Design guidelines for educational artefacts supporting physiotherapist treatments

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Abstract— The use of artefacts to support education in medicine and to practice medical procedures is becoming increasingly popular. Through the use of technology in an educational setting, medical procedures can be practiced in a safe environment. However, for physiotherapists there seem to be very few of these artefacts available, even though they have the potential to deliver direct feedback on a student's actions and provide a multipurpose and adaptive learning experience. In this exploratory study we have developed five guidelines to aid in the design of such artefacts, through the creation and evaluation of a prototypical artefact. This prototype was created via the rapid prototyping method and was tested by 28 students to evaluate and re-evaluate its usability and user interaction. Furthermore, experience practitioners confirmed that artefacts such as the evaluated prototype offer a meaningful addition to current educational practices, leading to new, meaningful opportunities for future research.

I.   INTRODUCTION

The use of artefacts to support education in medicine and to practice medical procedures is becoming increasingly popular. An artefact is what is referred to as an artificial system, in this case made to simulate a natural phenomenon. Examples of such systems are the LAP-X from Medical X to practice laparoscopic surgery [1], devices to simulate dental situations e.g. from Navadha Enterprises [2], or full body puppets to practice cardiopulmonary resuscitation (CPR). Through the use of technology in an educational setting, medical procedures can be practiced in a safe environment. However, to physiotherapists there seem to be very few of these systems available, even though they have the potential to deliver direct feedback on a student's actions and provide a multipurpose and adaptive learning experience.

In addition to giving advice to patients on improving posture through exercise, an essential part of a physiotherapist's job is to apply massaging techniques targeting for example: lower back pains, sports injuries and whiplash patients [3]. In order to perform these tasks well, physiotherapist needs a clear understanding of what different pathologies (abnormalities) exist, how they come to develop and how they can be treated. Currently, physiotherapist students only have their fellow (usually healthy) students to practice on and books to learn the techniques from, even though their profession mainly involves manual work focused on feeling with their hands. This means that most of the necessary experience comes only after completing their studies, when they have to participate in the real treatment of patients under the supervision of experienced practitioners.

In this exploratory study we will take a look at how we can support students with the help of artefacts to gain a better understanding of pathologies and more experience in treating real patients. The aim of this research is to conclude with a set of design guidelines that can be incorporated in future artefacts and eventually real products that are focused on bringing (part of) this experience inside the classroom. We will do this via a case study that is aimed at creating a haptic experience for physical therapy treatment of the lower back. This part of the body is most often affected by pathologies that require physiotherapeutic treatment. This case study will help answer our research question: *What are the necessary steps for designing a physical artefact that can support the education of physiotherapists?* We will investigate what designs have already been proposed for educational physiotherapeutic artefacts in section aimed in section 2. This is followed by a description of our method in section 3 and the explanation of our case study in section 4. In conclusion, the findings based on our design and tests will be described in section 5 followed by a discussion of the results and future possibilities in section 6.

II.   RELATED WORK

The research conducted for this study is regarded as an exploratory study to investigate means for students of physiotherapy to improve their professional skills during their education. There is a lack of research done in this area. This might be due to the fact that some therapies itself have not yet been scientifically proven to help [4]. In our case this

does not decrease the value of such a system since the effectiveness of the system itself can be empirically studied.

There are systems available that are dedicated to support the practitioner during the treatment of a patient, as well as systems meant to substitute the practitioner completely. These systems usually involve manipulating a robotic arm and focus on only one specific exercise for a specific pathology. The InMotion ARM, for example, is an interactive therapy system that helps to improve the motoric functions of stroke-patients [5]. This rehabilitation equipment involves a robotic arm that can be manipulated by the patient and needs very little intervening from the practitioner. Another one of these systems, the REHAROB, looks quite alike. It again, involves a robotic arm that can be manipulated by the practitioner to mediate upper limb physiotherapy of patients with spastic hemiparesis [6]. Although being bulky and single-purpose, the positive conclusion that can be drawn from the use of these systems is that they seem to be effective as treatment solutions [7, 8].

There is only so much we can learn from these systems: their focus is on treatment instead of education and thus their design goals are different from the goals of this study. For now these treatment systems seem to be far away from replacing real practitioners. A human touch still seems to be preferred by patients and therapeutic treatment in general is still difficult for mechanical systems since it involves careful analysis of the patient body via tactile and haptic methods.

III. METHOD

As a means to answer our research question a case study is conducted in which we investigate a prototype for the treatment of lumbar disc herniation (more information about this pathology can be read in textbox 1 on page 4). The prototype is subjected to user tests in order to evaluate the usability and user interaction and improve the design in the next iteration. The development of this prototype will lead to the conclusion of this paper and answer to the research question in the form of a set of design guidelines.

Figure 1: Participant is applying force on vertebra inside the prototype during user test.

This methodology is also described as Design Research: research is considered part of the design process by getting users involved in the development of the prototype [9]. In this section we will zoom in on the setup of the user tests, the aspects the prototype has been tested on (usability specifications) and an additional colour study that has been performed to support our design guidelines.

A. Prototyping

For our case study, we are going to develop a prototypical artefact meant to be used as an educational tool. To be able to conclude this study with a valid set of design guidelines it is important to test the prototype on its usability and design. The prototype (see figure 1) will be a high-fidelity [10], functional model [11] so we can focus on observing the test participants during the user tests. Furthermore to increase the effectivity of the user tests we want to focus on in-depth development of one specific functionality of the artefact.

The development of the prototype is divided into three physically different, distinctive iterations according to the rapid prototyping method following the waterfall model [12]. This means that each iteration will involve an analysis, design, implementation and test phase, leaving out the maintenance phase. In the analysis phase we examine the feedback provided in the user tests of the previous iteration. This feedback will lead to improvements that change the design of the current iteration. These improvements will then be implemented and tested again.

In preparation for the analysis phase of the first iteration, we first interviewed experienced practitioners to help come to an initial design. This iteration is mainly an exploratory phase wherein we try to replicate the pathology as realistically as possible in order to better understand the pathology and research possible materials to use for the next iterations. The design of this first prototype is then evaluated by the same experienced practitioners that helped in the analysis phase in what can be considered a pilot user test.

Following the pilot test, an improvement of the first design is made. This second prototype is tested on the usability specifications (as described in the next subsection) with the help of students. Within this iteration, small adaptations are made to the prototype in order to accommodate further development of it. These sub-versions are evaluated both qualitatively and quantitatively to confirm the added value of the improvements. For each iteration, at least five testers participated in the user test. This amount of testers is confirmed by Landauer and Nielsen to find around 80% of the usability issues of the design [13].

As a final evaluation in iteration three, the third and last version of the prototype is submitted to three experienced practitioners again as well as five students. This evaluation is meant to confirm that the usability specifications have been properly tested and the functionalities of the device are implemented properly. This last iteration is not meant to produce any real product, rather, it and all phases for that matter are used to affirm and reaffirm the guidelines resulting from this development process. Therefore, it can be considered a throw-away prototype.

B. User Tests

Apart from testing whether the design of the prototype meets our usability specifications, we also want to test how well the artefact is received by students and how they would rate the usefulness of the artefact as an educational tool. This is done with the second iteration prototype in a subset of four different versions each tested with five participants.

Our test group includes students from different disciplines between the age of 18 and 25, including both males and females. Ideally the artefact still has to be tested specifically on students of physiotherapy, however this research targets users with little knowledge about specific pathologies and therefor the current test group has been chosen to be sufficient for now. Furthermore, the focus of the artefact is on the learning process and it is important to observe users that have no experience with the treatment techniques. To confirm if the artefact is functioning correctly according to physiotherapist practices, in addition to the student test group, the prototype will also be evaluated with experienced practitioners in the third iteration. This includes three different practitioners with at least five years of experience in the field of both Manual Therapy and Cesar Therapy.

The user tests of the second iteration involve three separate parts. First, the participant receives a quick introduction to what a lumbar disc herniation is as a way for the participants to gain an initial understanding of the artefact and how it should work. This introduction is comprised of the same information as given in textbox 1 on page 4. The second part of the user test involves the actual use of the artefact. The participants are asked to use the thinking aloud method and talk about what they are experiencing. As a follow-up on this usage, the third and last part of the test includes the completion of two short surveys. The first survey is focused on the value attributed to the system as an educational tool, as well as the tactile- and visual experience. The second survey is a standard questionnaire, as proposed by John Brooke [14], to rate the system's usability and performance. Each participant

produces a score along this *System Usability Scale* between 0 and 100. The scores are used to compare different prototype versions and to evaluate each iteration's adaptations to see if they have improved the system's usability or not.

C. Usability Specifications

Besides the two surveys, the artefact is also evaluated along a set of usability specifications. These specifications, again, are used to make a comparison between the different prototypes. Usability, as defined by ISO 9241-11, is regarded as the extent to which a user's interaction with a system is efficient, effective and satisfactory in achieving a specified goal [15]. These three factors will be the focus of the test phases within every iteration since the design guidelines are only useful if they contribute to these three aspects.

To test the effectiveness or, in other words, the accuracy of completing the right task, we will observe whether the offered feedback from the system is correctly interpreted: can a test person find the pathology and how fast can he/she find it? We do this by means of two ratings: first, the time spent searching and second, the number of touches before finding the correct spot to treat. These measurements are noted in appendix I. The goal of the system is not so much to be as fast as possible, instead the timespan is only an indication of the effectiveness of the feedback since it states when the exploratory actions of a user are over and the actual treatment has begun.

Regarding the efficiency of the system or, in other words, how quickly it is understood what the right action is, it is necessary to look at the amount of time spent on treating a specific location. This will be timed. However, it is not so much about the duration itself as it is about the time between the different user groups that have used a different prototype. This measurement is used as a unit to test whether the system is getting more efficient across the different versions.

Finally, the most important segment of testing the usability specifications for this study involves user satisfaction. If the system is not deemed appropriate and realistic enough to use, the purpose of the build is defeated. As stated before there are two surveys to both qualitatively and quantitatively assess this aspect. The result of this measurement can also be found in appendix I.

D. Colour Study

While testing the second iteration prototype, we observed the colours we used to give feedback to the user, were not very effective. As can be read in section 5, these colour settings turned out to play an important role in the

design guidelines based on our case study. To support these findings we set out to do an additional study in the form of a short questionnaire. The questionnaire asks participants to rate the association they have between a certain colour (e.g. orange) and a specific term or action (e.g. "relief" or "navigating forward"). In particular they are asked to rate this association while imagining interacting with a user interface. Furthermore the participants were asked to rate the colours they believe to be best connected to a specific actions (e.g. "turning on the television"). The focus of this additional study was not so much to connect emotions to the different colours [16] but more so on the meaning the user attributes to them. The full questionnaire can be found in appendix II.

IV. CASE STUDY

As a case study for this research we propose a system designed to help teach the treatment of a spinal disc herniation or HNP. Textbox 1 explains what this pathology encompasses. HNP is quite common amongst patients of different ages and is an often seen complaint for physiotherapists to treat [17]. In education, students tend to practice on healthy, fellow students which do not have this or other pathologies. The aim of this case study is to see how we can introduce the experience of dealing with a real HNP-patient inside the classroom and in this way answer our research question. The artefact is by no means meant as a replacement of fieldwork or professional experience: it

merely provides an additional tool at the disposal of students and teachers of physiotherapy meant to increase their level of understanding the pathology.

A. Design Specifications

Before designing the artefact, there are certain design specifications that have to be taken into account. These serve as boundaries for development and limit the design possibilities just enough to facilitate the design of a testable prototype. Sometimes, they include presumptions that turn out to be false while performing user tests. In this section, we will discuss these specifications and how we have implemented them into the artefact of our HNP case study.

Since the main focus of the artefact is to serve as a treatment teaching device, the boundaries of the human body are considered in its design. Most importantly, it should react in a natural way to stimuli. This does not mean the inner workings or appearance need to be direct replications of the human condition rather, it means the system has to give the same haptic and tactile feedback a human body would and respond to treatment and applied pressure in a similar manner. This response can be either a simulated effect or a translation into another sensory modality. We will use these three aspects: haptic, tactile and visual feedback, to define the specifications for the implementation of the prototype.

Textbox 1: Herniated nucleus pulposus; a case study on the disc hernia

For the case study of this research, we focus on a specific pathology: the hernia, which is a common problem. There are many different types of hernias, but in this case we focus on the Herniated Nucleus Pulposus (HNP) also known as spinal disc herniation or Lumbar disc herniation. HNP occurs when heavy pressure is applied on one of the intervertebral discs in the human spine, which may occur due to a sudden movement, a fall or when something heavy is lifted. Physiotherapists are often the first in line to recognize HNP since patients visit them for backaches or having difficulty moving freely [17].

To understand HNP in better detail, it is important to know what a human spine is made up of. The human spine exists of three different parts: the vertebrae, intervertebral discs and the spinal cord. The intervertebral discs contain an outer ring (annulus fibroses) and a slow liquid inside it (nucleus pulposus). This liquid enables humans to tilt and bend our backs [18]. With HNP, the liquid has broken the outer ring, which makes the ring bulge out into the space of the spinal cord or one of its branches. The spinal cord is the main nerve going from any part of the body to the brain, enabling movement and registering pain. Besides putting stress on the spinal cord itself, HNP might also overload a branch (nerve root) from the spinal cord with stimuli. This results in the radiation of pain to other parts of the body (e.g. the legs)[17]. It is important to state that HNP cannot physically be felt by the practitioner; it is more often recognized by a lack of freedom of movement and/or the complaint of radiation to the lower body.

When a patient is experiencing pain and problems with moving for a longer period time, he/she will generally be referred to a specialist. Specialists have told us that it is possible to have the HNP surgically removed, taking into account a serious revalidation period. Before this trajectory however, treatment by a physiotherapist is often advised to help relieve the pain and stress on the spinal nerve. Different therapies can be applied to limit the amount of pain, though manual therapy is most often recommended [17]. The domains of Osteopathy, Chiropraxia and Manual Therapy all focus on pain originating from the spine but have different ways of treating it [19, 20]. In many countries, including The Netherlands but excluding The United States, these therapies are regarded pseudoscience and considered as additional treatments [4, 21, 22]. However, there is some empirical evidence showing that physiotherapy (not specifically including one of these disciplines) to be effective for treating patients with neurological, musculoskeletal, cardiopulmonary conditions [23, 24, 25].

1) Haptic feedback

Many treatment techniques for physiotherapists (especially manual therapists) focus on the human spine [26], which is also where the pathology from our case study usually manifests. Some lower back pathologies, like HNP, are normally diagnosed by performing the Straight Leg Raise (SLR) test [27]. In this test both legs are pulled up one at a time to see if they can be raised higher than 40%. If this is not possible, it is an indication for a lower back pathology and the practitioner has to massage the lower back area to find out where precisely the pathology is located.

The main focus of the system is to enable the user to do this exploratory research of the spine. Therefore the system should include what the user thinks to be vertebrae. The vertebrae do not have to be exact replications of real ones, they merely have to feel and react to physical manipulations in a similar way. In order for the user to do exploratory research on the spine, the vertebrae should be able to be manipulated. However, they should return to their initial position when let go off. Furthermore, the vertebrae influence each other when manipulated, so there has to be a form of dependency between them.

The haptic feedback to the user's touch, provided by the vertebrae, might be sufficient to improve the learning experience. However, while treating a patient, practitioners also receive feedback from the patient's muscles. They will tense or cramp up whenever the patient experiences pain. Simulating this haptic feedback inside the system might add to the immersion of the user.

2) Tactile feedback

To further convince the user he/she is treating a real patient, the system needs to have a natural feel. The haptic feedback as described above should be complemented with tactile feedback. Tactile feedback is different in that it focuses on the texture and structure of the artefact: it is a more passive feedback form when compared to haptic feedback. A realistic imitation of the human skin might help encourage the user to take the treatment more seriously and in turn learn more from the exercise.

Adding to this, it is important to make sure the body feels sturdy. Normally, muscles and fat would make up the patient's body and allow for a solid feel with the softer skin on top. The body of the artefact also needs to allow the practitioner to apply the same level of pressure on the system as he/she normally would on a real patient. This means we have to maintain the structural integrity of the system to prevent it from breaking in half while still being able to house the other parts and support their mechanisms.

3) Visual feedback

In a real scenario, patients are able to converse with the practitioner and vocally respond to his/her treatment. Since this would be overly complicated to integrate, we translate this auditory feedback into a visual modality, i.e. coloured lights to provide feedback. The choice to replace human speech by lights has two reasons. Firstly, if the system would react via speech, the user might expect the system to be able to converse with him/her or have a set of pre-programmed reactions ready. In this case we want the system to only show two different states: "you are touching a healthy vertebra" or "you are touching a vertebra affected by HNP." Secondly, the feedback can indicate a reaction to pain and different patients might vary in their pain threshold and thus in their responses, for example being very or not vocal at all about the pain they are experiencing. The lights are a neutral solution for this reaction. Furthermore they do not distract the user as a voice or exclamation would.

B. Implementation

The design specifications led to a prototype that has been tested to improve and learn from in order to draft the design guidelines from section 5. To give an idea of what this tested prototype looks like and what it is made from, we will discuss the implementation here, divided in five categories: the vertebrae, body, muscles, skin, and user interaction. As mentioned before, the artefact is simulating a HNP and the user is asked to find it and treat it.

1) Vertebrae

Imitating a complete human spine in this study would be overly complicated and is unnecessary for our case study. HNP mostly develops along the lumbar vertebrae. These are the bottom five last vertebrae before the sacrum (see figure 2). The system houses only these five vertebrae. They are imitated by using large, pressurized syringes. These enable the user to put force on the top plunger, but at the same time offer pressure so they do not give in completely. This is due to the air inside being compressed, at a certain point this requires so much energy, impossible to apply by force. In addition the air inside returns the top plunger to its initial position.

The syringes can be positioned next to each other in a metal rack. This rack makes the syringes dependent on each other. When one is pushed, the others are influenced. This adds more realims to the system.

2) Body

As a basis for the prototype the body is made of polystyrene. It can quickly be shaped in any form required and can support a lot of weight. However, it is not too hard

and gives a little when pushed on. The dimensions of the body for this prototype can be found in figure 3. These dimensions provide room for five vertebrae. It is made from one piece and is not able to rotate. This does prevent the SLR test from being applied, which is a conscious choice. The SLR test is only applicable to a small subset of pathologies (indeed including HNP). Even though it would fit this case study, with the current artefact we want to focus on a single functionality that is applicable to a broader set of pathologies.

Polyethylene tubing is added on both sides of the vertebrae on top of the body. This tubing is meant to imitate the feeling of muscles and allows the vertebrae to be deeper inside the body and the skin to be elevated from it.

3) Muscles

Besides the polyethylene tubing that functions as a firm surface to imitate the tactile feel of human muscles, the imitation muscles should also have the possibility to contract. To replicate this contraction a thin plastic sheet is placed over the body and vertebrae. This sheet can be pulled tight by an array of three servos. The idea is that, when the sheet is pulled tight, it offers more resistance to the user's actions. The user would have to reach the vertebrae through both this sheet and the skin replica.

4) Skin

The artefact represents a human body. Therefore the tactile feedback has to approach the human skin as much as possible as described before. To reach this level of realism the skin of our prototype is made of Ecoflex 00-30. This is a liquid silicone rubber existing of parts that have to be mixed in equal quantities. The hardness of these rubber silicones is measured in shore. A shore of 00-30 means that the rubber, once cured, is relatively soft and stretchable, which is ideal
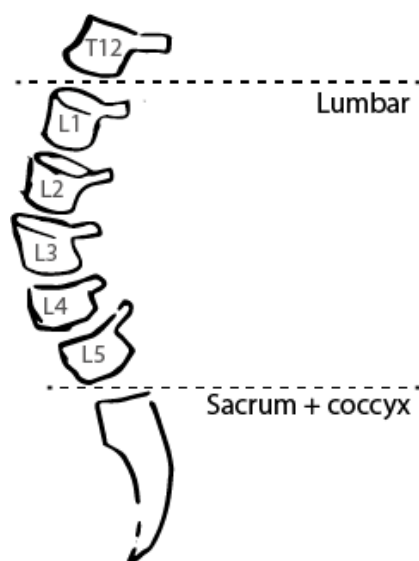
for our replica skin of the human back. The rubber is poured in a cast made from plaster of a real human's back. It is important to make this cast since this transfers the rougher texture of the human skin, upon the cured rubber and keeps it thin enough for the coloured lights to be able to shine through it. The rubber can be coloured with skin colour pigment and has to cure for about an hour before it can be taken out of the cast.

5) User interaction

In order to register user input and give feedback to his/her actions, there are three systems connected via an Arduino Uno microcontroller. The first system is an array of five sensors attached to the top plungers of the syringes simulating the vertebrae. These are force-sensitive resistors

(FSRs) and can detect how much force is applied to an area of 2.62 square centimetres and thus which specific vertebra is massaged. This is translated by the Arduino into a signal for the second system, a set of LEDs, and the third system, an array of servos. The array of servos, necessary for the muscle imitation, only react when the vertebra with HNP is massaged and are activated only when too much force is applied by the user.

The LEDs on the other hand give direct feedback to every touch and are positioned above each vertebra, in duos of red and green. We tested different colour settings in response to input registered by the sensors leading to the design guidelines in the next section. Furthermore we have included a fading effect to simulate a response of pain in reaction to the user's input. The Arduino makes use of a constantly looping function to execute its main code. The fading effect of the LEDs is realized by making use of this loop and a standard function called *millis()*, which returns the amount of milliseconds the system has been running. The pseudocode for this function can be found in Appendix III.
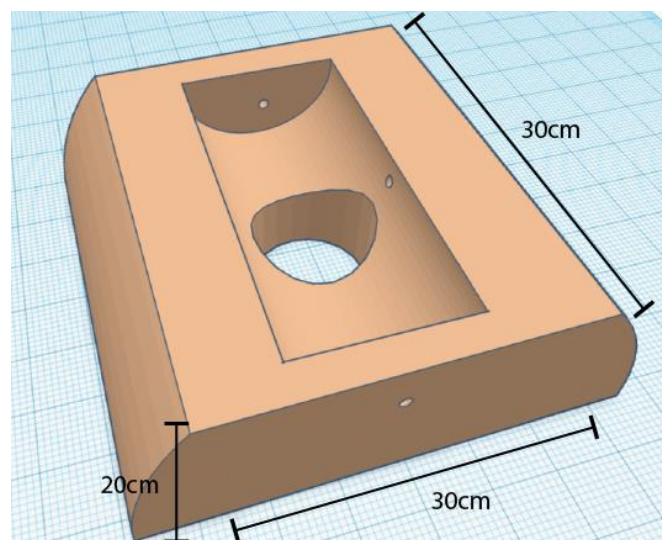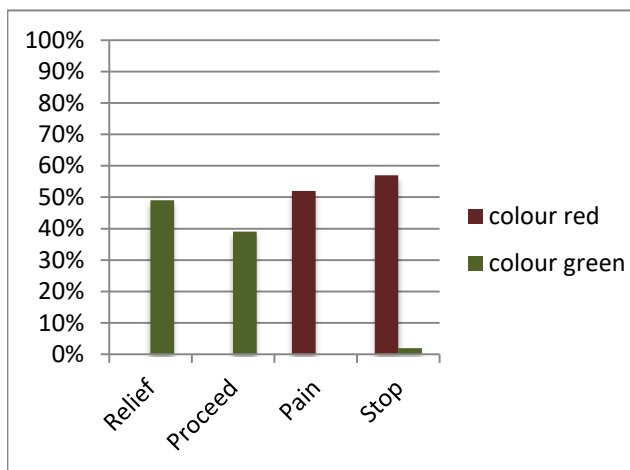

Figure 2: Top Thoracic vertebra (T12), Lumbar vertebrae (L1 - L5) and sacrum of a human spine.

Figure 3: CAD-model of polystyrene body including dimensions.

Figure 4: Percentage of participants to have an association or strong association between color and a specific term.

V. DESIGN GUIDELINES

For the case study as described in section 4, the user tests helped evaluate the system as implemented according to the aforementioned design specifications. The results of these tests have been used to come to the design guidelines and conclusion as described below. Some of the guidelines have resulted from the usability specifications of which the full test results can be found in appendix I. Other guidelines are based on qualitative data gathered during the user tests and observations of user performance.

A. The colour reversal theory

Having two coloured lights is a good alternative to generalize the feedback a patient would normally give. The main occupation of a physiotherapist revolves around finding the hurtful locations along the spine and drawing a conclusion from that for the proper treatment. All testers were able to figure out the distinction between the good and the bad vertebrae with the green and red lights. We can imagine, that in a few circumstances the representation of these two states (pain and no pain) might be insufficient (e.g. for colour-blind users). In this case the possibility is there to add different coloured lights or have RGB-LEDs to show any colour desired depending on the state.

In a regular system, users would associate the colour green with relief and proceed with their current action when this colour is shown. Furthermore they would associate the colour red with denial or stopping a task. This can be concluded from both the colour study we carried out, as can be seen in figure 4, as well as a study done by De Bortoli et al. (2001) [28]. However, through user tests with this artefact, it turns out the optimal and best understood colour setting is actually reversed. With the colour reversal theory, we state that when placed into the context of having to localize pain, the colour green is responded to with inaction whereas a red colour becomes the focal point of attention and is understood to be the location to treat. The system is only effective with these settings when the aim of the artefact is to find a pathology and only when the colours are placed in context. The user needs to have seen both colours first to understand their meaning and place in context before proceeding with the right action as shown in figure 5.

There are a few side notes to make for this theory. First, it is important to state that when red coloured lights are seen before green lights, it still leads to a cautious attitude of the user. The user might be reluctant to proceed. It is only after the colour has been placed in context that the user is assured to proceed with treatment on the red lighted vertebra. This happens when the user has seen multiple green coloured lights when touching different vertebrae. To take away the user's doubt and make the system more efficient, an orange coloured light can be used instead. The colour study shows the orange colour is assessed as being more neutral than the colour red (see appendix II). Second, the prototype's design did not take into account colour blindness and thus no colour blind people have participated in the test. Lastly, the associations as we have mentioned here may mostly apply to Western culture, and may differ in other cultures such as Asian cultures where associations with colours may be very different [29].

B. Fading lights

The artefact is meant to make the experience of treating pathologies accessible to students. To find the pathology and identifying it, the practitioner focuses either on pain, limited freedom of movement, or both In the case of the artefact for this specific case study, the focus is purely on providing
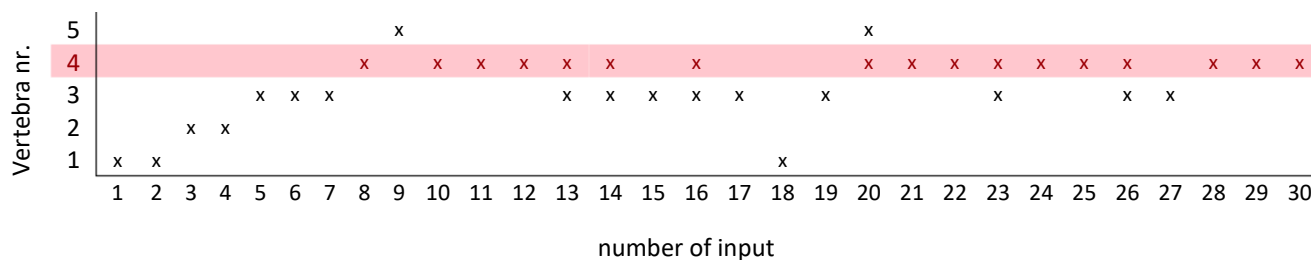

Figure 5: Pushes registered on vertebrae 1 to 5 in generic example case from user test, vertebra 4 has HNP

feedback for pain. Test participants have replied to the glowing of the lights as representing pain and as an immersive experience when massaging. It feels more natural than having lights simply in an on-or-off state. Furthermore, the brightness and duration of the fading can be associated relatively well with the amount of pressure the user is applying to give better feedback on the user's actions.

In contrast to fading, which indicates a correct treatment method, blinking can be used to indicate a wrong treatment method. This can be used in combination with a deeper coloured red light (or red as opposed to an orange coloured light) to indicate that the user should proceed with caution and re-evaluate his/her treatment method. We have not tested these settings but the qualitative data together with the results of the colour study support this as a suitable alternative approach.

C. Spine replication

Using pressurized syringes as imitation vertebrae seems to be an effective method. Users reply positively to the haptic feedback provided. Experts comment that the vertebrae can be pushed rather far inside the body, which would normally not be possible. However, this exaggeration of vertebrae movement can add to the educational value of the system by emphasizing the inner workings of the spine. Furthermore, because the syringes are pressurized to keep their initial stance, this gives the possibility to increase or decrease their height inside the body. To do so the system has a small pump integrated that can inflate or deflate the syringe at will.
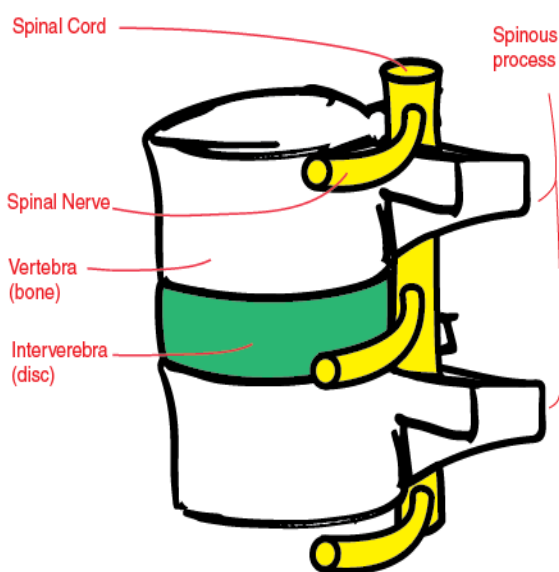
Figure 6: Two human vertebrae and an intervertebral disc including demonination

The only functionality that is missing from the current way of representing the vertebrae is the ability to torque, or twist, them. With the practitioners' techniques it is sometimes necessary to push at the side of the spinous process (see figure 6). This is done to release stress on one side of the intervertebral disc. In our current prototype, the syringes representing this spinous process are restricted by the body of polystyrene to only twist along the length of the body. Hence, this method can not be applied in our prototype and is something to take into account for future studies.

D. Skin replication

Using silicon rubber as a way to imitate human skin has the advantage of being able to endure vigorous actions from the user while still feeling human. Participants rated it fairly high on realism, both for visual as well as tactile feedback. For a more advanced artefact, heat elements can be placed under the skin so it warms up slightly. This would improve the realism of the experience.

E. Rotatable body

One of the functionalities that is not integrated in the existing prototype, and was often mentioned as a shortcoming by users, is the ability to rotate the body. The human spine can bend and rotate in many different directions and there are many techniques that make use of this to see the inability to move (e.g. the SLR test).

F. Conclusion

By designing a prototypical and testable artefact for our case study, we have arrived at five guidelines that can be used to design future artefacts suitable as education tools for physiotherapy students. We will shortly repeat the guidelines here: (1) the artefact is focused on finding a specific spot indicating pain, by using the colour reversal theory. (2) Fading lights help to indicate points of interest in the system. (3) Pressurized syringes can be used to imitate vertebrae. The vertebrae should be able to rotate. (4) Silicon is a suitable material to imitate human skin, preferably when it is heated. And (5), the body has to be able to be rotated by the user to enable different treatment methods. These guidelines have arisen from testing an artefact meant for practicing treatment on a single pathology. While limited, they can be applied to any system simulating pathologies since these systems would also have to include a simulation of the human spine and the human skin and interact with the user along similar lines.

The main advantage of any artefact used as educational tool is its adaptive power. Practicing on fellow students only gives a limited amount of body types and limited exposure to

pathologies to learn from and improve techniques on. This artefact, however, enables teachers to adapt the height of the vertebrae and increase or decrease the size of the body, allowing students to practice with and experience a wider range of pathologies. Ideally, a future system would have multiple pathologies implemented that can be practiced consecutively in the same classroom.

VI. DISCUSSION

As mentioned from the beginning, this study is exploratory and as a result it is rather limited. In the case study we have researched a single pathology and in the prototype only one functionality. Even though this offers a unique, first analysis of possibilities for educational artefacts supporting physiotherapist treatments, it is rather restricted and needs more research regarding different pathologies and approaches to such artefacts. Examples of future topics to research include whether a full body artefact is needed, or how to limit the rotation of body parts in order to enable practicing the SLR-test.

Furthermore, once the artefact has properly integrated the necessary parts and enables full practice experience of one or more pathologies, it will need an in-depth research on its effectiveness. This research will have to include a clinical test with control groups and track practitioners for multiple years to see whether the artefact improves the user's treatment procedures. If it does, a new foundation has been laid for the development of artefacts that not only improve not only physiotherapist treatment methods but also the lives of the HNP patients that were targeted with our case study.

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