
Little suitable	1	2	1		1	4	1	2	1	1	1	1
Somewhat suitable	2	1	2		4	1	1		2	1	2	2
well suited	3	2	4	3	2	1	2	2	1	3	1	2
very well suited	1	2		3			1	1				1
Healthy Subjects Heat-Pain												
Not suitable		2						2	1	1	4	
Little suitable		1	1	1	1		1	3	1	2	1	
Somewhat suitable	2	1		1	2		2	1	1	1		1
well suited	4		3	2	1	4	2		3	2	1	1
very well suited		2	2	2	2	2	1					4
Healthy Subjects Pin-Prick												
Not suitable		3	1	1	1	1	2	3	3	1	4	2
Little suitable			2		1	1	2		1	1	1	1
Somewhat suitable	1		2			2	1	2	2		1	1
well suited	3	2		5	3	1	1	1		4		1
very well suited	2	1	1		1	1						1
Healthy Subjects Algometer												
Not suitable		3	1			1	1	4	1	2	4	3
Little suitable	1		1	1	2	1	4		2	2	1	
Somewhat suitable	1		1	1		1			2		1	1
well suited	3	2	1	3	4	2	1	1	1	2		1
very well suited	1	1	2	1		1		1				1

	2A	2B	2C	2D	3A	3B	3C	3D	3E
Patients									
Not suitable		2	5	1	2	2	4	4	6
Little suitable	1	3	1		1	3	2	1	1
Somewhat suitable	2		1	1	2	1	1	1	
well suited	2	2		2	2	1		1	
very well suited	2			3					
Healthy Subjects									
Not suitable	1	1	2	2		1	1	1	1
Little suitable		1	3					1	
Somewhat suitable		2			1	1	2		1
well suited	1	1		2	4	2	2	2	1
very well suited	4	1	1	2	1	2	1	2	3

Figure 2: Results of the Questionnaire for evaluating interactive graphics.

The variable combinations were rated mostly equally and well suited by both patients and healthy subjects with QST stimuli. It was notable, that graphics, where color was available for selection were rated higher. Regarding the patients and their individual pain experience, especially graphic 1D (where color and size could be modeled) stood out. For the input form, *press-and-hold* was clearly favored by patients and healthy subjects alike, with and *single-face* selection also rated as good fit. Position change and was clearly rejected by both groups, shaking however was rated as "well suited" by two healthy subjects and three patients. The graphics for the number of input parameters were rated as similarly suitable by both groups, whereby the dissent increased with an increasing number of input parameters. It is noticeable here, however, that a significant number of the healthy subjects (3 of 6) rated the graphs with three and four parameters as "very suitable". The display forms were on average rated as less to not suitable by the patients, only the display of a jagged metal shape for the pin prick and fire for the heat stimulus were rated as well suited homogeneously.

5.2. Semi-structured interview and think aloud protocol

The statements of the patients and test persons were transcribed, and the reports were structured according the specific test graphics *(statements on visualizations, variables and interactions)* and the approach in general *(statements about potentials, requirements and challenges for interactive pain assessment).* According to the participants, the provided combinations of *shape, size, color* and *motion* could be used without exception for communicating their pain. One patient and two healthy subjects stated that they would need more than the provided two parameters in the first set of graphics. Of all the parameters, *motion* turned out to be the most significant for both groups alike. This was felt to be very helpful and fitting. On the other hand, several testers (3 of the patients and 2 of the healthy subjects) stated that the applied type of *motion* (pulsation) did not correspond to their experience and thus rejected the graphics as inappropriate. In the statements it became clear that they wished for more adjustment possibilities of the pulsation. Overall, both groups reported that a larger variety of adjustable parameters would substantially support their pain communication. The different input forms of Series 2 were discussed very reluctantly; only *press and hold* and the *discrete selection* were found to be practicable. In the latter, however, both patients and healthy subjects stated that they found the predefined selection limiting and that they would prefer the modellable graphics. The pictorial representations of series 4 were rated heterogeneously. One Patients and two healthy subjects stated that these would fit particularly well, as the pain was thus suitably represented, others rejected these, because they disliked the aesthetics and felt that they could express their pain more clearly in a graphic form. Overall, most patients (6 from 7) confirmed that they could well imagine using the presented, or a similar system for assessing their pain.

6. DISCUSSION

In the study, different interactive graphics were tested by healthy subjects and patients, aiming to explore the acceptance of both user groups to this novel approach in general and specifically to the parameters *input combinations, input forms, number of parameters* and *general visualization strategies.* These results form the basis for the further design (and re-design) of the system by defining specific requirements and adapting the focus of development. Furthermore, possible coherences to the pain experience or the QST pain stimulus and the selected settings of the interactive graphics should be investigated in the study. Through the use and application of the system, it became clear that the visual meaning of the elements (shapes, color, animation) cannot be generalized and were defined individually by the testers. However, the users were able to express their pain experience without using the logic of static symbols and signs, or pre-determined numerical systems. This underlines the potential of the approach not only regarding highly specific and intuitive pain assessment, but also addressing patients with impaired cognitive or sensory capability. With regard to the functionality of the graphical visualizations, the motion (pulsation) parameter clearly stood out; it was received very positively, but also rejected as it could not be changed in detail. Regarding the input forms the swipe gesture was widely accepted also the *press and hold* input was stated to be suitable. Regarding the pressing-input the similarity between a stabbing pain and pressing on the touchscreen was highlighted, reinforcing the approach of embodied input. Although the simultaneous processing of several parameters was too much of a challenge for some patients and healthy subject, those who were not overtaxed stated, that with three and four parameters they achieved the most accurate visualization of their pain. The conclusion could be drawn, that an increase in the number of parameters does directly correlate with an increased precision of the visualization and increased the user acceptance and operability. A particularly important requirement was that the input had to be simple and real-time. Although the level of detail with which pain quality could be defined was appreciated, the overall notational complexity, at the same time, was criticized. In the interview, the acceptance to assess pain by interactive graphics was postulated by almost all testers though.

6.1. Conclusions

Regarding the Development of a graphical interactive pain assessment, it became clear, that the big challenge is to mediate between the level of detail, complexity and usability. A consistency in expression has not clearly emerged. For certain pain stimuli e.g. the Pin-Prick stimulus a narrow triangular, certain shapes were primarily selected – correlations between the type of pain indicated by the patients on the *German pain questionnaire* (DSF, 2015) and the selected graphics cannot be stated due to the diversity of pain types and the small number of participants. The general approach seems promising, but special attention should be paid for keeping the complexity of the system low in the further development. In this way, the project attempts to meet the challenges of preserving human individuality and plurality in an increasingly standardized digitized world, empowering the user through bespoke interface solutions and intuitive data input and feedback processes, while, at the same time, fostering (truly) human-centered design principles for future health applications and patient care.

6.2. Outlook

The findings from this study will be further applied to develop a mobile application to document the pain history and to support a behavioral therapy for pain patients.

For this purpose, it will be important to further adapt the visualizations to the sensations described by the patients, but, above all, to systematize the input toward gradual, incremental, and individual steps. Another question to be further pursued is how the documentation of an acute pain experience should be structured. Such a system would be able to continuously deliver unambiguous and detailed data that would opening up completely new diagnostic opportunities (and applications, e.g. interconnected data documentation, prognostics and foresight etc.).

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