Developing a Tool for Training Pelvic Alignment Awareness in Dancers

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Abstract

The pelvis is often considered to be the cornerstone of overall skeletal alignment, and neutral alignment of the pelvis facilitates the proper use of related muscle groups and movement of the joints. For dancers, this influences the ability to technically execute dance movement and achieve the desired visual quality of dance steps. It also plays a role in injury prevention. Many dancers, at both the recreational and professional levels, persistently struggle with maintaining neutral pelvic alignment. While this is a relevant problem, it is not always explicitly addressed in dance education and training.

This research project aims to discover how to develop interactive technology into a tool for training awareness of pelvic alignment in dancers. This involved analysis of relevant literature, state of the art and expert opinions, leading to initial concepts for such a tool. A final concept was further developed, by specifying the user experience and requirements, and then realised into a final prototype. The outcome of this is CoreMnemo: a wearable core engagement memory aid for dancers. By measuring engagement of the transversus abdominis (TrA) muscle via electromyography (EMG) measurements, and providing real-time vibrotactile feedback cues to the wearer if the TrA is no longer engaged sufficiently, it serves as a tool to help dancers be more mindful of their core and pelvic alignment.

User evaluations indicate that CoreMnemo is able to help dancers in becoming more mindful of their pelvic alignment in the short term, without diminishing the experience of dancing. Further research is needed to determine whether CoreMnemo can help dancers to build automatism of active pelvic alignment in the long term. Several other aspects, such as limitations of EMG technology and the occurrence of false positives and negatives, should also be investigated going forward. Despite these challenges, it can be concluded that CoreMnemo shows potential as an inspiration for change in the field of dance training and wearable technology in dance.

Acknowledgement

First and foremost, I would like to thank my supervisor and critical observer, Erik Faber and Hemo Oumenad, for supervising and supporting me during this project. Thank you for having faith in my idea and letting me explore my process freely. I am very grateful for the experience you gave me. Besides my supervisors, I would also like to thank the dancers and dance teachers at Dansstudio X-Dance for going along with my wild ideas and letting me use the dance studios whenever I needed them.

Completing this graduation project has been a great challenge in which I faced many internal hurdles. While much of my energy was spent on overcoming them, I was able to persevere, for which I am very thankful. Last, but certainly not least, I would like to give my endless thanks to Astrid, my family, friends, beloved cats and partner in crime Max. Thank you for your unwavering support when I needed it, I would not have been able to do it without you.

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Chapter 1 – Introduction

1.1 Introduction

The pelvis is considered to be the cornerstone of overall skeletal alignment [1]. Correct neutral alignment allows for proper use of the related muscle groups and rotation of the hip joint. For dancers, particularly in classical ballet and contemporary styles, maintaining proper pelvis alignment is important for achieving correct technical execution and aesthetic quality of moves [1]. It also plays a significant role in injury prevention [2]. Deviations from a neutral pelvis, such as anterior and posterior tilt, anterior tilt (causing a hollow back [3]) being more common [4], can lead to muscular imbalances [5]. This causes various problems such as strained hamstrings [2] or pain complaints in the hip and back areas [6]. Furthermore, anterior pelvic tilt can cause the abdominal and pelvic muscles to weaken over time [7], making it more difficult to engage them correctly for neutral pelvic alignment. This in return compromises a dancer's ability to execute dance moves efficiently and successfully.

Many amateur and professional dancers struggle with maintaining proper alignment of the pelvis. This is especially the case for those who have grown accustomed to improper alignment over extended periods of time, or for those who started dancing later in life. The multitasking involved in dance can make it particularly difficult to focus on maintaining proper alignment while also addressing the other aspects (technique, musicality, expression, feeling) of dancing. Additionally, in a class full of dancers, it is difficult for dance teachers to give the needed attention to individual dancers that are struggling with awareness of their own posture. Combined, these factors can lead to frustration, taking away from the joy that dancing can give.

Research suggests that awareness of posture is a key element in reducing posture related complaints [8] and that training how to engage the related muscles could make a significant difference in a dancer's overall pelvic alignment [9], [1]. Both during their dancing and outside of it. Developing awareness of pelvic alignment should therefore be taken seriously by dancers and dance teachers, yet it is not always integrated enough into dance lessons to make a difference for those that struggle with pelvic alignment. The goal of this project is to develop an interactive tool that can form a supplement in dancers' training, helping them to become aware of their pelvic alignment and achieve healthier, happier, movement.

1.2 Research Questions

The following main research question was formulated to serve as a guideline for this research project:

***RQ**: How can interactive technology be developed into a tool for training awareness of pelvic alignment in dancers?*

There are several aspects that require investigation in order to successfully answer this question. In order to do so, a list of sub-questions was formulated. Firstly, the influence of pelvic alignment on body should be investigated. This will provide knowledge regarding the influence the pelvis and related muscles have on each other as well as the injuries dancers may be facing. Researching the current teaching and training methods for pelvic alignment in dance education will provide insights into the efficiency and shortcomings of traditional teaching and treatment methods and will help shed light on areas where interactive technology could be used for improvement. These aspects are addressed by sub-questions one and two:

SQ1: *What is the influence of pelvic alignment on musculoskeletal health?*

SQ2*: How can pelvic alignment awareness be trained most efficiently?*

The final outcome of this research project will be used by dancers; therefore, it should fit their needs and routines. Investigating the level of understanding dancers possess of pelvic alignment and identifying the problems they are facing regarding their pelvic alignment will help determining the aspects that the tool should address. Studying dancers' routines and preferences regarding their training schedules will provide further insights into the dancers' needs. This leads to sub-questions three and four:

SQ3: *What are dancers' needs concerning pelvic alignment awareness training?*

SQ4*: How can interactive technology be smoothly integrated into dancers' lessons and routines?*

On the technical side, it may be necessary to measure a dancer's level of pelvic tilt/alignment, in order to determine the effectiveness of a potential solution or to serve as an input method for the final tool. How this may be done should be further investigated. Additionally, researching sensory feedback techniques and how they can help humans retain knowledge will provide insights into the ways in which these techniques (combined with interactive technology) could be used to achieve pelvic alignment awareness more effectively. These final points are formulated in sub-questions five and six:

SQ5*: How can pelvic alignment be measured?*

SQ6*: How do different ways of giving sensory feedback influence habit formation?*

1.3 Report Outline

The following chapters of this report will describe the development process of the previously mentioned tool for training pelvic alignment awareness in dancers. The second chapter focusses on background research, including literature analysis, state of the art and expert opinions. The third chapter discusses the creative technology design process, as well as the methods and techniques applied during each phase of this project. Chapter four will describe the steps taken during the ideation phase. This includes stakeholder analysis, definition of preliminary requirements and concept generation leading to a final concept. In chapter five the outputs of the specification phase are covered, further defining the final concept through personas and scenarios, leading to a final list of requirements. Chapter six will cover the realisation phase, discussing the development of the final prototype. Chapter seven will explain the user evaluation process and its results. The final two chapters will contain the discussion and recommendations for future work, as well as the conclusions.

Chapter 2 – Background Research

In order to obtain the knowledge necessary to answer the previously defined research questions and develop a well-informed design, several topics must be investigated. This chapter will focus on background research of the realm of pelvic alignment, dance and related interactive technology. The first section will focus on literature analysis of several topics. These topics include pelvic alignment & musculoskeletal health, pelvic alignment in dance, measuring pelvic alignment, pelvic alignment training approaches, dance imagery and the influence of sensory feedback on habit formation & learning. The second section will discuss current state of the art, including interactive technology applications in dance and training posture. The third section will cover the personal experiences and opinions of involved parties (dancers, dance educators and physiotherapists), shedding light on real-world perspectives.

2.1 Literature analysis

2.1.1 Pelvic alignment and its effects on musculoskeletal health

Pelvic alignment in this project refers to the angle of the pelvis along the sagittal plane (seen in Fig. 2.1.) in relation to the rest of the body [1]. Neutral alignment of the pelvis is considered to be point where the anterior superior iliac spines (ASIS) and posterior superior iliac spines (PSIS) are on the same horizontal plane [1]. The term “pelvic tilt” refers to states of the pelvis in which it is tilted outside of this equilibrium. The degree of pelvic tilt (as seen in Fig. 2.2) may also be used to describe pelvic alignment. Pelvic tilt can be divided into two main types. Anterior pelvic tilt refers to the top of the pelvis being tilted too far forward, causing an increased arch in the lower back (also known as lumbar lordosis or curvature of the lower spine) [10], which can be seen in Fig. 2.3. This is the most prevalent form of pelvic tilt [3]. Posterior pelvic tilt is the opposite of posterior tilt, referring to the top of the pelvis being tilted too far backward as seen in Fig. 2.4. This causes flattening or even curving of the lower back [10].

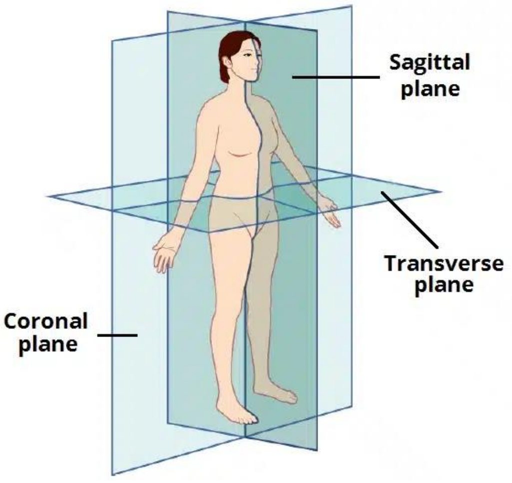


Fig. 2.1. *Anatomical planes of the human body.* [11]

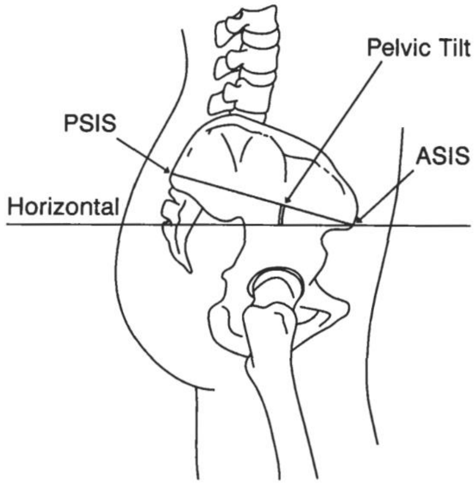


Fig. 2.2. *ASIS, PSIS and Pelvic tilt angle.* [12]

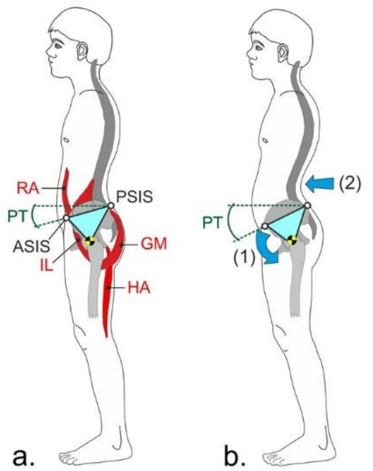


Fig. 2.3. *(b) increased anterior pelvic tilt (PT), causing increased lumbar lordosis (2).* [13]

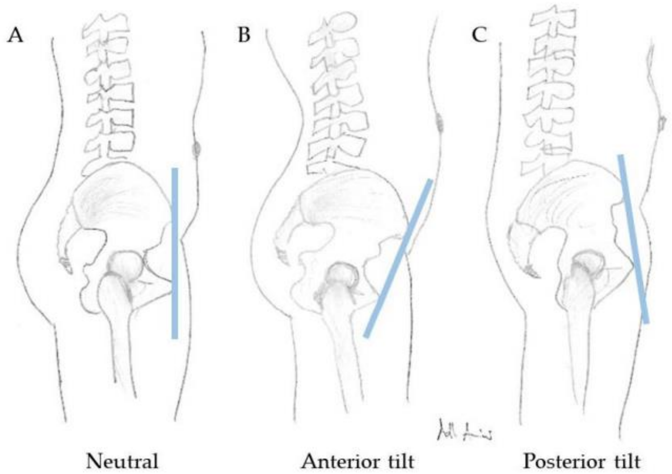


Fig. 2.4. *(A) Neutral pelvic alignment, (B) Anterior pelvic tilt, (C) Posterior pelvic tilt.* [14]

Several muscles are engaged when actively tilting the pelvis. The muscles that seem to be responsible for anterior tilting are the bilateral lumbar multifidus (MF, as seen in Fig. 2.5) and erector spinae (ES, seen in Fig. 2.6) [9]. The transversus abdominis (TrA, seen in Fig. 2.7) combined with the bilateral MF seems to be responsible for posterior tilting [9]. The MF is the largest of the deep back muscles and acts as an important stabiliser of the lumbar spine [15]. Together with the TrA and pelvic floor muscles it facilitates spinal stability [16]. The TrA, the deepest of the abdominal muscles, is one of the key muscles supporting the lumbopelvic (lower spine and pelvis) region [17]. The ES is a deep muscle of the back and serves to rotate the back to either side and straightening it [18]. The MF, TrA and ES are part of the more widely known category of core muscles [19]. Apart from actively tilting the pelvis, these are also the muscles responsible for maintaining (neutral) pelvic alignment [19].

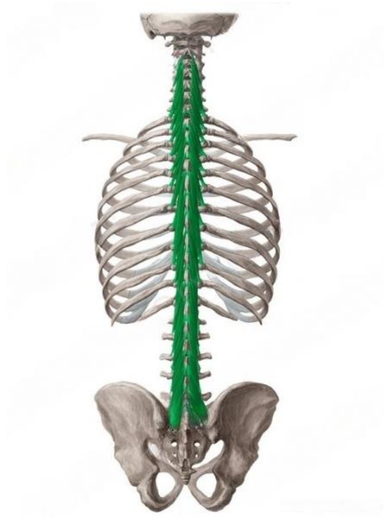


Fig. 2.5. *Bilateral lumbar multifidus.* [20]

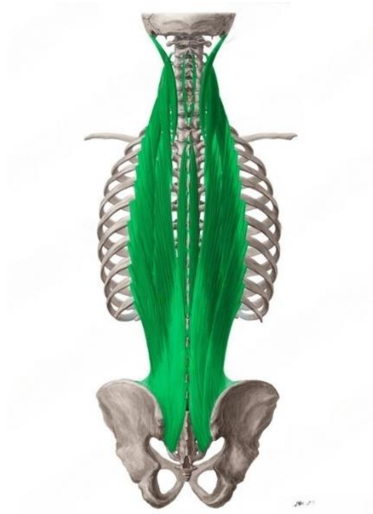


Fig. 2.6. *Erector spinae.* [21]

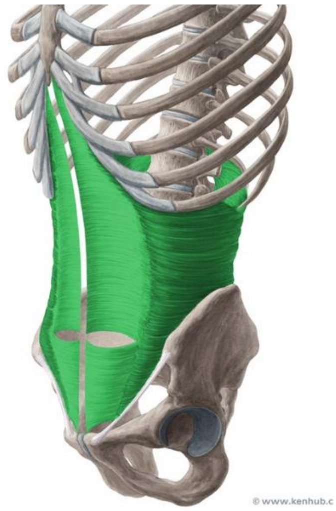


Fig. 2.7. *Transversus abdominis.* [22]

Continuous states of either anterior or posterior tilt (in individuals without structural anomalies) can negatively affect musculoskeletal health. Effects of anterior pelvic tilt seem to be studied most frequently, presumably due to the fact that it is the more commonly occurring form of pelvic tilt. Mendiguchia et al. [2] discovered that anterior pelvic tilt could be linked to hamstring strain injuries. This claim is supported by Alizadeh [23]. Additionally, pelvic tilt is considered to be an important factor in lower back pain [6]. Anterior pelvic tilt causes increased lumbar lordosis [12], which is thought to be a major cause of lower back pain [24], [25]. Therefore, pelvic tilt is also likely to indirectly cause lower back pain. Further complaints associated with anterior pelvic tilt are sacroiliac joint pain, pelvic girdle pain [26] and hip pain [27]. The hip rotation range also seems to be decreased by pelvic tilt [6]. It has been documented that pelvic tilt can result in musculoskeletal imbalances that include weakening in the abdominal and pelvic muscles [7]. Since these muscles groups are involved in tilting the pelvis, this could presumably either be causing the pelvic tilt or be an effect of prolonged inactivity of the muscles due to the pelvic tilt. While these seem to be the most well-known issues related to pelvic tilt, there may be even more conditions indirectly caused by (or related to) pelvic tilt and its associated issues.

2.1.2 Pelvic alignment in dance

Within dance, pelvic alignment seems to be most important for technical execution of movement, depending on dance style. In classical ballet this is stressed to great extent. Ballet training focuses greatly on perfecting the overall alignment of posture. Ballet dancers should aim to maintain a neutral pelvis [28]. One of the exceptions to this rule is in the case of lifting the leg in the back, in which case it is inevitable that the pelvis changes orientation to make room for the leg [28]. A well aligned posture is mainly important to maintain balance and centre of gravity in turns. Efficient alignment may also allow for overall movement to be more efficient and facilitate efficient movement in the hip and lumbar spine [1]. A lack of proper posture (and therefore pelvis) alignment may lead to compensatory movements and excess muscle tension, causing spinal stress and knee, foot and ankle injuries [1].

There is a lack of scientific literature on the desired pelvic alignment across other dance styles, but some conclusions can be drawn from observing dance performance. Jazz (lyrical) and modern dance styles rely on technical movements derived from those in classical ballet [29], adding more jumps and dynamic movement. For this reason, neutral pelvic alignment is also desired in these styles. An element present in both jazz dance, as well as modern or contemporary dance, is “contraction” [30]. This movement is initiated by tilting the pelvis posteriorly and contracting the core muscles (pulling the navel inward), letting the shoulders and head somewhat follow, to create a concave shape through the spine. This is a clear element where the movement alignment of the pelvis is more dynamic than what can be seen in classical ballet. Contemporary dance in general, as it seems to be a more free and less rigidly defined style, implements more elements of dynamic pelvis movement [31], [32]. Examples are isolations, rotations and forward and backwards tilting of the pelvis as standalone movements or initiations of other movements [31], [32]. While the movement is freer, dancers still seem to maintain control and engagement of the muscles [31], [32].

In urban styles (e.g. hip-hop, locking, popping, breakdance) the alignment of the pelvis seems to be more relaxed and grounded, emphasising rhythm and isolated pelvis movements [33]. It seems that dancers use the pelvis more intuitively, also using it in conveying style, rather than it being rigidly defined [33]. Tilting the pelvis is also intentionally used as part of “groove” [34]. Another style in the urban category is commercial or feminine dance (based on street dance) [35], [36]. This style seems emphasise feminine movements of the hips, resulting in very fluid motion and tilting of the pelvis [35], [36].

Muyor et al. [37] found that the dance movements involved in Latin style dancing involve tilting the pelvis, showing anterior pelvic tilt and lumbar lordosis in dancers’ dancing postures. This did not affect the dancer’s regular standing postures outside of dance [37]. From observation, it is evident that the movement of the pelvis indeed frequently involves tilting the pelvis anteriorly, aside from overall dynamic movement of the pelvis.

Studies on the injuries in dancers across styles related to pelvic tilt in dancers are limited. A study by Janura et al. [38] shows that ballet dancers overall have better postural alignment than non-dancers. However, Deckert et al. [1] state that many ballet dancers still struggle with anterior pelvic tilt. This also does not provide any further insight into the types of injuries that could be caused by pelvic tilt in dancers specifically, across different dance styles. While it seems reasonable to assume that the same ailments as those previously discussed are also present in dancers, it would be helpful to further study the dancer-specific problems related to pelvic tilt across a variety of styles.

2.1.3 Measuring pelvic alignment

When assessing pelvic alignment, three measures seem to be frequently used. The first, most commonly utilised in the presented literature, is pelvic tilt angle. The healthy range of pelvic tilt angle is between 0 and 23 degrees [39], [40]. Values above 23 are considered to be anterior tilt and neutral tilt angles vary per person [1], [40]. Improvement of pelvic alignment seems to be determined through an observed decrease in tilt angle. Pelvic tilt is most commonly measured by utilising reflective markers attached to the subject's body (usually to the ASIS and PSIS (Ch. 2.1.1) as seen in Fig. 2.8) and capturing this via visual recordings. Drawing a line through the ASIS and PSIS and determining its angle can give an estimation of pelvic tilt. Deckert et al. [41] applied this method, taking videos of movement and extracting still images at pre-determined points in the movement sequence. The images were analysed using software and the mean tilt of the movement sequence was calculated. Holt et al. [40] based their approach on this and took measurements in the same way. In contrast, Kaushika et al. [39] took non-dynamic measurement and instead took photographs of still-standing individuals. A similar approach to measuring pelvic tilt is implemented by Huang et al. [42], using radiographs instead of photographs. various pelvic alignment parameters were measured, and the relative positions of visual markers were compared through software. Mendiguchia et al. [5] used a completely different approach, utilising a wireless inertial sensor device to measure pelvic tilt kinematically by sensing the angle of the wearer during movement, rather than observing it visually.

Fig. 2.8. *Placement of reflective marker (white dots) on ASIS and PSIS.* [41]

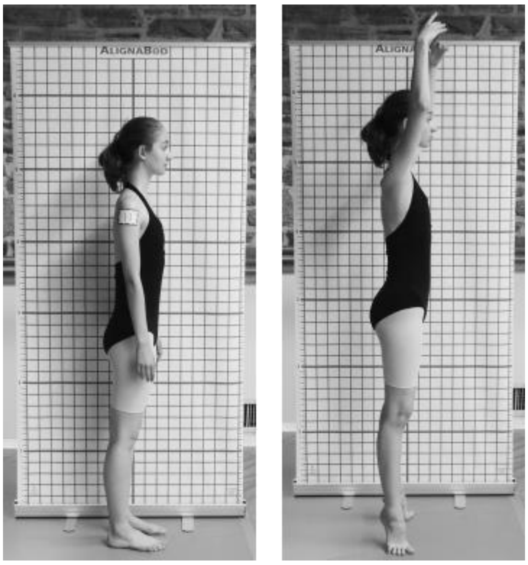


Fig. 9. *AlignaBod method grid.* [43]

The second measure is lumbo-pelvic alignment. This measure takes more than only the pelvic tilt angle into account and includes the alignment of the spine. The AlignaBod posture assessment method used by Ahearn et al. [43] measures postural misalignments by taking a side-view of the subject in front of the AlignaBod grid screen (seen in Fig. 2.9) and drawing a plumb line of the spine. Postural misalignments are studied via assessment of this line. Similar to the method to measure pelvic tilt described earlier, Abraham et al. [44] used reflective markers attached to the dancers' body to measure lumbo-pelvic alignment. Markers were attached to various anatomical landmarks and the dancer was recorded by two different video cameras. The relative locations of the markers were used to determine alignment using software. Gamboian et al. [45] use a similar, but instead placed a slightly smaller number of markers and used only a single camera. Pelvic tilt and lumbar lordosis angle were analysed specifically to measure lumbo-pelvic alignment.

Lumbo-pelvic stability is the third measure used to assess pelvic alignment. In this case the ability to maintain alignment rather than the alignment itself is assessed. Shah and Kubal [46] applied various physical tests, e.g. a single leg squat, with an observer rating the quality of the participant's alignment stability. A similar lumbo-pelvic stability test is used in Holt et al.'s [40] assessment approach. In the techniques mentioned by Smith [47], alignment is also analysed through observation of exercises that test the strength and control of the related muscle groups. However, rather than determining execution quality, the ability to perform the exercise is assessed. Mendiguchia et al. [5] combined the pelvic tilt measurements mentioned earlier with tests measuring trunk endurance, in order to determine stability as a secondary outcome. An overview of the techniques introduced in this section is provided in Appendix A.

2.1.4 Pelvic alignment training approaches

Training approaches

There appear to be three categories that Pelvic alignment training approaches can be divided into: solely exercise-based approaches, multimodal approaches and experimental approaches; within the category of multimodal approaches there seems to be a clear sub-category of Pilates based approaches. Approaches relying on exercise alone seem to focus solely on strengthening exercises as a method to improve pelvic alignment. Shah and Kubal [46] studied guided training programs involving core strengthening exercises and general trunk exercises. The core strengthening exercises focused on stability and activation of muscles while the trunk strengthening exercises focused on strengthening of the abdominal muscles in general. Smith [47] mentions a variety of similar techniques focusing on stability and muscle activation, elaborating on more personalised and supervised lumbar control exercises. While Shah and Kubal [46] targeted a more general audience, Smith [47] discussed these methods specifically in relation to dancers.

The majority of the training approaches studied fall into the category of multimodal approaches, frequently combining strengthening exercises with other methods. Kaushika et al. [39] discuss the effects of gluteus maximus activation exercises compared to spinal stabilisation exercises, where the exercises are combined with interferential therapy (IFT). The intervention introduced by Mendiguchia et al. [5] also combined a set of exercises with other forms of physical therapy. Aside from exercises focusing on both gluteus maximus activation and spinal stability (lumbopelvic control) similar to those examined by Kaushika et al. [39], hamstring and mobility exercises were included into the training regimen. In this approach participants received manual therapy and massages instead of IFT.

A considerable number of the reviewed multimodal approaches involved Pilates sessions as part of their training interventions. Two of which included some form of informational instruction to their approaches. The Pilates method is a 'holistic exercise system developed to elongate, strengthen and restore the body to balance' [48]. Deckert et al. [41] implemented elements of the Pilates method in constructing an individualised tutoring intervention for university ballet dancers. Dancers would take part in this intervention next to their regular technique classes. This intervention included informational sessions on pelvic alignment and anatomy, supplementing training-based sessions focusing on posture awareness while performing ballet, Pilates and relaxation exercises. In the approach for dancers discussed by Ahearn et al. [43], a pelvic alignment workshop including information about Pilates and anatomy preceded coached Pilates classes on both the mat and Pilates apparatus. Similarly, Huang et al. [42] studied a training program in non-dancers consisting of individually coached Pilates exercises among which were pre-Pilates breathing exercises and pelvic tilt centering exercises. Deep abdominal and pelvic floor muscle activations were also included.

The final category of more experimental training approaches includes interventions applying imagery, somatic training and innovative feedback methods within the context of pelvic alignment training in dance. These techniques all seem to be rooted in connection between mental awareness and posture. The Dynamic Neuro-Cognitive Imagery (DNI) technique applied by Abraham et al. [44] is a 'codified, structured, imagery-based approach for movement and postural retraining, focusing on enhancing motor (e.g., range-of-motion, posture, and breathing) and nonmotor (e.g., concentration, goal-setting, self-confidence) aspects of performance, and promoting optimal, safe dance practices.' [44, p. 3]. This approach focuses on understanding and embodiment of correct pelvic alignment, combining imagination exercises and connected physical exercises. Gamboian et al. [45] focused on similar aspects of body awareness and movement education, also addressing concepts of imagery in the somatic training intervention investigated. Exercises combined the physical and mental aspects rather than addressing them separately. While the approaches investigated by Abraham et al. [44] and Gamboian et al. [45] focus on a comparable wide range of aspects, the method involving innovative feedback studied by Holt et al. [40] only addresses the aspect of directing attention towards the body. This method deploys a remotely activated vibrating pager, worn on the dancer's body. An observer watches the dancer and activates the pager if the dancer visibly tilts their pelvis away from the neutral position, giving them physical feedback to correct their pelvic alignment. A summary of the methods discussed in this section can be viewed in Appendix A.

Efficiency and shortcomings

Shortcomings in the discussed training approaches mainly involve the need of additional resources and variations in study approaches. A disadvantage shared by all training methods is the need for supervision and specialised guidance. Specifically in Holt et al.'s [40] remote queueing technique, an observer is needed to operate the intervention at all times. Some methods, such as the Pilates based method examined by Ahearn et al. [43], require additional materials or facilities. The need for such additional resources could form a restriction in making these methods accessible to a wide audience. Additionally, some of the programs require a rather intensive number of sessions, which could be difficult to schedule for dancers.

It is difficult to draw conclusions on the efficiency of the different types of training approaches, as both positive and somewhat ambiguous outcomes have been observed in relation to the different measures (lumbo-pelvic alignment in particular) and categories of training approaches. This is likely related to the variation in study approaches. Each study combined methods and types of exercises differently in varying contexts, measured outcomes differently and had greatly varying sample sizes. In multimodal approaches it is also exceedingly complicated to determine which of the combined methods are responsible for the study outcomes.

2.1.5 Dance Imagery

Imagery in dance

Dance instructors and dancers alike of all ages and levels utilise mental visualisation examples in their teaching, execution and performance of dance movement [49], [50]. This is known as imagery. Imagery in dance can be defined as “a consciously created mental representation of an experience, either real or imaginary, that may affect the dancer and her or his movement” [50].

Imagery techniques have a broad array of applications within dance. One way it is often used, is as a tool in teaching. Here it may be applied to improve the quality of certain movements, point out important aspects of steps, express thoughts and feelings that should be felt or expressed alongside movement, or describe how a step should be executed [50], [51]. An example of this could be a ballet teacher telling their students to imagine rubbing gum, that is stuck underneath one’s shoe, on the street when brushing their feet through first position in tendu.[1] Various studies have shown that this use imagery can help students and dancers improve the execution of dance movement [50]. Choreographers describe using imagery for inspiration or to solve problems that may arise in pieces [51], [52], [53]. May et al. [53], in their study describing the creative process of a choreographer and his company, discovered a multitude of uses for imagery. They found dancers used it to enhance their movement quality (e.g. strong emotional imagery for more dramatic effect, anatomical images for improved technical execution [50]), navigate the space they were moving in and to help them ordering and remembering dance sequences [53]. This is supported by various other studies showing that imagery can help dancers remember and understand movement both mentally and physically through muscle memory [50]. Dancers also seem to use imagery as technique to mentally calm or motivate themselves in stressful situations [52], [51]. This is supported by research suggesting that imagery can positively influence self-confidence during training and competition [54].

Apart from its use in dance, imagery has been widely applied to enhance motor function in both rehabilitation and various sports [55]. However, compared to athletes, dancers seem to

[1] Another example of imagery in the context of pelvic alignment is mentioned in Ch. 2.2.2.

use imagery more frequently than other athletes [49]. Dance instructors also report using more imagery than other sports coaches [56] with a focus on improving their students' technique and creativity [50]. In the medical field, practitioners often use imagery to shape movement [50]. Several somatic techniques have been developed based on imagery. An example of such a somatic technique is Ideokinesiology. Ideokinesiology, also known as ideokinetic imagery, is 'a postural development technique that involves using movement images to gain subcortical control over the spinal musculature' [57, p. 385]. Fairweather and Sidaway [57] studied the effects of a program combining flexibility and abdominal exercises with an ideokinetic imagery program on lower back pain and postural alignment. Outcomes of these experiments suggest that ideokinetic imagery may positively influence the spinal column and lower back pain in males, as well as improving spinal angles in both males and females.

Effects of imagery on dance technique

Effects of imagery on specific dance technique have been studied to some degree. Studd [58] studied the influence of ideokinetic imagery on single dance skills and complex dance combinations. Results indicated that ideokinetic imagery was more effective in improving basic dance skills than relaxation methods.

Another study by Couillandre et al. [59] investigated the effects of kinesiological explanations and mental imagery on performance of demi-plié (Fig. 2.10) and a first position jump (jumping from the same position) in ballet dancers. The approach relied on explanations of the anatomy of the foot and how weight distribution of the body influences and stresses different areas of the bones. Following this, dancers were given two mental images via verbal explanation. The first (for plié) was that of 'an arrow passing from above the knee, in front of the knee cap, down and out through the back of the heel and continuing down and back for another few meters' [59, p. 94] and then the two arrows 'crossing each other far below and in directions opposite to the dancer's feet' [59, p. 94]. The other image (for the jump) was that of 'the heels being like the prow of a ship, leaving the dock; they slowly initiate the movement, followed by the rest of the foot and the legs' [59, p. 94]. Various parameters of plie and jumping were assessed and muscle activity in four muscles of the legs was measured via electromyographical (EMG) measurements. Results showed that the technical aspects such as knee flexion and jump height stayed consistent. However, the EMG measurements showed increased hamstring activity in both plié and jump, implying decreased disruption of dynamic alignment.

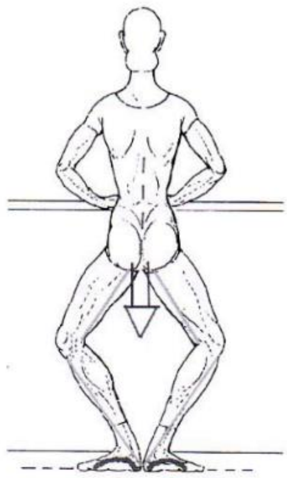


Fig. 2.10. *Demi-plié illustration.* [59]

Another study, conducted by Abraham et al. [60], studied the influence of a motor imagery practice (MIP) intervention on performance of elevé in ballet dance students. Dancers participated in sessions consisting of visuo-kinaesthetic motor imagery with tasks focusing on specific ankle and foot movements involved in elevé. Tasks were first performed “visually” (shown images and examples visually), for example a visual representation of ‘both heels ascending and descending together while keeping the same distance from the floor’ [60, p. 6]. Following this, they were performed kinaesthetically (through feeling and executing movement), for example feeling ‘increased pressure under fore-feet when rising up’ [60, p. 6] or ‘the sensation of equal pressure underneath both feet’ [60, p. 6]. During assessment dancers were asked to perform a repeated elevé task, (repeating the step multiple times) and a static elevé task (maintaining the elevé position for a certain amount of time). Measurements of ankle plantar-flexion and range-of-motion were taken. The results showed that MIP may be beneficial in increasing ankle plantar-flexion and range of motion during the performance of repeated elevé. The authors also concluded that MIP could serve as additional training method for dancers alongside regular training.

Applying imagery

When considering applications of dance imagery, several factors should be considered. The first factor is the type of imagery. Nordin and Cumming [61] categorise dance imagery (in line with the applications previously discussed) into four categories. The first category is “technique imagery” containing imagery involving mental rehearsal of movement or choreography. The second category, “mastery imagery”, relates to mental fortitude, focus and planning tasks. The third category of “goal imagery” encapsulates imagery that targets working towards specific goals related to dance. The fourth category is “role and movement quality imagery”. This category includes acting and metaphorical related, or more indirect emotional imagery. Alternatively, Hanrahan and Vergeer [52] specify eight categories that largely fit into the previously introduced categories but focus more on the specific sensations experienced during imagery. Examples of this are “emptying out” and “filling up” imagery, describing images of the body draining or filling up with undesired/desired substances or energy.

In accordance with this categorisation, dancers appear to not only see and hear mental imagery. Dancers frequently report also feeling (and possibly even smelling or tasting) parts of the imagery they use [51], [52]. Additionally, there also seem to be two perspectives to imagery: external (outside point of view) and internal (own point of view) [50]. These perspectives are applied in different ways by different dancers [50]. Even though dancers extensively “feel” imagery, evidence suggest that dancers may not always have a good sense for the influence the imagery has on their dancing [50]. It is therefore recommended that outside feedback is collected aside dancers’ feedback when studying the influence of mental imagery on dance.

When developing imagery, it is suggested that the benefits of (motor) imagery increase with its resemblance to reality [62]. For this purpose, Holmes and Collins [62] created the PETTLEP checklist for creating motor imagery, to aid in creating imagery that more accurately represents the real activity. Researchers also recommend that dance instructors prepare and organise their images before and during teaching [50].

2.1.6 Influence of sensory feedback on habit formation and learning

From the analysed literature, roughly six types of sensory feedback could be identified: auditory, visual, audiovisual, haptic, smell and taste. Visual feedback seems to be most commonly studied among the different feedback modalities mentioned. Often combinations of these different types of feedback were studied [63, 64, 65, 66, 67, 68] and approaches to applying feedback methods varied greatly. These combinations comprised of visual & haptic feedback, visual & auditory feedback, haptic & auditory feedback, or a multimodal approach applying a mix of feedback types together. The applications of the different feedback methods investigated could be categorised into three fields of learning. The first is focuses on knowledge, the second on motor learning and the third on other specific skills.

Knowledge learning

Within the category of knowledge-based learning, focus is mainly placed on comprehension of concepts, memory and knowledge retention. Feiereisen et al. [69] studied the impact of learning strategies (analogical learning vs. mental simulation) and presentation formats (words vs pictures) on product comprehension of Really new products (RNPs). Results suggested that the use of pictures may be effective at conveying information for products of a more indulgent nature rather than more utilitarian products.

Walsh and Magana [68] also investigated the influence of sensory feedback on concept comprehension, studying the effects of visual (enhanced, i.e. elaborated, and non-enhanced), haptic and visuohaptic feedback (visual and haptic feedback combined) on learning about friction. Participants were asked to manipulate a device in the physical environment in order to move a cube in a virtual environment, as seen in Fig. 2.11. The device provided haptic feedback to the participant and the virtual environment provided the visual aspect. Results suggest that both visual and haptic feedback have a positive influence on comprehension of friction. Even more positive effects were achieved through visuohaptic feedback, although the visual aspect may overpower the haptic aspect in this.

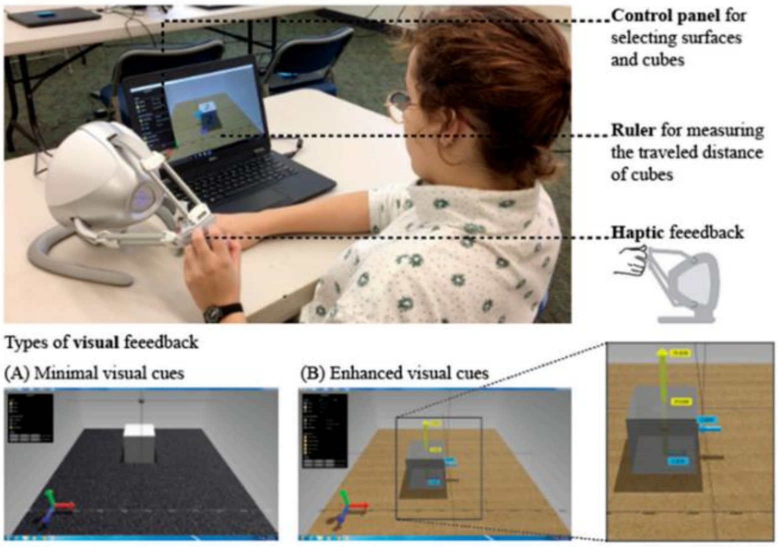


Fig. 2.11. *visuohaptic simulation setup.* [68]

Klašnja-milićević et al. [64] focused on studying the influence of different sensory inputs (scent, taste and audiovisual) and combinations of them on memorisation tasks in an educational setting. Outcomes showed scent and combinations of scents and taste could improve performance of memorisation tasks at varying rates depending on the scents and tastes. The combination of citrus scent with chocolate and coffee appeared to be most promising, with 65,0% of participants performing better than those in the control groups. Audiovisual input administered via VR designed to study the solar system also showed a higher result with 71,67% of participants performing better. The highest results were achieved in the multisensory test combining audiovisual VR input with the previously mentioned combination of citrus, chocolate and coffee. In this test 79,1 % of participants performed better than those in the control groups. The influence of scent on perception and behaviour was investigated more by Herz [70], who suggests that there is further evidence supporting that learned associations between scents and experiences can influence perception and learning capabilities.

Motor learning

The main forms of feedback studied in the context of motor learning are verbal (auditory), visual and haptic methods as well as combinations of them. Meng et al. [65] studied different feedback strategies on learning of a rehabilitation tracking task (Fig. 2.12) and motivation by providing a combination of haptic resistance feedback and visual representations of the task. Specifically, the effects of error reduction and amplification (i.e. optimistic and pessimistic representations of performance) were investigated. Results suggest that in general all of the visuohaptic feedback increased participants motor learning abilities. Visual error reduction (reducing the error between the visual point and the actual point in movement, Fig. 2.13) and haptic error amplification (additional physical resistance at points of the movement, Fig. 2.14) specifically seemed to increase participants competence of the task and reduce unnecessary muscle activation. A similar investigation into rowing was performed by Sigrist et al. [67], studying the influence of sonification of movement combined with visual feedback, haptic resistance combined with visual feedback and visual feedback alone. All groups showed improvements in motor ability, with audiovisual feedback appearing to be more effective than visuohaptic and visual feedback.

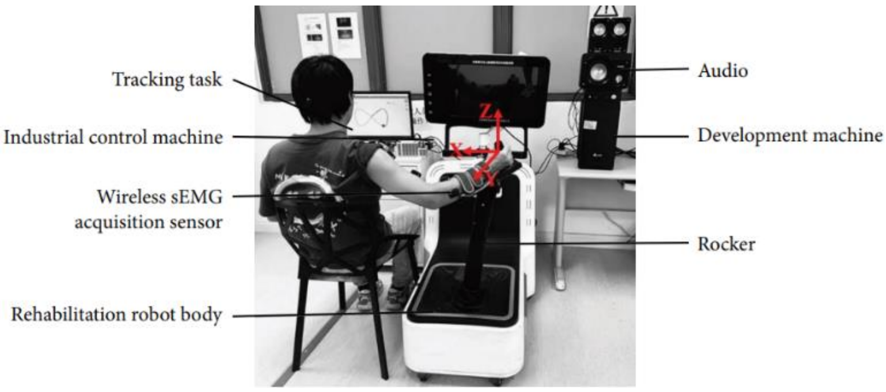


Fig. 2.12. *Tracking task setup.* [65]

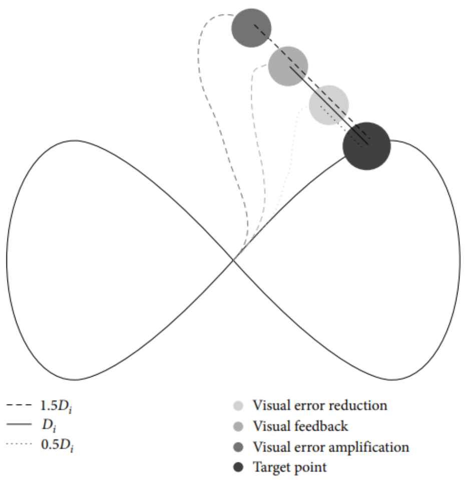


Fig. 2.13. *Visual error modulation. (D_i) differences between the actual point and the target point.* [65]

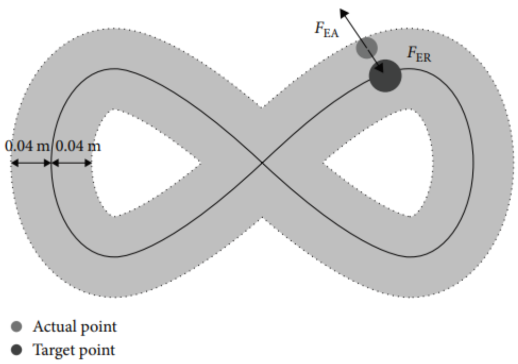


Fig. 2.14. *Haptic error modulation. (F_{ER}) Assisting force. (F_{EA}) Resisting force.* [65]

Zhou et al. [71] studied the effects of verbal and visual feedback, but instead looked at its effects on learning within physical education. The results indicated that the studied feedback intervention improved participants motor learning skills. However, results were not conclusive regarding the effects of visual versus verbal feedback. It also remained unclear what the effects of information feedback were in comparison to praise or corrective feedback. A type of informational feedback is augmented feedback, which provides information to athletes about their performance corresponding to the expected performance and execution [63]. Frikha et al. [63] studied the effects of different sensory modes of augmented feedback on motor learning acquisition, retention and execution competence while executing a gymnastic parallel bars task with more conclusive results. Outcomes suggested that verbal and touch-based haptic feedback improved learning acquisition and retention. However, combining verbal and haptic feedback seemed most effective, particularly in the retention phase. The studied feedback methods also seemed all to reduce perceived task difficulty during the acquisition phase, with combined feedback decreasing this significantly more in the retention phase. Execution competence also appeared to increase with verbal and haptic feedback methods during the acquisition and retention phases, again increasing most when combined verbal and haptic feedback was administered.

Learning other skills

Within the third category of other skills applications of feedback within music teaching and dance specifically were discovered. Pardue and McPherson [66] studied the effects of auditory and visual feedback, as well as combined audiovisual feedback on improving violin intonation. Using a violin with fingerboard sensors, a visual representation of the participant's pitch was created (Fig. 2.15), providing feedback on the desired pitch. The auditory feedback took the shape of a guide track with the correct pitch being played alongside the participant's playing. The results varied per participant but suggest that feedback methods may be beneficial to some participants. However, it was also suggested that the feedback interventions can be distracting (especially combined auditory and visual feedback) and that results may also depend on the time it takes to adapt to the feedback method.

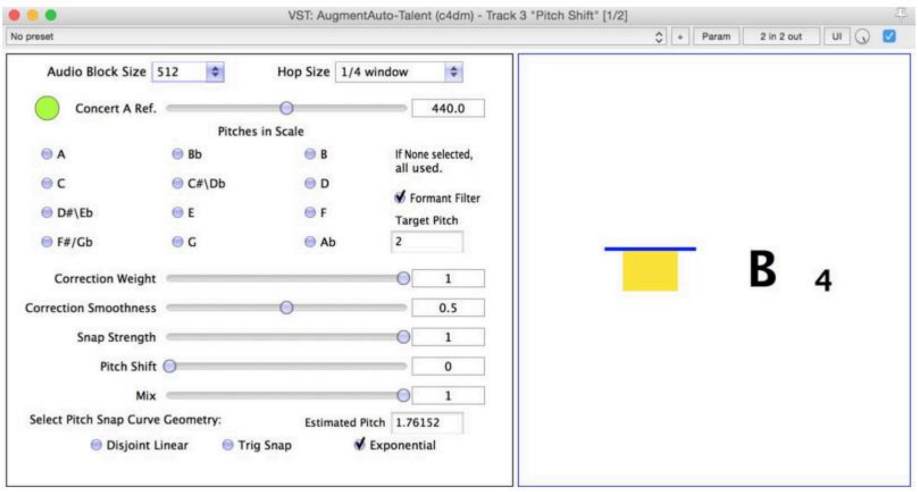


Fig. 2.15. *Visual feedback interface, with representation of played pitch (right).* [66]

As previously discussed, imagery is ubiquitous within dance. Imagery techniques can be transferred in various ways. Heiland et al. [72] investigated the effects of visual, auditory (verbal delivery) and kinaesthetic (haptic) delivery modes of mental imagery on dancers' execution of plié arabesque. The researchers found that different delivery modes have different benefits for different parts of the analysed movement. Both visual (Fig. 2.16) and haptic (Fig. 2.17) modes seemed to be effective for joint rotation, while only the visual mode seemed to produce improvements in plié execution. All three of the modes appeared to improve the tri-fold score of the movement, suggesting that this measure is most attuned to improvement via imagery. Visual delivery seems to be the most effective overall. Visual feedback may be linked in some way to imagery and its effects on motor learning, as visual representations lead to mental images. This is somewhat supported by Feiereisen et al. [69] who suggested that increased visual attention also improved product comprehension during mental simulation, where some form of mental representation is used to represent an event or series of events like often done within dance imagery.

Fig. 2.16. *Visual delivery mode, providing imagery through demonstration of a skeletal model.* [72]

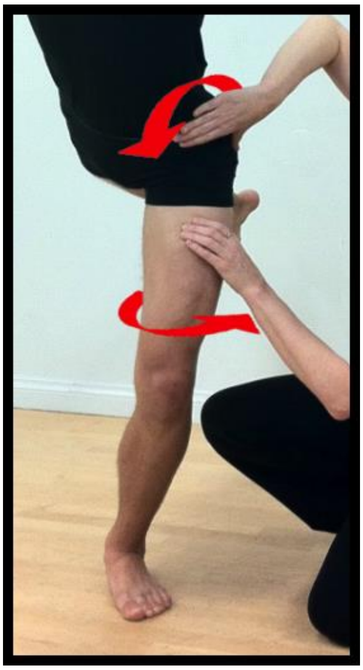


Fig. 2.17. *Haptic delivery mode, touching participant to provide tactile guidance as means of delivering imagery.* [72]

2.2 Expert opinions

As the concept of pelvic alignment touches upon multiple facets of dance, dance education and physical therapy, it is important to gain knowledge regarding the experiences and needs of medical experts and experiential experts within these fields. This will also help in further shaping the design space. In order to collect such insights, semi-structured interviews were conducted with two physiotherapists (one of which had experience treating dancers), a dance teacher with a broad teaching history and 4 dancers with varying dance backgrounds. The interview question guides that were used are listed in Appendix B.

2.2.1 Physiotherapy

Two physiotherapists were interviewed. Therapist 1 has a background in paediatric physiotherapy, hydrotherapy and is also specialised in scoliosis treatment. She also actively participated in dance classes herself and has been treating dancers for approximately two years. Therapist 2 specialises in psychosomatic physiotherapy and dance-physiotherapy. Dance-physiotherapy, known as “dansante fysiotherapie” in Dutch, focuses on using dance movement in treatment of movement problems. Therapist 2 had no experience treating dancers.

Injuries

Therapist 1 reported that the most common injuries she sees in dancers are injuries of the lower extremities such as ankle and problems. She also occasionally sees shin splints. As dancers land on their feet and carry their entire bodyweight with their legs, small changes in positioning of the feet can already significantly impact how the joints and muscles respond. As girls grow into adulthood their pelvis widens, which she mentions also changes one’s movement and can increase the risk for injuries during this period of change. Therapist 2 stated, based on her knowledge, that mostly stress injuries occur in dancers because dancers tend to push the limits of the body.

Healthy alignment

When asked to define what healthy pelvic alignment looks like, she elaborates that she often explains how to do this through pulling in the bellybutton, causing contraction of the transversus abdominis, which in turn causes the pelvis to tilt. She also states that proper posture varies per person. A person’s anatomy, genetics and motor ability all influence what a person’s proper posture looks like. Therapist 2 answered in line with this, but from her line of work she often defines correct alignment based on what the most relaxed alignment is for someone. This usually is somewhat neutral and facilitates smooth movement. She further explained that she focuses mostly on how clients move their pelvis and whether they lock this in place by clenching their muscles or are able to move freely. Therapist 1 defined the importance of alignment somewhat differently focusing more on stability. She stated: “If you want to move and don’t want to fall over you need a certain level of muscle tension”. She continued by explaining that specifically the core plays a big role in maintaining this stability and controlling one’s centre of gravity. Tilting the pelvis causes engagement of these core muscles and enables overall stability. She also questioned herself out loud whether she thinks that “neutral alignment” is necessarily the best way to describe this. Her conclusion was that finding a balance in muscle tension is most important.

In some cases, dancers notice lower back pain. Therapist 1 notes that this is often seen in people that struggle to engage their core, or as she often referred to it, their “muscle corset”. This corset stabilises the spine and pelvis. Lacking control and tension in this area, she explains, causes the vertebrae to move and shift too far causing pain. This can be observed especially in styles such as commercial that require extreme movements of the back and hips. The pelvis does then not necessarily need to be neutral, but the muscles should still be engaged to control the movement within healthy bounds. Problems usually arise during fast movements. She further explains that by dancing alone a dancer already automatically engages a lot of their muscles, but as dancers often try to push boundaries movement can at times be pushed too far. This also depends further on dance style. In Afro there is also a lot of extreme movement, but this is usually more controlled so problems that arise much differently here. She suggests that consciousness and awareness can already go quite far in avoiding such problems. She also states that these lower back problems caused by lack of control are usually also the result of previously existing core weakness. These weaknesses are simply emphasised by the extreme dance movements causing pain.

Recognition and treatment

Regarding this balance of body tension, therapist 1 noted that due to her experience she can often easily identify whether a client is activating the muscle corset. She explains that a reason for ballet students wearing tight fitting leotards is for teachers to be able to see whether a student is activating their core. When treating clients for such instabilities, she focuses mainly on core stabilisation exercises. This usually starts with explanation and feeling exercises lying down on the floor to learn how to control the movement. She adapts these explanations based on the clients age and experiences. She states that “if you don’t know how to perform an exercise, you don’t know if you’re doing it right”. Explaining to people how to identify this and move correctly is an essential part of treatment and increasing body awareness. She noticed that dancers usually already show much better body awareness to begin with. When asked about adult dancers, she answered that adult beginners often find it more difficult to adjust to such postures and motion control and take longer to grasp concepts in their dance classes than younger dancers. This of course also depends on the person.

Therapist 2 mainly tries to identify how a person moves in order to identify whether they are locking up their pelvis. A concrete example she mentions is that of an overweight person, that through shame or for other reasons sucks in their stomach, causing their pelvis to lock up. Finding the right relaxed posture in cases like this often immediately visibly improves their movement smoothness. Other causes she observed that caused people lock up are stress, pain general bad posture or even uncomfortable clothing. She treats people by helping them become more conscious of how they are standing and how movement feels. This can be targeted through awareness or experience-based exercises, which can often be as simple as simply tensing everything and then relaxing everything again. For some people awareness alone can be enough to improve their pelvic alignment, but this completely depends on the person.

Improving stability and overall awareness

Both therapists note that the general population is not at all aware of their pelvis and posture. As mentioned by therapist 2: “people are usually stuck in their minds, and as soon as that attention is directed downwards towards the body improvements can be seen”. Therapist 1 noticed that dancers are often much more in control and usually more aware. However, this does not guarantee that they are aware of their postures outside of dance either and she frequently notices dancers forget about this completely as soon as they leave the dance studio. She expressed that everyone has different needs, but that generally anyone could benefit from core stability exercises. Therapist 2 recommends breathing exercises and feeling exercises as good practices for anyone.

When asked about their recommendations for teaching about pelvic alignment, both gave different answers. Therapist 1 recommended to mainly focus on the pelvic floor and core. In her opinion, any form of attention towards this topic is already helpful, even if done unconsciously. Integrating core stability and awareness exercises into warm-up would also be helpful. She noted that this is often already applied in ballet and contemporary classes, but sees room for improvement in the fields of commercial and heels. She then made the suggestion that some form of feedback mechanism may have potential for filling this gap. She also mentioned that electromyography (EMG) measurements are frequently used in pelvic physiotherapy and speculates that it might be interesting to apply this to dance in some way. Therapist 2 thought that the most important part in teaching about pelvic alignment would be to explain it in a way that it can be felt by the student. She emphasised the importance of tailoring explanations in way that is relatable to the student, as misunderstandings and unclarity usually only cause more tension.

Both therapists were asked about any techniques that may help with multitasking during dance while trying to focus on awareness of the pelvis. Therapist 1 answered that it is essential to focus on training foundations and basic technique and practicing this to an extent that it becomes automatic. Mental space is then freed to work on other aspects. Therapist 2 supplied a somewhat different approach, focusing on slowing down and pausing if things become overwhelming. She states: “Sometimes focusing on yourself and your process is more important than what the rest of the class is doing”. She recommends directing attention towards what is felt and being done to deal with situations of task overwhelm.

2.2.2 Dance education

The dance teacher that was interviewed has a background as a professional dancer before becoming a teacher. She had a background in gymnastics and physical education, before obtaining an MBO show dance degree. She danced in various dance companies and did commercial work, before deciding to go into teaching. She taught at various higher dance education and preparatory dance education institutions such as Lucia Marthas Institute for Performing arts and an MBO degree in Rozendaal, among various other teaching projects. From her background in physical education, she also had a lot of previous experience in teaching other sport to a wide range of people. She has mainly focused her dance teaching on teenagers and young adults at advanced or (pre)professional level. In terms of dance styles, she has mainly taught contemporary, jumps and turns, ballet and commercial.

When asked about her experience with injured students she answered that she mostly saw students with growing pains, general knee injuries, groin injuries, shin splints and stress injuries. She did not often witness serious long-term injuries and voiced that this is likely due to the fact that the type of dancers she teaches are often already very experienced and know how to treat their bodies in comparison to amateur dancers. She stated personally she is of the opinion that in recent years the notion that dance training should be enjoyable has taken the upper hand too much. She explained that this doesn't mean that dancing shouldn't be fun, but that less fun elements strength training and practicing certain techniques are very important for avoiding injuries. She supported this by mentioning a time where she taught body conditioning classes at a dance institution. In the period of these classes being taught, none of the students reported having injuries. She also stated that she regrets seeing this type of conditioning disappear from many dance curriculums. While she thinks dancers take care of their bodies and train, many dance institutions now put this responsibility on the shoulders of dancers. Many of these dancers are not yet mature enough to realise what the importance of this aspect is.

Regarding the topic of anatomy, she reported having had lessons on basic anatomy in her education. She shared that pelvic alignment is important because otherwise it is not possible to engage one's core. Even if the lower half of the body is aligned properly, if the pelvis is misaligned the centre of gravity is disturbed. She often notices dancer then try to compensate by leaning their upper body backward or forward. She explained that she often uses imagery of the tailbone being the tip of a compass. If the tip is pointing backwards the back is hollow, if it is pointing down it is neutrally aligned and if it is pointing forwards you are contracting. Anatomically this is significantly more difficult for some people in comparison to others, she mentioned. Dancers will than need to work very hard in order to achieve the desired centre of gravity.

When questioned about the ways in which she addresses pelvic alignment in her classes that she addresses it somewhat differently per style. In ballet she puts a lot of attention on the topic of pelvic alignment, starting with floor barre exercises. This is especially important when teaching younger dancers. She was of the opinion that pelvic alignment is her most commonly addressed feedback point that she addresses in her lessons. Especially in contemporary because the element of contraction comes into play here. In terms of limitations, she noticed that for some people it seems to be a concept that is very difficult to understand. She stated trying her best to explain what the desired posture is and how to achieve this, but in the end the dancer has to figure out how to apply this to their own body by themselves. She believes that positive reinforcement in particular helps in achieving this. Another limitation she encountered was a lack of attention towards the topic in other classes. She noticed that dancers whose other classes did not address pelvic alignment took significantly longer in adapting to proper pelvic alignment. She also recalls having students tell her that they had never heard about pelvic alignment before she addressed this in her teaching. While she believes that likely the topic had been addressed, students often did not seem to actively recall this. She thought that this may be due to the fact that pelvic alignment is not perceived to be as important as it is.

Another interesting point that she addressed was that she had in the past always struggled with anterior tilt, causing her to receive a lot of feedback about this and actively working on improving this. She suggested that dancers who might naturally have more neutral alignment might never be corrected about this topic and therefore never really learn about the importance of pelvic alignment and core engagement. While compensation of the upper body may allow dancers to still achieve the movement, at some point in time the dancer reach their limit and will be confronted with their lack of pelvic alignment. Overall, she thinks that not enough attention is placed on pelvic alignment. She stated that a general lack of awareness is especially present in children's classes. This teacher specifically felt that she had enough knowledge to adequately teach dancers about pelvic alignment. However, she thought that extra knowledge may enable her to help students with anatomical difficulties even better.

When asked what the most challenging part of pelvic alignment training is she answered "awareness". If someone is not used to tilting their pelvis, aligning it properly will feel strange and it will require constant attention to work towards full awareness and automatic alignment. She also stated that students' mindsets greatly influence their ability to improve. Mindset is often influenced by age and maturity of dancers, as well as their motivation. Young dancers are also often confused by mixed messages about pelvic alignment being delivered across styles. When introducing pelvic alignment training to dancers that have not yet addressed this topic before, she also stated thinking that some dancers might feel like everything they have been doing is wrong and become demotivated by it. To close of the interview, she mentioned being completely open toward trying out new online and in person teaching tools and methods.

2.2.3 Dancers

Four dancers in pre-professional and professional dance education were interviewed. Each dancer had varying dance backgrounds and all of them aim to go into dance careers at the time of being interviewed. Dancer 1 (age 16, female) follows a preparatory professional dance curriculum aside from her regular secondary education classes. This curriculum mainly focuses on modern dance, ballet, character dance and improvisation. She started taking ballet classes at the age of 6 before deciding to take dance more seriously and enrolling in the pre-professional dance program at age 11. In recent years she also joined a recreational dance studio, taking classes in Hip Hop, K-pop, urban contemporary, locking and competitive dance team training. Dancer 2 (age 20, female) is in her first year of a full-time MBO all-round dance course. She started dancing at age 9, taking street dance classes, which later turned into modern dance classes. At age 18 she enrolled at a different dance studio, where she started taking commercial, Hip Hop, K-Pop and locking classes as well as competitive dance team training. This prompted her to audition for professional dance education where she currently takes Hip Hop, commercial, freestyle, ballet, modern and jazz classes. Dancers 3 (age 18, male) and 4 (age 20, male) are both in the final stages of the Dutch National Ballet Academy which focuses on classical ballet and modern dance. Dancer 3 started dancing at age 4 and enrolled in serious ballet training from age 6. Dancer 4 started taking street dance classes at age 7 and not much later enrolled in more serious classical ballet training. Both dancers 3 and 4 showed particular drive for classical ballet and working hard.

Health and education

All of the interviewed dancers reported having had some form of pain or injuries at some point in their dance journeys. These injuries included (lower) back, shin, knee, foot, wrist and hip problems. Dancer 3 and 4 who are enrolled in professional ballet stated that they both never struggled significantly with any long-term injuries and that these injuries mostly arise from the heavy toll of their education on their bodies. Dancer 3 reported more problems than dancer 4 due to anatomical misalignments such as a slight scoliosis and tight hips. Dancer 1 also had problems with tight hip. All dancers sought help for their injuries with physiotherapists, but dancer 1 mentioned having a tendency to wait too long to seek help and still has pain complaints she needs to get examined. Dancer 2 mentioned having to cut her treatment short at times due to restrictions in her insurance and treatment not being effective enough in her opinion. The Dutch National Ballet Academy and preparatory dance curriculum both have partnered physiotherapists available to treat and advise dancers. Three of the dancers had specific recurring feedback points regarding their posture. Dancer 2 frequently receives feedback on activation of her core or "closing her ribs", dancer 3 has had problems with tilting his pelvis posteriorly in certain movements and dancer 4 frequently received feedback to "open his collarbone" rather than slouching his shoulders forward. Dancer 1 mainly received feedback on needing to increase flexibility, but also mentioned that her program does not give enough feedback in her opinion in general.

Out of all dancers only dancer 3 reported having anatomy lessons as part of her curriculum. Dancers 3 and 4 mentioned that they took lessons on injury prevention and pain management, but these did not go into anatomy. When questioned about their knowledge regarding the importance of pelvic alignment all four dancers gave similar answers. The connection between engagement of the core muscles and pelvis was mentioned first. It was also mentioned that it is necessary to tilt your pelvis for the execution of dance movement and that the core and pelvis form the base that the rest of the body builds on. Dancer 4 specifically mentioned that he thought having pelvic alignment trained into the body from a young age could be particularly beneficial in one's future dance career.

Dancers were asked about the way in which they were educated about pelvic alignment. Dancers 3 and 4, who have classical ballet backgrounds, recalled being taught to tilt the pelvis from a young age and mentioned that this decreased as they progressed in their training. Specific examples they mentioned were teachers telling them to drop their pelvis straight down during grand plié and forward port de bras (ballet movements) or tilting it posteriorly during contraction in Graham technique. Dancer 4 also stated teachers used imagery of headlights being attached to the hipbones, that need to shine forward at all times. According to dancer 4, the Dutch National Ballet Academy has recently also added PBT (Progressing Ballet Technique) to the curriculum for younger dancers, which focuses on stability and strength. Dancers 1 and 2 both mentioned that they had likely been taught about it at some point when they were younger, but only consciously recalled having heard about the topic when a teacher specifically addressed this in classes in their teenage years. Dancer 1 reported that in her current training not much emphasis is put on pelvic alignment directly. She recalled having her ballet teacher telling her to engage her core but not specifically to be aware of her pelvis. She mentioned that a teacher in modern technique once dedicated a small of time towards awareness of the pelvis, how to stand and how to engage the right muscles. She found this very beneficial and mentioned still benefiting from this and that this has caused her to work more consciously with her pelvis in more challenging dance pieces. Dancer 2 takes classes on body placement and awareness in her dance course, which she stated had also addressed pelvic alignment and core engagement.

When asked about their opinions regarding their education on pelvic alignment and attention towards pelvic posture awareness, mixed opinions arose. Dancers 3 and 4, who previously already stated having received a lot of attention to the topic in their youths, were satisfied with their training and did not identify any need for improvement. Dancer 1 was more critical towards her education on the topic. She stated that the topic wasn't addressed enough for a course that aims to prepare dancers for professional dance education in her opinion. The thought that learning about one's body is an important part of dance and would like to learn more about the functioning of the body. She suggested this includes more theoretical and anatomical explanations to increase body awareness. She stressed that she found the aspect of awareness to be particularly important, as the small teaching moment about pelvic alignment described earlier has helped her a lot. Dancer 2 Reported remembering things easily and so therefore she was content with the knowledge she received until that point. However, she mentioned that for those who do struggle with pelvic alignment it would have been necessary to receive more attention towards the topic. In her opinion this is also something that dancers need to take responsibility for themselves if they encounter problems. She also noted that teachers in her course frequently told students to tilt their pelvis, but do not necessarily elaborate why this is important.

Alignment awareness and needs

Some questions were asked to gauge dancers' personal level of pelvic awareness and their needs in this area. Outside of dance they seemed to not really be aware of their pelvic alignment specifically. Dancer 1 was relatively satisfied with her overall alignment and only sometimes thought about standing upright. Dancer 4 was frequently complemented about his upright posture and mentioned that this has likely become a habit for him due to his extensive ballet training. Dancer 3 answered in line with dancer 4. Dancer 2 mentioned having some misconceptions about healthy posture at first and thought that tilting her pelvis anteriorly would help. Her physiotherapist then told her that this in fact caused her core to weaken more and advised her to strengthen this.

When questioned about the awareness during dancing, both dancer 3 and dancer 4 stated that they were very aware of their alignment. Dancer 3 stated that ballet dancers are trained to be aware of their body at an almost robot-like level, especially when a teacher gives a correction about a certain point, causing them to be very conscious of their posture when dancing. Dancer 1 reported not being very conscious of her pelvic posture during choreography-based classes and more during technique-based classes. She also stated that she adapted her level of pelvic alignment awareness depending on style, because each style requires her to move her pelvis differently. During Hip Hop and other styles, she felt that she completely lets go of her pelvis and is not consciously aware of engaging her core either. Dancer 3 answered similarly, stating that she does not think about it much outside of jazz, modern and ballet class. She reported thinking that she is usually able to engage her core, but noticed she sometimes lets go of this in commercial class when going all out, causing her back after class. She described that arching the back is not a required for the movements, but some of the movements articulate the hips in a certain way that makes it easier to release the core unintentionally. In line with the answer that dancer 1 provided, she also stated that she mostly thought about it during specific movements requiring the pelvis to move in a certain way. She mentioned contraction as an example.

None of the dancers reported having any major problems personally regarding pelvic alignment. Dancer 2 mentioned sometimes finding it difficult to focus on multiple things at once during technically challenging classes. She mentioned that she only started taking ballet classes later in life. She then described that ballet requires her to pay attention to many different aspects of her body, making it difficult to stay aware of her pelvis when also paying attention to all of the other aspects. Apart from this she reported she didn't really personally feel the need to work more on pelvic alignment than she has already been doing. However, she did mention that she noticed many other dancers around her, who mostly come from urban dance backgrounds, struggling more since pelvic alignment has not been addressed much in their past training. She also reported that many of them are still rather young, and did not seem to really care about their body alignment or understand the importance of this. She then speculated that their educational backgrounds could also play a role in their lack of understanding and that it could also be related to an overall lack of growth mindset. She said that in her regular dance studio there would be more room for improvement, but there is limited time in a class and giving additional attention to pelvic alignment awareness could take away from other important parts of the classes. Dancer 1 repeated that she would like teachers to pay more attention the topic and to work more on awareness and conscious learning about alignment. Even if these were only small moments during class. She also expressed a need for additionally body conditioning and stretching to facilitate maintaining proper posture. While she said that she would like to be given these extra tools, she also stated her opinion that dancers are in part responsible for working on their own improvement. Dancers 3 and 4 did not observe any problems around them and were content with the current state of things.

When asked about their opinions regarding the use of tools and training methods outside of their regular dance classes dancers expressed mainly being limited in time. Dancer 1 mentioned that she is aware of needing to work on various things such as flexibility and strength outside of her dance curriculum but does not find the discipline to do this in her limited time. She also finds it difficult to find the right moment do to it, especially because some exercises require her to be warm. Having more restriction and people holding here accountable may help, she suggested, but she would most likely still find it difficult to actually start. Dancer 2 reported that she has a long commute and would consider working on her body and alignment if it was possible to do so sitting upright in the train. Her main requirements would then be for it to easy to use and not requiring extra steps or energy. If an intervention would fit in the few minutes she has around her classes, or could be done while listening to explanations she also would consider applying this. She also stated that she finds it difficult to remain motivated if there are too many things she wants to work on at once. Dancer 4 stated that this point in his career he is more focused on artistic expression, and with the limited time available to him it would be difficult to integrate extra training. He mentioned that for dancers still in training it could definitely be more valuable to use extra tools for alignment improvement. Dancer 3 reported similar opinions, but stated that if he was still struggling with specific problems, he would certainly work on them.

2.3 State of the art

In order to successfully develop a new tool, it is important to determine what the current developments, similar projects and other technological applications are within the field of dance and sports as well as body sensing and guiding. This may provide insights into what has already been done, the technological possibilities, and inspiration for the further development process.

2.3.1 Interactive technology applications in dance.

Wearable technology in dance performance

Within dance, applications of interactive wearable technology can often be found in the sector of performance art. The use of such technology could be implemented add a deeper layer to dance pieces or open new doors within the creative process of dance choreography and performance. An example is an integrated responsive lighting system for dance costumes, developed by Emily Daub [73]. LED circuits sewn into costumes translate dancers' input into visual light output, in order to enable more creative possibility in dance performance creation. Another wearable technology used in dance performance art, titled "Dissolving Self" [74], was developed by Maziar Ghaderi. A wearable module, as seen in Fig. 2.18, sensed the dancer's speed of rotation which was combined with lateral movement measures captured by a Microsoft Kinect. This data was translated into an interactive visualisation that formed the centrepiece of the performance and visualised the dancer's movement in an artistic way. A wearable device that is more intended the creation process of dance art is the SOMI-1: a bracelet (Fig. 2.19) that translates movement into sound [75]. Tilt and multidirectional acceleration of the wearer are converted into MIDI parameters in real time. The possibility to use advanced sound processing and editing capabilities allow for a wide range of creative applications and sound design options.

Fig. 2.18. *Dissolving Self, dancer wearing motion sensing module around waist.* [74]

Fig. 2.19. *SOM-1 kit* [75]

Wearable technology in guiding dance movement

Other applications of wearable technology in dance are found in the space of training and practice of dance movement. Some of these devices focus on the guiding of movement. GuiDance [76] is a prototype for a device designed to guide dancers' movement through space remotely, through haptic feedback, by indicating dance steps as if being guided by a leader. One user takes the role of the leader, who is in charge of giving remote cues to the other user who takes the role of follower. Cues given to different parts of the body are meant to indicate a small set of predefined movements. These patterns were designed to be as close to human-guided cues as possible. In the evaluated prototype, vibrotactile actuators were placed only on the back and front of each shoulder as can be seen in Fig. 2.20. User studies of this first prototype showed promising results and users reported enjoying the experience.

Fig. 2.20. *GuiDance system*. [76]

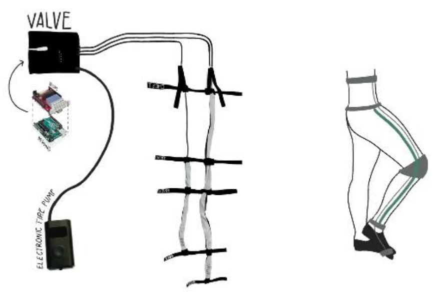


Fig. 2.21. *Wearable choreographer illustration.* [77]

The "Wearable Choreographer" [77] is another prototype designed to guide movement, but instead aims to do this by directly manipulating limbs through wearable soft robotics. Soft robotics often utilise soft or malleable materials that are deformed in some way to achieve movement in a non-mechanical fashion [78]. The prototype utilised an electronic tire pump, electronic valve and tubes allowing for the flow of air. The device was attached to the leg via straps on the chest, thigh, knee, ankle and foot as demonstrated in Fig. 2.21. The airflow through these tubes caused the leg to bend. User evaluation showed that the device both constrains and inspires dancers to dance in new ways.

A non-technological intervention that guides the body physically is the Backalast [79]. The Backalast (Fig. 2.22) is ‘a jacket like garment reinforced with several discrete layers of webbing in order to maximize the awareness around several key postural corrections’ [80, p. 2]. It was designed specifically for dancers to aid in achieving neutral posture. This garment looks very similar to products using elastic bands for correcting posture that are widely available for sale on websites such as amazon. Hackney et al. [80] evaluated the effects of the Backalast on dancers’ trunk-pelvic joint angle. Participants were asked to wear the Backalast garment and perform a set of trunk movements. Results showed that wearing the Backalast can help dancers in reproducing trunk-pelvic joint angle and increasing awareness of the position and movement of the pelvis. However, it did not influence dancer’s tendency to adopt and maintain more neutral posture without the Backalast.

Fig. 2.22. *Backalast.* [81]

Technology in dance training

Another application of technology within dance is in education. A variety of systems and services providing online dance lessons and training materials are offered, usually on a subscription basis, in order to bring the dance studio to anyone’s home. This makes dance classes accessible to anyone that can access the internet. An example of such a service is Steezy [82]. Steezy provides dance teaching videos in a large variety of dance styles and levels with advanced viewing options, mimicking a dance studio experience. Some of these options include the ability to switch views (viewing the teacher from either the front or the back), mirror the video or using a webcam (or smartphone camera) as a virtual mirror. You [83] investigated online dance training frameworks and studied the effects of a self-developed online dance training intervention. Results showed that dancer’s competencies improved, specifically those of biomedical knowledge and cultural competence. Smaller improvements were observed in practical skills and theoretical knowledge. You [83] suggests that online dance training programs show promise, but is critical towards quality control of such systems.

In recent years there have been explorations into the use of virtual reality environments as dance training systems. Chan et al. [84] developed a virtual environment inspired by traditional dance classes (Fig. 2.23). A virtual dance teacher on a screen demonstrates moves, which the dance student follows. The student's movements are collected via motion capture and comparison-based feedback based on real-time analysis of the motion capture is visualised inside the virtual environment. Students are also given a score-report of their overall performance and a slow-motion replay of their movements is shown to them. Evaluation suggested that this system could help student's in improving their dancing abilities. Kyan et al. [85] investigated a similar, somewhat more detailed, CAVE (Cave Automatic Virtual Environment) VR dance training system (Fig. 2.24). This system targeted ballet training specifically and instead of motion capture used Microsoft Kinect to analyse movement. Visual and score reporting feedback methods as those introduced by Chan et al. [84] were also applied by Kyan et al. [85].

Fig. 2.23. *Virtual dance teaching system.* [84]

Fig. 2.24. *CAVE VR dance training system.* [85]

2.3.2 Interactive technology for training posture

A variety of technological interventions targeting posture and guided movement can be found outside of the field of dance. Subtletee, developed by Wozniak et al. [86], is an example of such technology in the field of sports. This system (see Fig. 2.25) aims to help beginner golfers with posture awareness. Weight sensors underneath the feet and flex sensors around the elbow are used to analyse the user's posture. Based on this, sensory feedback is given to the user. Three versions of this system using different sensory feedback modalities (vibrotactile haptic feedback, visual feedback and auditory feedback) were assessed. The goal of this feedback was to help participants in remaining aware of the positioning of their feet and elbows when swinging. Results suggest that the vibrotactile haptic and visual feedback modes improved swing quality and users reported feeling an increased control. However, the auditory mode was perceived as frustrating and distracting.

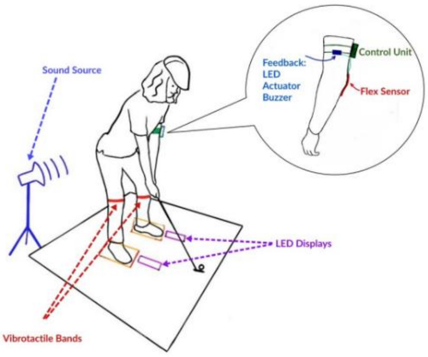


Fig. 2.25. *Subtletee.* [86]

Fig. 2.26. *MusicJacket.* [87]

Comparable interventions have been developed in the field of music education. An example developed by van der Linden et al. [88]is the MusicJacket. MusicJacket (as shown in Fig. 2.26) is a wearable system, targeted towards beginner violin players, that captures inertial motion to track whether the user is holding their violin correctly and applying correct bowing technique. Vibrotactile haptic feedback cues are given to help the student adapt their posture. Motion is captured via inertial measurement units (containing three-axis accelerometers, gyroscopes and a magnetometer) attached to a Lycra suit worn on the user's upper body. Vibration motors were attached to hands and elbows as well the ribs. Evaluation suggested that the MusicJacket could help violin students improve bowing arm coordination and body awareness and shows potential to be applied within a violin teaching environment [87], [88].

Outside of sports and music, various solutions addressing sitting posture and slouching have been developed. Two examples of devices developed for sitting posture sensing are Sitsen [89] and UPRIGHT [90]. Sitsen (Fig. 2.27) is a contactless posture recognition system utilising a radio frequency to detect different sitting positions on a chair. UPRIGHT (Fig. 28) is a small sensing device that is worn on the upper back and detects whether the user is slouching or not. If the user is slouching, vibrotactile haptic feedback is given as a reminder to sit upright. Users can also analyse their posture data through a smartphone application. An early example of such slouch-sensing wearable technology was studied in 1968 by Azrin et al. [91]. Using a more mechanical form of sensing posture as can be seen in Fig. 2.29.

Fig. 2.27. *Sitsen illustration.* [89]

Fig. 2.28. *Upright device.* [90]

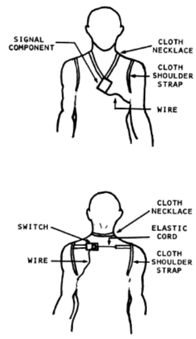


Fig. 2.29. *Illustration of early slouch-sensing example.* [91]

2.3.3 Other relevant technologies

An aspect of body-sensing not yet explored in the previously discussed examples is the measurement of muscle activity. An example of a wearable technology system using muscle activity sensing was developed by Ribas Manero et al. [92]. The aim of this system was to measure muscle fatigue of the upper leg in runners as a potential measure for the prevention of injuries. The device consisted of sports leggings with embroidered circuitry including an EMG sensor, as can be seen in Fig. 2.31.

Embroidered circuitry as used in the previous example is a commonly used technique in the realm of smart textiles. A category of smart textiles that is of interest to this project is the field of fibre-based actuators. Textile fibres are particularly suitable to be worn on the body due to their flexible qualities. Through technologically driven manipulation of these qualities, it is possible to achieve new ways of delivering haptic feedback. The OmniFiber (Fig. 2.30) developed by Kilic Asfar et al. [93] is an example of one of these fibre-based actuators. Through different integrations into textile garments and structures, the OmniFiber can deliver haptic feedback in the forms of axial pull, compression, vibration and lateral skin stretch. Some applications of the OmniFiber include use in robotics, haptic remote communication, a contracting breathing trainer and a wearable spine tensegrity intended for spinal posture sensing. This last example was developed with the context of dance in mind, suggesting implementations as a dance training guide or choreographical tool. The spine tensegrity was constructed by combining the OmniFiber with a more rigid structure, as seen in Fig. 2.32, and could be applied both as a sensor and as an actuator.

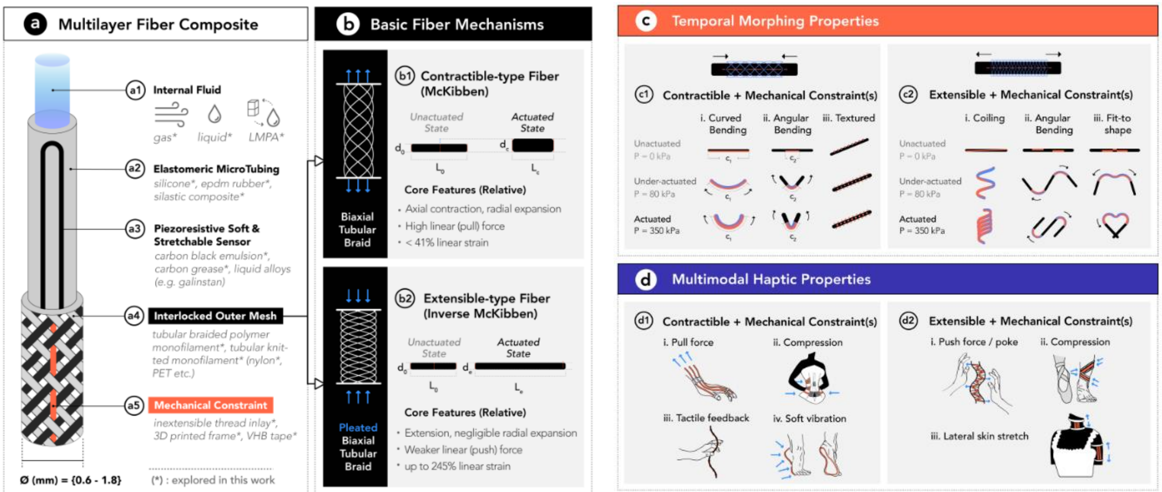


Fig. 2.30. *OmniFiber Architecture.* [93]

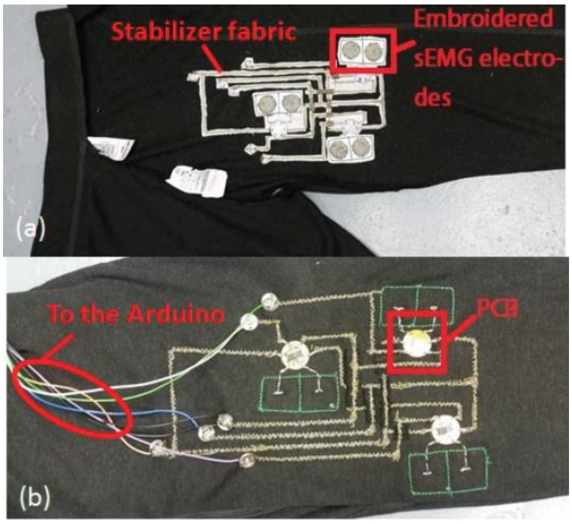


Fig. 2.31. *Wearable technology system for measuring muscle fatigue of the upper leg.* [92]

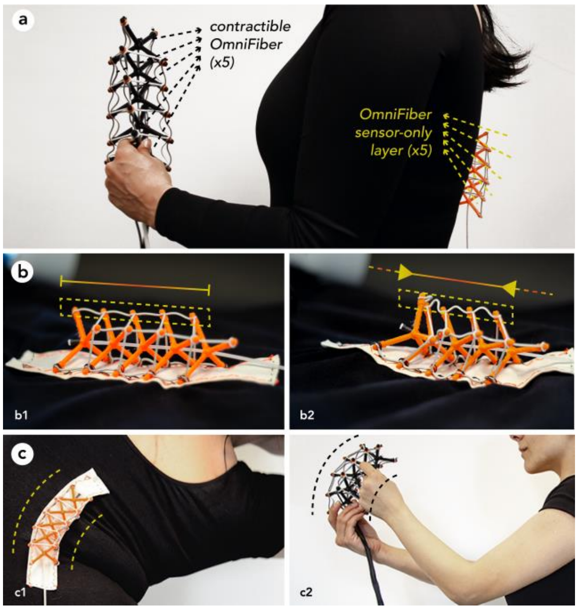


Fig. 2.32. *OmniFiber application as a movement guide.* [93]

2.4 Conclusions and discussion

The goal of this background research was to gain the necessary knowledge to answer the previously defined research questions and form a complete image of the design space. Some of these questions can now be answered.

Firstly, conclusions can now be drawn on the influence of pelvic alignment on musculoskeletal health (**SQ1**). It seems that pelvic alignment and core-muscle stability are directly connected. If the core is not stable or weak, the pelvis cannot be actively tilted and the core cannot be activated if the pelvis is not aligned properly. The pelvis also influences the posture of the spine and vice versa. The imbalance of muscles, i.e. the inability to continuously control the spine and pelvis, appears to influence general motor ability. Weakness in this sector could cause problems of pain and injuries in other areas. Findings from the interviews with physiotherapists support this. The lack of control can cause vertebrae to shift around, which causes pain if shifted too far. It was suggested that rather than looking at the alignment of the pelvis itself, it is more important to focus on a dancer's ability to maintain core engagement and find a balance in muscle tension in order to avoid problems. Additionally, healthy alignment differs per person, based on genetics (build) and motor ability. The most "relaxed" (i.e. not tense or locked in other places) alignment appears to usually be close to an individual's "neutral" alignment.

These findings are also reflected in the ways in which pelvic alignment are measured (**SQ5**). The measures frequently used are pelvic tilt angle, lumbo-pelvic alignment and lumbo-pelvic stability. The relation between the (lumbar) spine and pelvis is reflected in the measure of lumbo-pelvic alignment and the angle of the pelvis (influencing the ability to control the core) itself. Both usually measured by visual observation of anatomical landmarks in relation to each other, but more experimental techniques such as inertial measurements can also be applied. The ability to control the lumbo-pelvic region was usually tested through physical tests. However, as found from the interviews, it may be possible to measure muscle activity itself through EMG measurements to determine core engagement and therefore lumbo-pelvic stability.

Pelvis alignment training approaches (**SQ2**) often target the previously mentioned aspects, and seem to mainly involve exercises and techniques aiming to achieve lumbo-pelvic stability and both mental and body awareness. Often multiple of these methods are combined in order to reach the goal of pelvic stability. These combinations seem to be mostly based on literature and experience-based knowledge; however, they are rarely studied separately. This makes it complicated to determine the effects of the separate methods. The element of informational instruction seems to be an important factor in increasing the awareness aspect of pelvic alignment specifically. It should be noted that all of the investigated training approaches require supervision or instruction by experts and teachers. This could be worth considering in the scope of the tool developed in this project. The technique of imagery, which is ubiquitous in dance education, also shows great potential in increasing body awareness. Particularly the method of Ideokinesis showed potential in addressing postural alignment. In the approaches studied specifically in the context of dance, it appears that there is lack of work outside of classical ballet and modern dance which should be investigated further. It also remains difficult to draw conclusions on the efficiency of the existing training approaches, as the study methodologies used vary too greatly. However, it can be concluded that the discovered approaches could all positively influence pelvic alignment. The techniques discussed could all potentially be applied to reach the desired outcome of this project.

In terms of the influence of different sensory feedback methods on learning and habit formation (**SQ6**), it can be concluded that sensory feedback overall has positive effects on learning. Some evidence suggests that memory retention may be positively influenced as well. Combinations of different sensory feedback modes (multisensory approaches) in particular seem to be more effective than standalone modes of sensory feedback. However, there may be a risk of causing distraction when combining feedback modes and the effects of the different feedback techniques tend to be highly task dependent as well. The application should be carefully considered before choosing a sensory feedback approach in order to reach the desired effects. An interesting point to note is that there seems to be a possible link between sensory feedback and (dance) imagery. Sensory feedback evokes some form of feeling based experience in each individual, possibly causing sensory based associations, which could point to some connection between sensory input and forming mental imagery.

The conducted interviews held the biggest role in determining dancer’s needs concerning pelvic alignment awareness training (**SQ3**). There seems to mainly be a problem around pelvic alignment training within dance training outside of the classical ballet world. This is likely do the technical rigidity and strictness of posture training involved in ballet. However, in other styles dancers often seek out extreme movement. Which is especially relevant in this project in styles that emphasise hip and back movements a lot such as commercial. It seems that pelvic alignment awareness and core stability are not addressed frequently in most amateur dance education, particularly in the urban styles such as commercial, and at times also left aside in professional dance education. There seems to mainly be a lack of (consistent) education regarding the importance of pelvic alignment and its workings anatomically, as well as a lack of additional training to build the required strength. It is particularly surprising that anatomy classes do not seem to be widely taught in professional dance education. However, age/maturity and motivation of dancers themselves also seem to play a role in the quality of pelvic alignment awareness among dancers in training. While it appears that dancers in general are often (subconsciously) more in control of their pelvic posture than non-dancers, awareness of this fact could possibly lift them to greater heights.

A note that can be made so far on the ways in which interactive technology could be smoothly integrated into dancer's training routines (**SQ4**) is that dancers are particularly tight on time. Those taking their dance training seriously do not seem to have much spare time outside of their regular (mandatory) class schedules. In the case they do have time it is usually limited, and dancers expressed they would not (want to) train more in this time. Furthermore, the specific points that dancers would like to work on are highly individual, which is important to consider. In terms of the technologies that could be applied the possibilities are wide. Both wearable and application-based technologies could be considered. Concepts such as visualisation, motion capture, sensory feedback, notification mechanisms, movement guidance and smart textiles are all options to consider in the further development process.

It seems that within dance, technology applications are mainly focused on tools to support the creative process (creation and performance), guiding dance movement and dance training/learning. Developments in the field of guiding dance movement, seem to be mostly in the experimental stages as of this moment, with a lack of commercial applications. Regarding dance training technology applications, they are mainly focused on teaching and/or training strength, rather than tools to be used alongside or during regular dance training and classes. The discovered other relevant technologies are inspiring example that could be valuable during the further ideation process. Overall, it seems that wearable technology has not yet been extensively explored within dance training and there is room to branch out into new directions withing this project.

Going forward

Based on the very clear connection between pelvic alignment and core stability, this connection should be kept at the centre of this project going forward. Awareness of importance of pelvic alignment and motor-skill education/training are important factors to consider. In this, it seems most appropriate to target dancers in training of any kind. Specifically, but not limited to, those participating in dance styles that frequently require extreme back and hip movements.

Chapter 3 – Methods

In this chapter the methods and techniques applied within this project are explained. First the design method applied in this project is introduced. The following four sections, each covering a phase of this design method, discuss the process and methods applied within each phase.

The design process applied in this project is based on the Creative Technology Design Process (Fig. 3.1) developed by Mader and Eggink [94]. This method implements elements of divergence & convergence and spiral models to form a process structure suitable for developing creative technology solutions. The design process is characterised by four phases: ideation, specification, realisation and evaluation. The model allows for iterations between the phases as needed throughout the process. This chapter will cover the methods used in the four phases of the Creative Technology Design Process applied within this project.

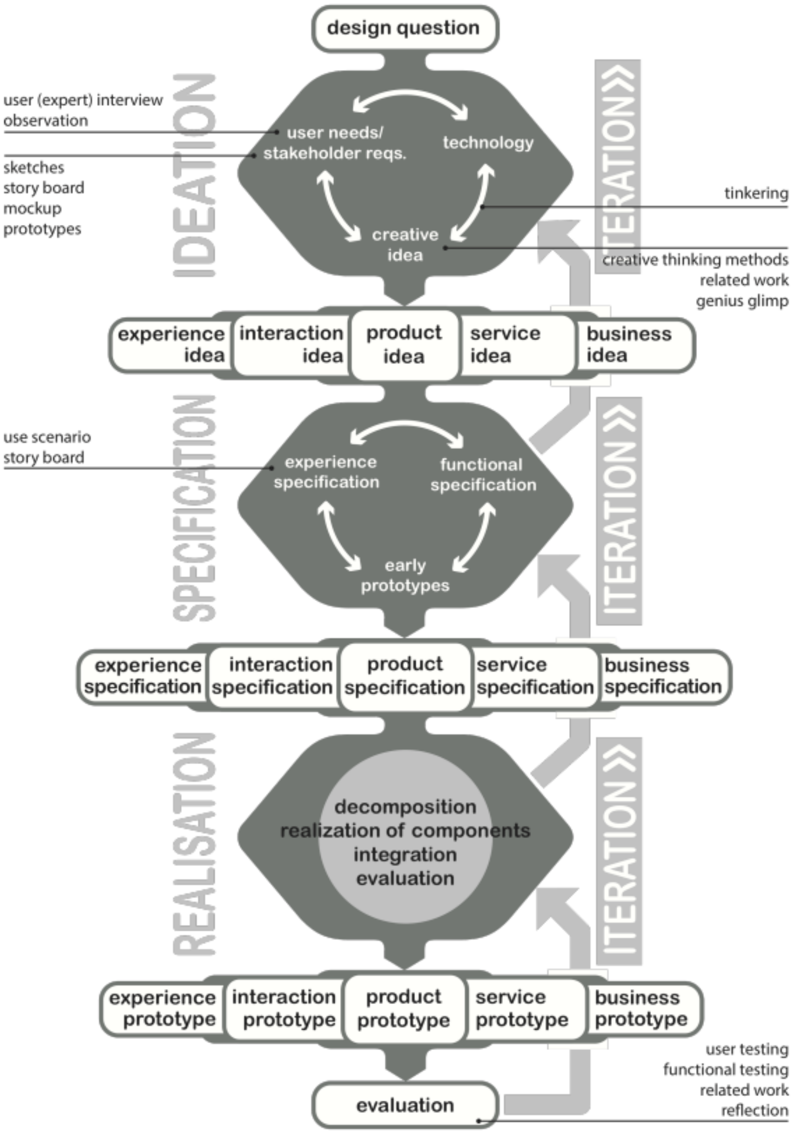


Fig. 3.1. *Creative Technology Design Process.* [94]

3.1 Ideation

The ideation phase is the first phase in the design process. This phase is initiated by a design question based on a starting point (User needs/stakeholder requirements, technology or a creative idea). Subsequently, a process of divergence is started, exploring a wide range of knowledge and ideas in order to form a complete image of the design space. This leaves the designer with a collection of knowledge which is then built on and refined (convergence) to find initial requirements that should be met and a conceptual solution to the design question.

3.1.1 Diverging – Background research

In this project the design question is the main research question defined in the first chapter, with user needs (dancer's struggles with pelvic alignment) as the starting point. The diverging phase was then started with an in-depth literature analysis, state of the art analysis and expert interviews.

Academic sources for the literature analysis were collected via database searches. These sources where then filtered, analysed and compared. Broader google and internet searches, also including non-academic sources, were performed to research state of the art. The expert interviews were conducted with field experts and target audience members (experience experts). These interviews were laid out as audio-recorded semi-structured interviews [95], for which the interview guides can be found in Appendix B. The interview question-guides were designed to get as comprehensive as possible qualitative information about the problems, experiences, opinions and needs of participants regarding pelvic alignment in the context of dance. Participants received an informational letter (Appendix D) providing all details on the interview study, and Informed consent (Appendix D) was obtained prior to conducting the interviews.

3.1.2 Converging – Ideation

Building on the obtained knowledge until this point, stakeholders and initial requirements were identified. This then forms the starting point of a brainstorming session. The outputs of this brainstorm are a list of potential concepts, after which a final concept idea is selected.

The purpose of a stakeholder analysis is to identify all parties involved and determine how to manage them throughout a project [96]. They are sorted based on their levels of interest and influence in the project. The stakeholders are placed into a stakeholder matrix (Fig. 3.2), categorising them into four groups. This is a straightforward way to identify how to manage different stakeholders throughout the project.

Brainstorming is a creative thinking method [97] and (in this project) is used as a concept generation tool. In this project's brainstorm, pen and paper were used to "dump" thoughts and ideas on paper and connect them to one another, resembling a mind-mapping [98] approach. These initial thoughts are then further categorised and clarified to form initial concepts. The concepts that are generated from this are then carefully considered based on requirements and attainability within the scope of this project. Finally, a concept is selected to be further developed.

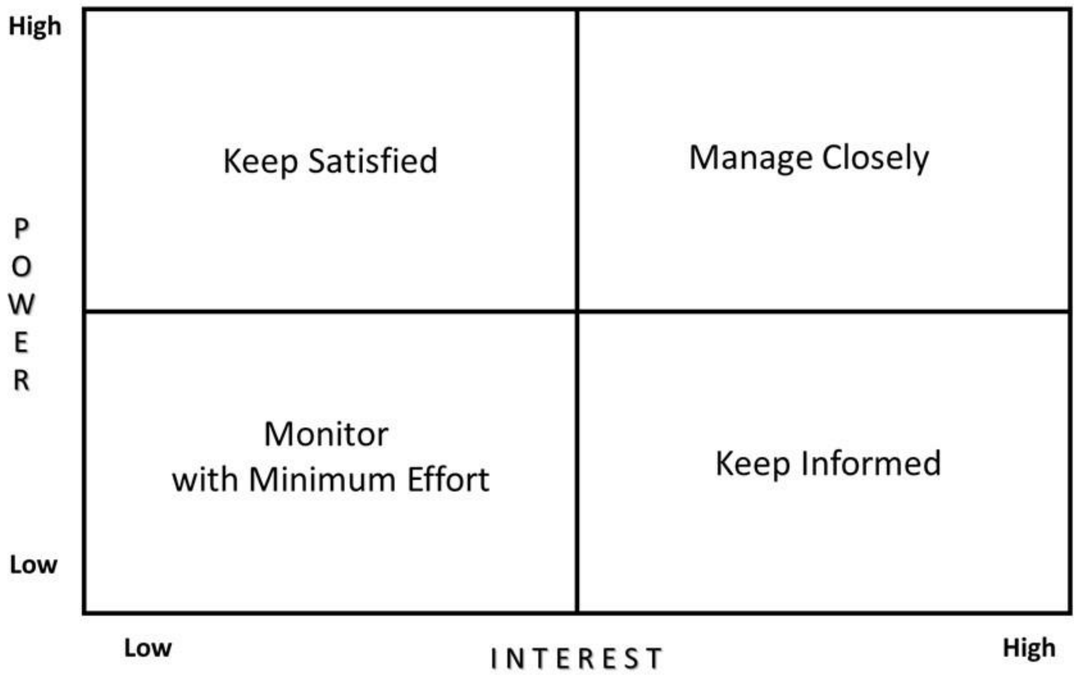


Fig. 3.2. *Stakeholder Matrix.* [99]

3.2 Specification

The second phase of the design process is the specification phase. The main goal of this phase is to further specify the user experience and functionality of the final solution. The solution concept and preliminary requirements from the ideation phase are used as a starting point in this for cycles of rapid prototyping. This process involves various iterations of prototypes and short evaluations to test and develop different aspects (focusing on experience and functionality) of the final solution. Other tools that could aid in this process may also be applied. Through this process, the designer builds an increasingly more in-depth understanding of the requirements that the final solution must meet to fulfil its purpose successfully. The output of this phase is a complete list of requirements.

3.2.1 Specifying

In this project, the main tools that were applied to further specify the user experience and interactions for the final prototype are user personas and scenarios. User personas are fictional characters of possible users, who might use a product or service [100]. These personas are described in a profile format presenting personal details, such as background information, demographics and motivations of the hypothetical person. The elements described for the personas in this project are a few basic demographics (photo, name, age, occupation), dance experience, a short biographical description, dance goals and challenges and their stance on technological interventions. Creating personas may help to form a better understanding of who the end-users may be and what their goals, needs and behaviours are like.

User scenarios place these previously defined personas into a potential context in which the persona might be using the product or service [100]. This scenario is presented as a description of a sequence of actions that the persona takes when interacting with the product or service in question. This can clarify the intended interactions with the product or help identify potential roadblocks that the user may encounter. In this project these scenarios are described in short story form outlining how, and for what purpose, each persona uses the solution prototype.

Another aspect of specification is defining the functional architecture of the final prototype. A functional architecture includes a detailed description of the functionality of a system and how the different components interact with each other to achieve its goals [101]. This architecture helps to guide the further development of the system. Diagrams are often used to describe such a functional architecture. A variation of an activity diagram [102] was constructed to visualise part of the functional architecture of the solution prototype in this project. To describe the functional relations of the device, a functional block diagram [103] was constructed. A more detailed description of these diagrams is given in Ch. 5.

3.2.2 Defining Requirements

Having specified the solution's interactions and functionalities, this forms the base for the definition of a final list of requirements. Requirements need to be met by the solution prototype in order to achieve a successful outcome and are used for evaluation [104]. These requirements are divided into the two categories of functional and non-functional requirements. Functional requirements do not require a user to evaluate them, whereas non-functional requirements do require evaluation with a user. In order to determine the priority level of each requirement they were analysed and ordered using the MoSCoW analysis method [105].

The MoSCoW technique defines four priority categories into which requirements can be classified. MoSCoW is the acronym of these four categories: must have (M), should have (S), could have (C) and won't have (W). These categories define their importance of implementation. "Must have" requirements must be met in the project. If they are not met this would mean the project as a whole has failed. "Should have" requirements are features with high priority and value, but are not essential to the final delivery. "Could have" requirements include features that could be good to include but are not necessary and of lower importance than "should have" requirements. "Won't have" requirements are features that will not be implemented during the current development process. They might still be included but may also be implemented in future iterations. Prioritising requirements as such ensures that the further development process is attainable, and the most important aspects of the solution are clear.

3.3 Realisation

The realisation phase centres around the creation of a final prototype, taking the outputs from the specifications and building on them to develop a functional product. This process is defined by analysis of the requirements, designing and creating the required components and integrating them into a whole and complete product. This process usually involves intermittent functional evaluations of prototypes, using the previously defined functional requirements, in order to determine success of design decisions and determining the next steps in the process. Models applied in this phase are most often linear processes that allow for backtracking of steps. The final output of this phase is a completed and functional final prototype.

In this project the realisation phase started with a review of the requirements and specifications and through this determining the components required for the prototype. After having determined these components, design and development of them was started. Components were first developed, through sketches and iterations of (paper) prototypes, and then integrated to work together one by one. In between implementations, components were frequently tested and changed in order to reach the desired outcome. This was applied to the hard- and software components first, followed by the wearability components. With each step of further integration, the prototype was further refined, perfecting the final construction. While the realisation phase in the Creative Technology Design Process [94] is typically defined to be a mostly linear process, this project at times applied a more open process, jumping between steps and working with iterations of prototypes in order to reach the desired outcome as previously described. After integration of the components was completed, a final test session, evaluating the device based on the functional requirements and analysing the outcomes.

3.4 Evaluation

The final phase of the design process is the evaluation phase. The most important goal of this phase is to evaluate the final prototype based on the non-functional requirements, but functional testing may also be included here. Evaluation of non-functional requirements is usually done through user testing, determining whether the requirements have been met. After having evaluated the solution prototype, the designer can now finish the design process by evaluating their own design process. This requires placing the final outcome into the context of the state of the art, as well as critical reflection on the outcome and the decisions leading to it.

The solution protype in this project was evaluated based on the non-functional requirements via user testing, in the same way as described in the design process. User testing involves potential users using the device and analysing their behaviours and experiences [106]. The purpose of this is to assess whether requirements are met, and the device solves the problem it was designed to address. The tests in this project were conducted with target audience members (dancers) and were structured into an interaction segment and evaluation segment. The interaction component was designed to closely resemble a real-life use case and videorecorded for observation afterwards. The evaluation component consisted of a short audio-recorded semi-structured interview [95] and a paper survey. The semi-structured interview was designed to get a conversation started with the participant about their experiences and create room to ask further questions as needed, to get a clear image of the participant's experience. The paper survey was constructed of statements for which the participant could rate their level of agreement with statements, on a Likert scale [107] ranging from "completely disagree" to "completely agree". These statements were designed to evaluate whether the non-functional requirements have been met. The interview guide and paper survey can be viewed in Appendix E and E. Prior to the user-testing sessions, participants received an informational letter (Appendix G) including all the details of the steps involved in the user study and what is required of the participant. Participant signed informed consent forms (Appendix H) before starting the user study.

Outcomes of the evaluations were determined via analysis and comparison of the evaluation outputs. Observations made during the interview and from the video recordings were analysed and compared between subjects. Interview responses were analysed in the same way. Survey responses were processed and visualised using Microsoft Excel [108]. Last, outcomes were used to determine whether the non-functional requirements have been met.

Chapter 4 – Ideation

The purpose of the ideation process is to build on the previously explored background research and develop concept ideas that could target training pelvic alignment awareness in dancers. Through stakeholder analysis and brainstorming, a final concept is then selected. This chapter will discuss the steps taken in the ideation process leading up to a final concept. The first section will cover the stakeholder analysis. In the next section preliminary requirements will be discussed. The third sections will cover the generation phase and its outputs. Finally, the fourth and last section introduces the selection process of the final concept.

4.1 Stakeholder analysis

The first step in conducting a stakeholder analysis is determining the parties involved. This section will cover the identified parties which are in the end arranged within a stakeholder matrix, as seen in Fig. 4.1.

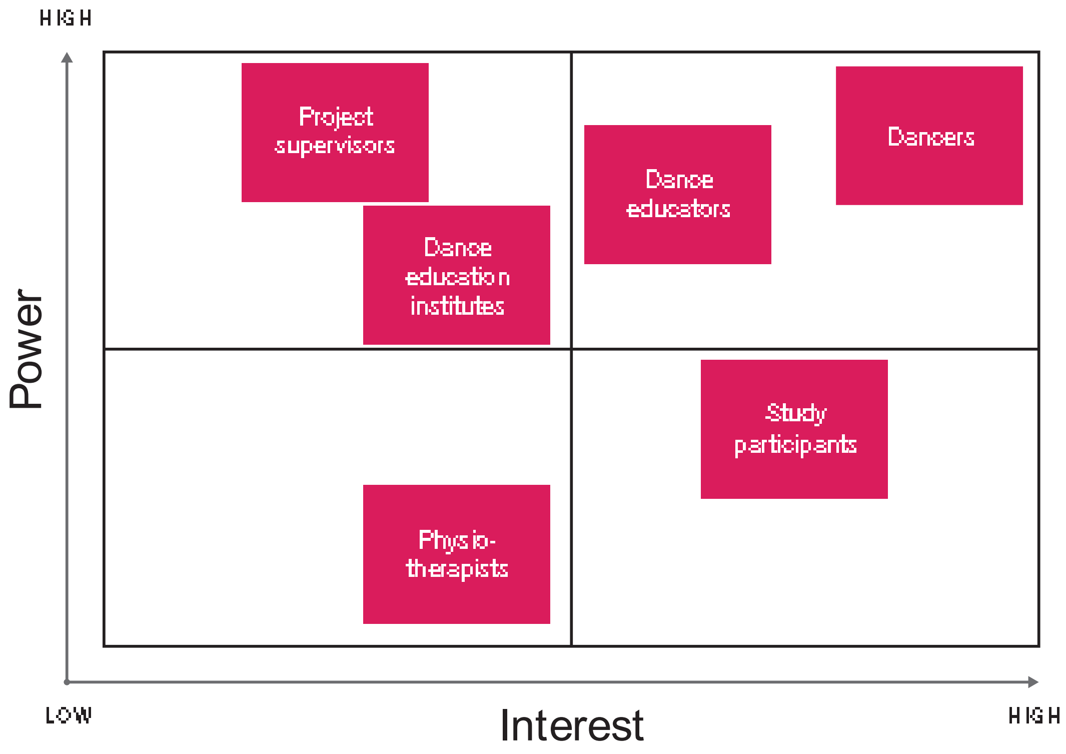


Fig. 4.1. *Stakeholder matrix.*

4.1.1 Dancers

The most important stakeholders in this project are dancers. Specifically, those in training or struggling with pelvic alignment. They are the target users of the tool developed in this project. Since dancers needs and requirements will determine the final shape of the tool and their opinions greatly influence the design decisions made, they can be classified as high-power. Additionally, dancers have high interest in the outcome of the project, as the final tool may be beneficial to them as dancers if the outcome is successful. Therefore, dancers are categorised as “high-power, high-interest” in the stakeholder matrix and should be managed closely.

4.1.2 Dance education

Two other groups of important stakeholders are dance educators and dance education institutions. These groups are closely involved with dancers shape the boundaries in which dancers are educated. They influence the dance curriculum taught to dancers and what topics are emphasised within classes and therefore influence the knowledge and training that dancers obtain regarding pelvic alignment. This influences the aspects addressed by the final product. Therefore, both dance educators and dance teachers can be considered as high-power. Furthermore, class schedules and duration are determined by dance education institutions. This affects dancers’ routines and needs, which in return influences the design of the final outcome, placing education institutions somewhat higher on the power scale than educators. Both parties have medium to high interest, as they benefit from educating well performing dancers, but still put dancer’s performance of part of their own responsibilities. Dance educators are more closely involved in teaching than the institutions behind them. Therefore, they have higher interest in a successful outcome than the institutions they work for, as the main goal of most teachers is to see their dancers thrive. Additionally, they may be able to apply the tool in their own teaching, further improving dancers’ abilities. Based on this knowledge, dance education institutions can be considered as “high-power, medium-interest” and dance educators as “high-power, high-interest” within the stakeholder matrix.

4.1.3 Project stakeholders

Another category of stakeholders is those involved with the study organisation of the project. The first group in this category are the project supervisors. Supervisors advise the designer, but do not directly benefit of a successful outcome of the project and therefore have low to medium interest. As they also assess the designer and give feedback regarding the projects outputs, it is necessary to address their needs and concerns throughout the development process. Therefore, they are considered to be a high-power stakeholder. The second group involved in the study are research participants. They influence the findings and discoveries made that further developments and evaluation of outcomes are based on. They play a significant role in the development process, but don’t determine final decisions at all times, and therefore have medium to high power in its outcomes. As all members of this group are likely chosen because they are in some way part of the target audience or in connection with the target audience, they have high interest in the outcome of this project. Additionally, they are personally involved in the project and therefore entitled to information. In the stakeholder matrix, study supervisors placed in the group of “high-power, low-interest” stakeholders and study participants as “low-power, high-interest” stakeholders.

4.1.4 Physiotherapists

The final group of identified stakeholders are physiotherapist. They are relevant in the field of injuries and movement health, but are not involved in the development of the project (aside from being a source of information) and therefore have low power throughout the project. Physiotherapists that are involved with dancers specifically do have some level (medium-high) interest in the final outcome of the project as it may be relevant to them in the realm of injury prevention and physical education. This is a group that should be monitored but not necessarily involved, and can therefore be placed in the box of "low-power, low-interest" in the stakeholder matrix.

4.1.5 Concluding notes

This stakeholder analysis has brought forward the most important groups to consider within this project and led to a clear overview of the way in which each group should be managed. Dancers and dance teachers seem are at the forefront of this project and therefore need to be managed closely. Other important stakeholders, which influence the direction of the final outcome and therefore need to be kept satisfied, are dance education facilities and project supervisors. Lastly, it is important to keep study participants informed about the study and physiotherapists should be monitored.

4.2 Preliminary requirements

After having completed background research and stakeholder analysis, some preliminary user requirements can be identified. A first observation is that dancers usually have rather busy schedules and therefore limited free time. Dancers frequently answered that they would not be likely to work on training pelvic alignment outside of regular classes unless it requires very minimal effort. It seems that in order to increase pelvic alignment awareness the solution should focus in some way on either improving body awareness, building strength & understanding or both. In the case of a tool being designed for use during dance movement, it should be usable and wearable while dancing and not restrict dancers' movements in any obstructive way. In this case it should also be taken into consideration that the pelvis moves dynamically while dancing, as this may affect the employed measuring and sensing techniques. A partial goal of this project is to fill a gap where there is a lack of sufficient teaching and attention towards the topic of pelvic alignment in dance education. As traditional training approaches require supervision and guidance from a teacher, the final tool should be usable without external supervision if it is intended for use outside of regular mandatory training/class. A summary of the preliminary requirements can be found in Table I.

TABLE I

PRELIMINARY REQUIREMENTS

Nr.	Preliminary requirement
1	Is usable during dance training/class. **OR** Requires very minimal effort and energy if intended for use outside of dance training/class. **OR** Is mandatory in some way as part of regular training/class.
2	Should address body awareness of the pelvis. **AND/OR** Addresses building lumbo-pelvic stability. **AND/OR** Addresses understanding of pelvic alignment.
3	If intended use case is outside of regular mandatory training/class: Is usable without external guidance.
4	If intended use case is during dance movement: Is usable while dancing, and allows for free range of movement of the spine.
5	If intended use case is during dance movement: Should address the dynamic movement of the pelvis in sensing and measuring techniques applied.

4.3 Concept generation

The concept generation phase consisted of an individual brainstorm. Taking the outcomes of the background research (including state of the art and interviews), stakeholder analysis and preliminary requirements into account, a first range of ideas was put to paper. The process started by considering ideas based on their intended use: being used during dance class or outside of regular class. Any ideas surfacing (considering knowledge obtained so far) were documented in a way resembling a mind-map (Fig. 4.2) leading to multiple ideas. The combinations made in the mind-map were condensed into two sheets of ideas (Fig. 4.3). These final ideas were then further specified into six concepts. The sections of the mind-map and idea sheet that in some way led to one of these concepts are marked as such in the figures. The concepts are described in sections 4.3.1 – 4.3.6.

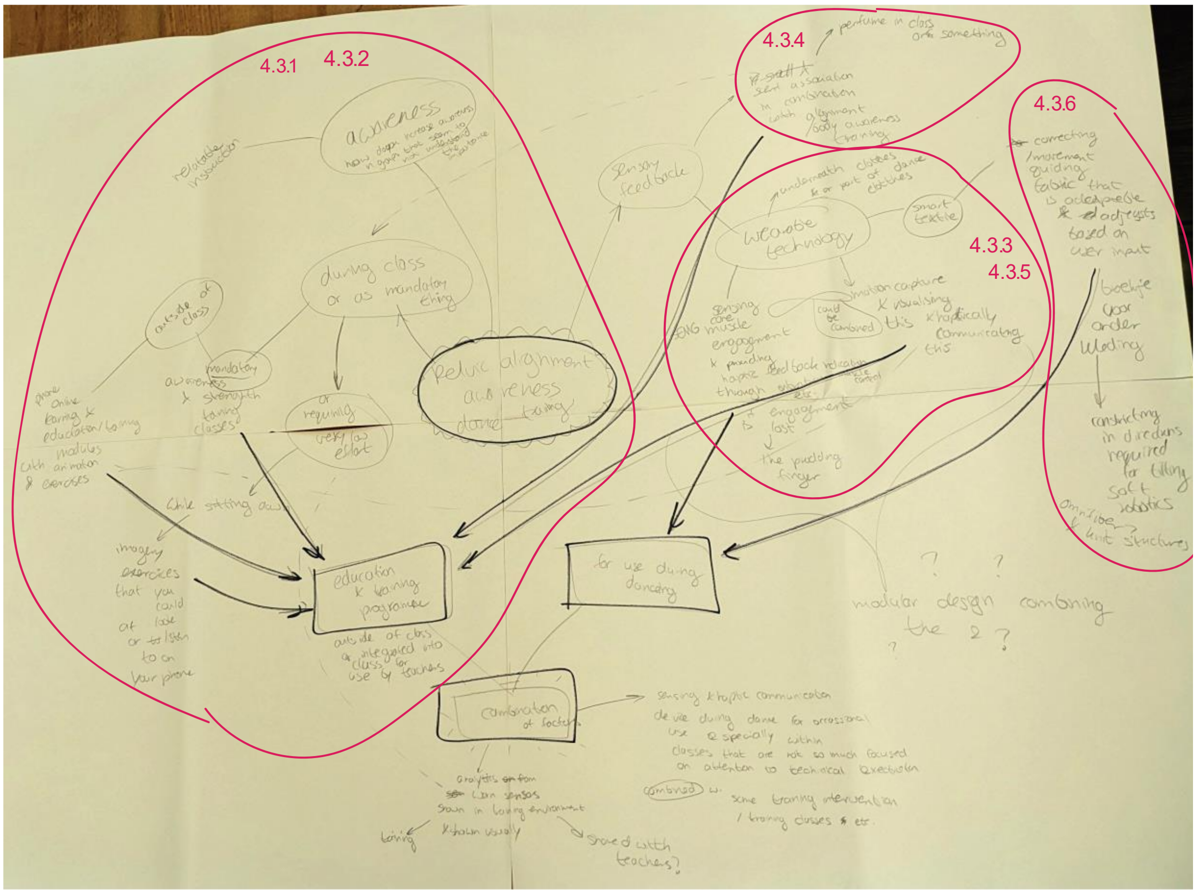


Fig. 4.2. *Individual brainstorm mind-map.*

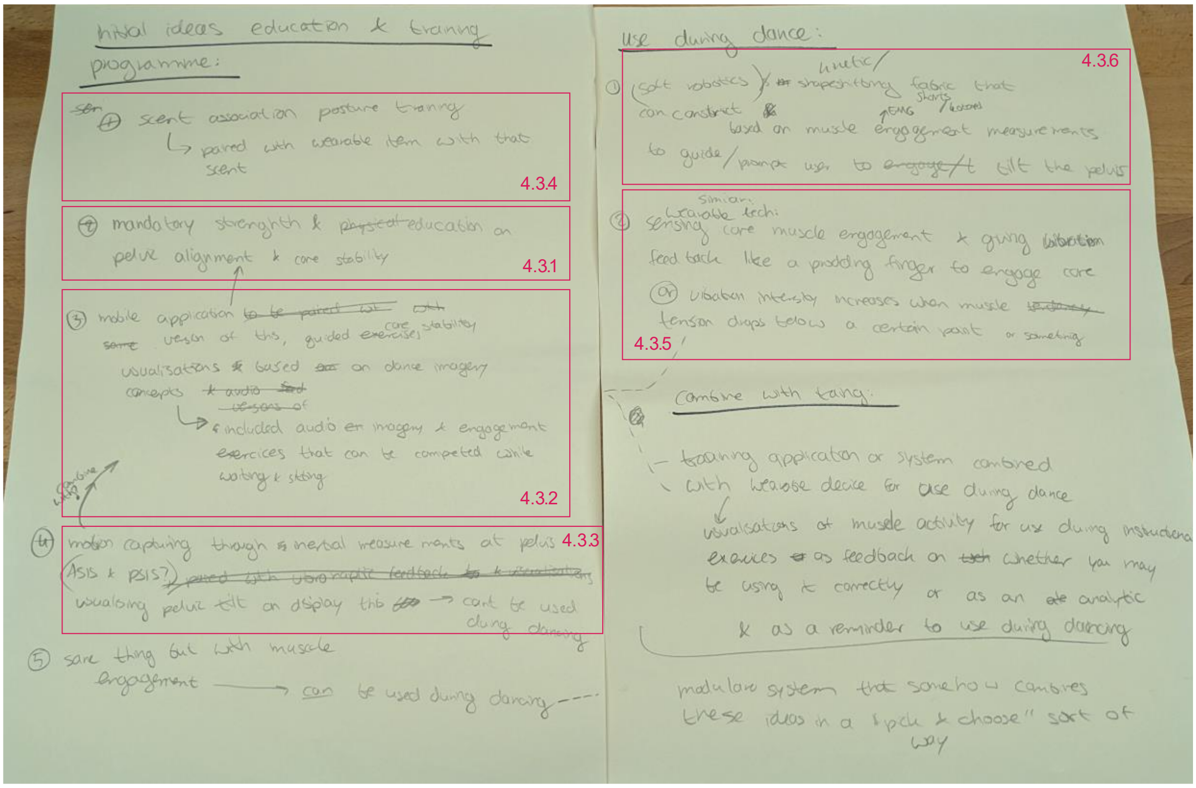


Fig. 4.3. *Individual brainstorm idea sheets.*

4.3.1 Pelvic alignment training classes

A straightforward approach to improving pelvic alignment awareness would be to have dancers participate in mandatory classes taught by a teacher. These classes could specifically target building core stability, educating dancers about anatomy and the workings of the pelvis, as well as focusing on body awareness exercises. Repeated training is necessary to build muscle memory and subconscious activation. However, this approach does not involve any interactive technology and requires a specialised teacher to teach classes.

4.3.2 Mobile pelvic alignment training application

An alternative version of the concept introduced in 4.3.1 is a mobile training application. This application could include guided exercises (focusing on the same topics as those in the previous concept) and visualisations. Concepts of imagery could also be applied in this concept to help dancers gain understanding. This could be used by dancers by themselves, but it is hard to monitor consistent training. Teachers may also be able to use such an application in their classes if they wished. A functionality that could be added to this application is an audio-mode that includes audio fragments with spoken, imagery based, exercises for core activation and awareness. These exercises would require minimal effort and could be performed while sitting/standing anywhere.

4.3.3 Wearable pelvic alignment visualiser

This concept focuses on visualising the dancer's pelvic alignment and pelvis movements in order to help them build awareness of their alignment and help them in learning to properly activate the core to tilt the pelvis. This would work by having a wearable device in the hip area that captures motion or tilt angle through inertial measurements. This information is then visualised in some way on a display. The wearer can sit down/stand/lie down and observe their alignment, possibly with guidance from a teacher, and observe what their body sensations are like in relation to their actual posture. This could possibly also be incorporated into the mobile application in section 4.3.2, using it as an additional guide in explanatory exercises or as a way to determine if the user is execution exercises correctly. A downside of this concept is that it cannot be used while dancing if the tilt angle is used as a measure, due to pelvis moving dynamically. An alternative could be to measure muscle activity (EMG measurements) and visualising core engagement instead.

4.3.4 Scent association training aid

Based on findings from the literature analysis it seems that humans strongly associate scents with experiences (see Ch. 2.1.6). Utilising this notion, dancers may be able to train pelvic alignment (e.g. via the ideas mentioned above) and simultaneously be exposed to a specific scent. The goal of this would be for dancers to start associating consciously tilting their pelvis or focusing on their pelvic alignment to this scent. Some form of a wearable device, capable of giving of scent, could then be worn by the dancer while they are dancing in order to stimulate awareness of the pelvis and pelvis alignment in association with the scent.

4.3.5 Wearable “prodding finger”

A wearable solution intended for use during dance could use vibrotactile feedback based on muscle activity. Dance teachers sometimes “prod” their finger into a student’s stomach to feel if they are engaging their core properly or to encourage them to activate it. This could be simulated by measuring core muscle activity and giving the dancer vibrotactile feedback of their muscle activity drops below a certain point. This could either be local notification-like vibrations, like the prodding finger, or more of a continuous sensation that changes strength more fluidly based on muscle activity levels. Higher intensity vibrations could indicate more need for engagement in this case.

4.3.6 Kinetic textile shorts

Another solution involving haptic feedback, inspired examples from the state-of-the-art analysis such as the wearable choreographer and OmniFiber (Ch. 2.3.3), could be shorts made out of a kinetic fabric intended to be worn while dancing. This fabric would be able to constrict and expand based on core muscle activity, giving the user tactile feedback. Additionally, the constrictions could be designed to guide or encourage movement of the pelvis and engagement of the muscles.

These initial concepts, as already implicated in some of the examples, may be suitable for combinations among each other. For example, the examples of the “prodding finger” and kinetic textile shorts may be used in combination with the mobile training application for analytical purposes. Data collected by the devices during use would then be analysed by the mobile application to visualise muscle engagement statistics, for example, allowing the user to track their improvements or to see at what times awareness is often lost. Some sort of modular approach may be possible as well allowing the user (with a mobile application as a baseline) to pick and choose tools that fit them best and use them in combination with each other or separately to meet their own personal needs.

4.4 Final concept

Several aspects were considered in choosing a final concept (sketch in Fig. 4.4). These aspects included the previously gained knowledge from background research, the feasibility to further develop the solution within this project and the potential it has to be integrated into dancer’s routines. After considering these aspects in a process of elimination, the “prodding finger” (section 4.3.5) solution was selected as the final concept for which a prototype is developed in this project going forward.

The first concept that was ruled out was “Pelvic alignment training classes” (4.3.1). This concept does not involve some form of (interactive) technology, and is therefore not suitable as a project in the creative technology scope. Following this, the “scent association training aid” (4.3.4) was excluded. This solution seems to be too experimental in comparison to other concepts. The concept is less based in factual evidence, and it remains far more uncertain whether this solution would indeed be successful. While this is an interesting concept to explore, it would not be a reasonable decision to make in the scope of this project. Similarly experimental, and additionally largely technologically complex, are the “Kinetic textile shorts” (4.3.6). While the kinetic textile technology shows great potential, the idea seems too complex to fully develop and study within the scope of this project. Another point to consider was brought forward by the expert interviews. Dancers did not seem to possess a lot of time outside of their training schedules. While the use of some of the solution concepts could be made mandatory or implemented by instructors into lessons, it seems most ideal if dancers themselves are in control of their training. This would rule out solutions, such as “Mobile pelvic alignment training application” (4.3.2) and “Wearable pelvic alignment visualiser” (4.3.3), which must be used outside of regular dance training or for which lesson format needs to be adapted in order to be able to use the solution. This leaves the “prodding finger” as the last solution left.

Aside from simply being the final concept left after this process of elimination by feasibility, there are several other factors that speak for choosing this concept for further development. From a dancer’s perspective, receiving feedback that is similar to previous feedback experiences may feel most organic and intuitive to them. The vibration feedback could be viewed as a form of dance imagery (introduced in Ch. 2.1.5) which is suggested to be more beneficial if it resembles reality [62]. Secondly, the manually administered vibration feedback cues, studied by Holt et al. [40] showed positive results regarding improvement of pelvic alignment in the subjects studied. This provides additional reasoning to further develop the “prodding finger” concept, as the feedback mechanism is similar to that of the method studied by Holt et al. [40]. Furthermore, one of the main issues that dancers are facing, is their struggle to remember to be conscious of their pelvic alignment while dancing. The “prodding finger” solution, acting as a constant observation and feedback mechanism, could potentially combat this issue.

From a more technical standpoint, a difficult point about measuring pelvic alignment is the dynamic nature of dance. Throughout dancing the pelvis (and body as a whole) often intentionally moves and tilts in various directions. Measuring core muscle activity instead of positioning and tilt of the pelvis does not only seem to work around this problem, but also seems to target the problem at the base of pelvic alignment issues: a lack of core engagement. As a lack of core engagement is usually the cause of the pain and injuries caused by (anterior) pelvic tilt, and engaging the core is necessary to tilt the pelvis to a neutral position. Therefore, measuring core engagement directly seems to be a straightforward method to address this problem. The simplicity of the concept also does not rule out implementation of the other concepts into some bigger whole, leaving room for future development to combine multiple concepts modularly.

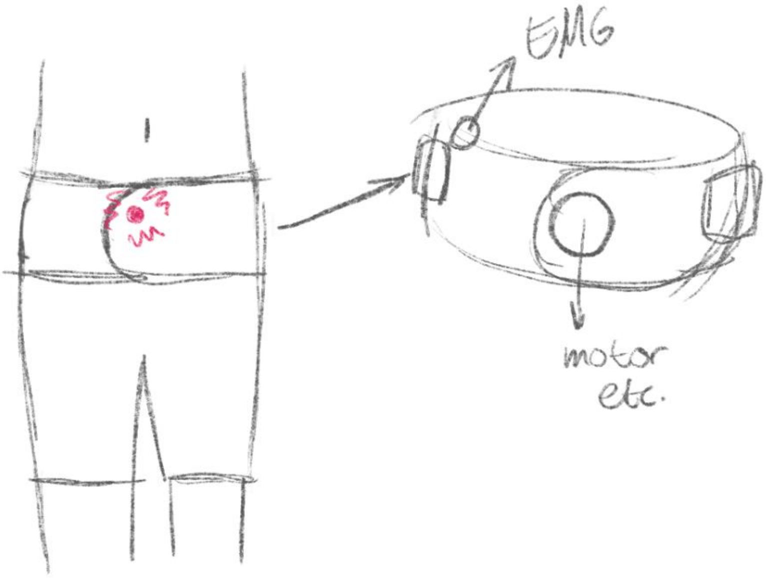


Fig. 4.4. *Sketch of final concept*

Closing remarks

After having considered the knowledge gained from background research and gaining further insight into the stakeholders involved in this project a final process has been chosen. While all concepts may be of value, the most feasible concept with the most potential has been selected for further development. With this, specification of the design is now possible and will be addressed in the following chapter.

Chapter 5 – Specification

The main goals of the specification phase are to form a clear image on the use and functionality of the concept. Through this, a final list of requirements that the final prototype should meet is formed. This chapter contains the process and outputs of the specification phase. First, a suitable name is chosen for the device. In the second section, a collection of user personas and scenarios is listed. The third section will cover the functional architecture and the fourth section of this chapter contains a final list of requirements.

5.1 Naming CoreMnemo

In order to clarify communication about the final solution of his project and to give the device an identity, it is helpful to give it a fitting name. Using the knowledge gathered up until this point, a suitable name was selected. Encompassing the functionality and goal of the solution, the prototype that is being developed in this project will from this point may be referred to as the "CoreMnemo" device. The "Core" portion of the name speaks for itself, as it refers to the fact that this device targets the activation of core muscles necessary for healthy and efficient dancing. The second half of the name is a playful derivative of the word "Mnemonic", which is "a device such as a pattern of letters, ideas, or associations that assists in remembering something" [109].

5.2 User scenarios and applications

In order to develop a clearer image of the potential applications of the final solution and possible user needs, user personas and user scenarios were written. This section will first introduce three different user personas, who were placed into three different potential user scenarios.

5.2.2 User personas

Persona 1 – Aspiring young dancer

Name: Emily Chen
Age: 16

Occupation:
Secondary school student, and trainee at a pre-professional dance program at a dance studio

Dance experience:
10 years of experience dancing a variety of dance styles, focusing on contemporary dance.

Biography:
Emily is a very motivated young dancer who hopes to get accepted into a good dance course at a university and become a professional dancer in the future. She spends most of her free time training and taking dance lessons at her dance studio as part of the pre-professional dance program she participates in. Her love for dancing and expressing herself through dance is her biggest motivator.

Goals:

- Improving her technique to improve her chances of getting accepted into the dance course she is interested in.
- Build strength to support her body and build good habits to minimise injuries throughout her future career.

Challenges:

- Struggles to keep control of her core during complex choreography pieces and performances.
- Due to her busy dance schedule, she struggles with balancing school and dance.

Technology:

- Is looking for innovative tools that could help her in improving her technique and strength.
- She is well versed in using technology and she is open to wearable technology and other technological interventions.

Persona 2 – adult beginner dancer

Name: Nina Janssen

Age: 43

Occupation:

Consultant at a marketing firm.

Dance experience:

Did ballet for 2 years during her childhood, has been taking a beginner ballet class for adults once a week for 4 months.

Biography:

Nina has always been very busy meeting other people's needs but is now starting to prioritise her own needs and finding (creative) outlets for herself. She remembered enjoying ballet classes during her childhood and has decided to pick this up again. She is greatly enjoying the lessons she has been taking at a local dance studio. At times she is a bit overwhelmed by the complexity of ballet but also feels accomplished whenever she learns something new.

Goals:

- Learning the basics of ballet.
- Stay fit through her ballet classes and improve her posture.
- Enjoying the process of learning a new skill

Challenges:

- Has difficulty understanding the complexities of the very specific posture required for ballet and doesn't always understand her teachers explanations.
- Struggles with remembering the combinations while staying conscious of her form and posture.

Technology:

- At times struggles with navigating technological devices and therefore prefers simple and easy to use products.
- Is willing to invest in tools to help her improve, but does not have additional time available outside of the lessons she is already taking

Persona 3 – dance teacher

Name: David Woźniak

Age: 34

Occupation:

Fulltime dance teacher

Dance experience:

14 years of teaching jazz, contemporary and commercial dance. Completed a university dance education course. Total dance experience of about 20 years.

Biography:

David has been dancing since he discovered it at a school dance workshop when he was 14 and hasn't stopped since. When he discovered that he loves sharing his passion with others he decided to aim for a career in dance education. He greatly enjoys seeing his students flourish in his classes and is always looking for new ways to help his students grow. He now runs his own dance school and works with dancers of all ages and skill levels.

Goals:

- Help his students to build strong technical foundation to support them in their dancing.
- Enhance his teaching methods to help his students improve.
- An enjoyable dance class experience for his students where everyone feels included and taken seriously → equal and individual feedback.

Challenges:

- Limited time to provided one-on-one attention to every student in his classes.
- Sometimes find it challenging to address the largely varying needs and skill levels of the students within a class.

Technology:

- Is always interested in new innovative tools that he could try out with his students.
- Prefers that tools do not interrupt class flow or distract students.

5.2.3 Scenarios

Scenario 1 – Emily

Emily is planning ahead regarding her training for the upcoming school year, where she will start the auditioning process for her further education. She has noticed recently (which has also come through in feedback from her teachers) that at times during intense or complex choreography, especially during fast-paced sections involving jumps and turns, she tends to lose control of pelvis and core. This has been causing her to fall out of movements sometimes and her back feels a little sore. With her busy schedule, she is looking for an efficient way to work on this without needing to attend additional lessons or private tutoring. Ideally, she'd like to work on being more mindful of her core and pelvis while rehearsing the choreography in class. Online she found out about CoreMnemo, a piece of wearable technology for dancers that will give her reminders to engage her core while she is dancing. Thinking this might be the perfect solution for her, she decides to try out this device.

Using the included instructions with illustrations, she learns how to operate and charge the CoreMnemo and how it works. She decides to first try it out during one of her regular contemporary dance classes. After applying the CoreMnemo correctly on her stomach (using the included guide) she turns the device on and starts her dance lesson. During her lesson she receives real-time haptic feedback whenever her core muscles disengage, prompting her to re-engage her core and tilt her pelvis. Once her class is finished, she turns the CoreMnemo off and removes it from her stomach. She finds the feedback to be intuitive and helpful, so she decides to continue using the product more. After checking the CoreMnemo's battery level, she decides to charge the battery before her next use.

Over multiple weeks, making sure to also participate in training sessions without the CoreMnemo, Emily notices that she is starting to see improvements in her muscle memory. The continuous reminders have helped her to make engaging her core and pelvis more automatic than it was before. She now feels more stable during challenging moments in her dances and has received less comments from her teachers about her lack of control. She also noticed she is starting to receive less feedback from the CoreMnemo. She feels more confident and more balanced, which has helped to improve her self-assurance for the coming year.

After some more time of continuing her training, she feels solid in her technique and barely receives reminders from the CoreMnemo anymore. Over multiple weeks, she reduces the number rehearsals and classes she participates in while wearing the device until she has completely phased it out of her training schedule. She can now engage her core on her own. Occasionally, she will still use the CoreMnemo to evaluate her progress and verify whether she is maintaining her muscle memory properly.

Scenario 2 – Nina

Nina consistently attends her weekly beginner ballet class. She is eager to improve, but often feels overwhelmed by the large amount of information that comes her way. As she has

not yet built the muscle memory to make some of the aspects of the ballet posture automatic, she frequently struggles with addressing them all. Remembering the combination, focusing on the different postures and moving in time with the music all at once have proven to be a complicated task. She finds aligning her pelvis to be especially difficult. While her teacher has explained to her how to engage her core correctly to tilt her pelvis, she still finds it difficult to execute and constantly forgets to do so during exercises.
She brings this up with her teacher, who then recommends a wearable technology device for dancers to her called CoreMnemo. This device is supposed to help with building awareness of pelvic alignment. The device seems very simple and straightforward to use and therefore she decides to try it out.

She brings the CoreMnemo to her next ballet lesson and finds that, using the provided instructions, the process of applying CoreMnemo is simpler than she expected. She chooses her place at the ballet barre and turns the device on. The teacher notices that she has decided to start using CoreMnemo and decides to add a pelvic alignment exercise to the class. While using the CoreMnemo during the exercise, Nina notices the gentle vibrating sensation on her stomach every time she sits in a certain position. Starting to see a pattern and feeling the location of the vibrations, she feels that she is starting to get a better grasp of how she is supposed to align her pelvis. Throughout the rest of the usual ballet exercises, she continues to receive feedback whenever she forgets to tilt her pelvis, which is helping her to stay mindful of her posture. Once the lesson is over, she turns the CoreMnemo off. She feels accomplished for having made progress today.

While it will likely take a considerable amount of time to build the experience and skill, she needs to automatically tilt her pelvis, she sees potential in CoreMnemo and decides to continue using it for the foreseeable future. The device is helping her to understand her teacher’s instructions better than before, making the complicated aspects of ballet posture more accessible and understandable to her. After a few months, Nina notices that she is slowly but surely becoming more aware of her pelvic alignment. She feels proud of her progress and has started to become less overwhelmed during class. Depending on her progress and needs she will decide on the frequency with which she will be using CoreMnemo going forward.

Scenario 3 – David

David has noticed that a few students in his jazz technique class for talented dancers (aged 14-18) are struggling to maintain proper pelvic alignment. Most of these students do not have backgrounds in classical technique training and have therefore not mastered to tilt their pelvises and engage their cores automatically. Since the students also participate in a multitude of dance classes in other dance styles, such as commercial and contemporary improvisation, he is worried about their physical health and wants to help them improve. While he tries his best to pay close attention to every single student, it is impossible for him to watch every student at the same time. Thinking that there must be a solution to his problem, he decides to search the internet for potential tools that he could use. He stumbles upon a tool called CoreMnemo, which is designed to help dancers improve awareness of their pelvic alignment. David thinks that this may be a potential solution to his problem, he orders multiple devices for his entire class.

After having received the products, he plans an entire class to introduce CoreMnemo to his students. He studies the instructions by himself beforehand and prepares a class to teach every student how to apply the device correctly and how it works. First, he explains the aim of training with CoreMnemo and explains that it will give them gentle vibrations if they stop tilting their pelvis or lose control of their core. Then, he explains how the CoreMnemo should be applied and they practice multiple times how to apply and operate the device together. Followed by this, he gives his students multiple exercises focusing on pelvic alignment awareness, teaching students about sensations they should be feeling and how to adjust their posture. He uses CoreMnemo as a teaching tool and creatively applies its features to help him instruct his students. At the end of the class, he explains further what his student’s training schedules with CoreMnemo will look like. After everyone has turned off their devices, they each take one home for them to use in other dance lessons as well. The lesson went smoothly, his students all seemed to quickly understand how the device works, due to its intuitive and simple interactions.

In the following weeks of his class, he continues to teach a pelvic alignment exercise during his lessons next to the usual jazz technique exercises. Students have gotten used to using the CoreMnemo devices and continue to receive real-time haptic feedback ques to correct their postures and engage their cores. David has noticed that he can now focus more on giving other corrections, since monitoring of pelvic alignment has been taken over by the CoreMnemo. This has made him feel more relaxed.

Over time, David notices that his students are starting to show improvements in their technique and execution of the exercises. Especially their turns are greatly improving. He feels proud and happy that his work and research seem to have paid off. After some more time his students have grown more self-sufficient in correcting their own alignment. He schedules personal meetings with every student to discuss and tailor their further training plan with the CoreMnemo. Going forward every student will keep using CoreMnemo on their own schedules until they no longer need to use it regularly, which is when they will be handing the CoreMnemo devices back in with David for use with other students. Occasionally David will bring the CoreMnemo devices to class for everyone to wear, in order to give students an opportunity to check where they stand and to ensure that students don’t slowly start to unlearn their good habits.

5.3 Functional architecture

Constructing potential user interaction scenarios has provided more clarity on the functionality and interactions of the final solution. It is now possible to further build on this by defining the functional architecture and an interaction timeline. A functional architecture describes the functions and their relationships within a system [110]. This provides an outline of how the different components of the system interact with each other in order to reach the desired outcome. In this project, two diagrams were constructed to specify this functional architecture. The first diagram (Fig. 5.1) is a variation on an activity diagram [102] showing the steps the user takes (interaction timeline) and how the CoreMnemo device responds to this. The left side of the diagram shows the actions of the user and the right side those of the prototype. The second diagram is a functional block diagram [103], showing the functional blocks of the CoreMnemo system and how they relate to each other.

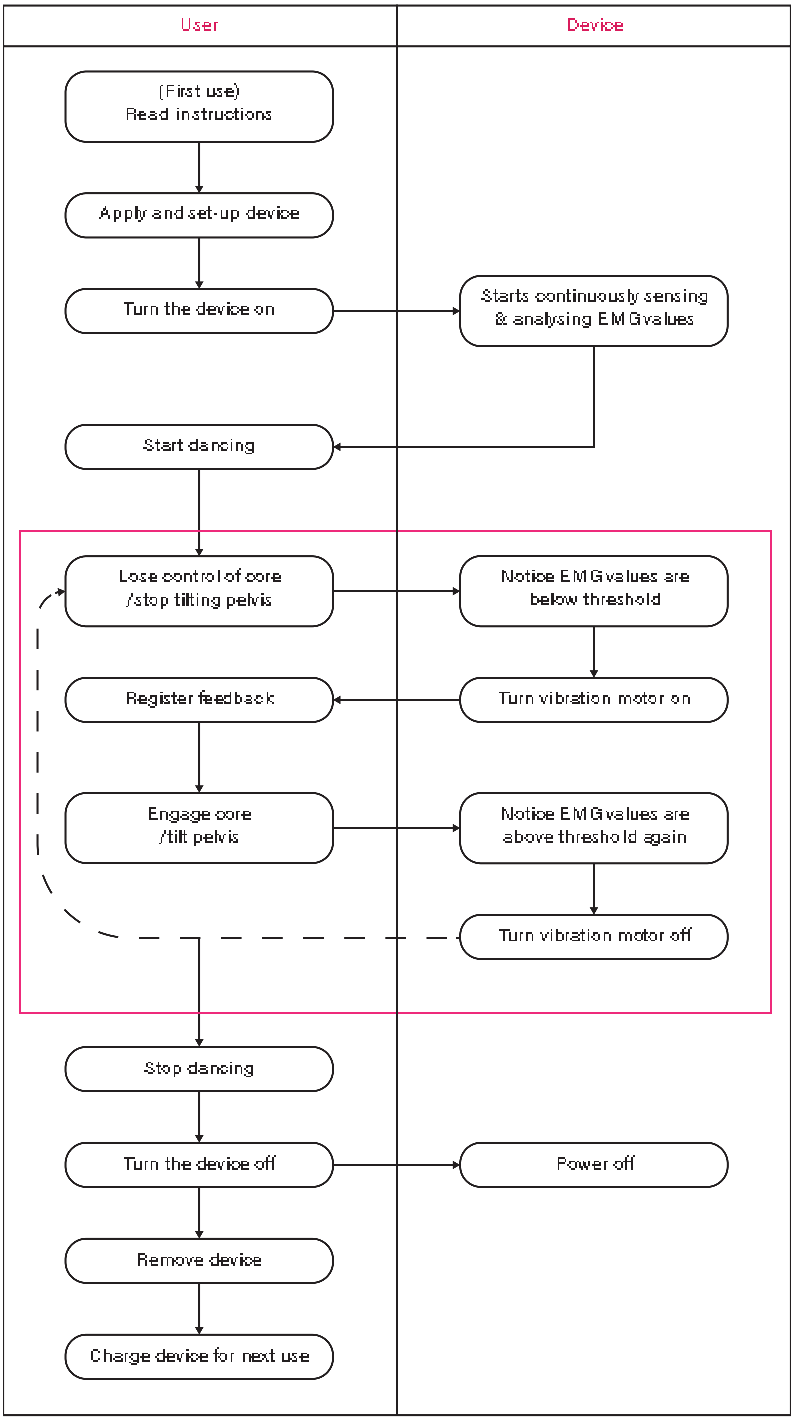


Fig. 5.1. *Activity diagram.*

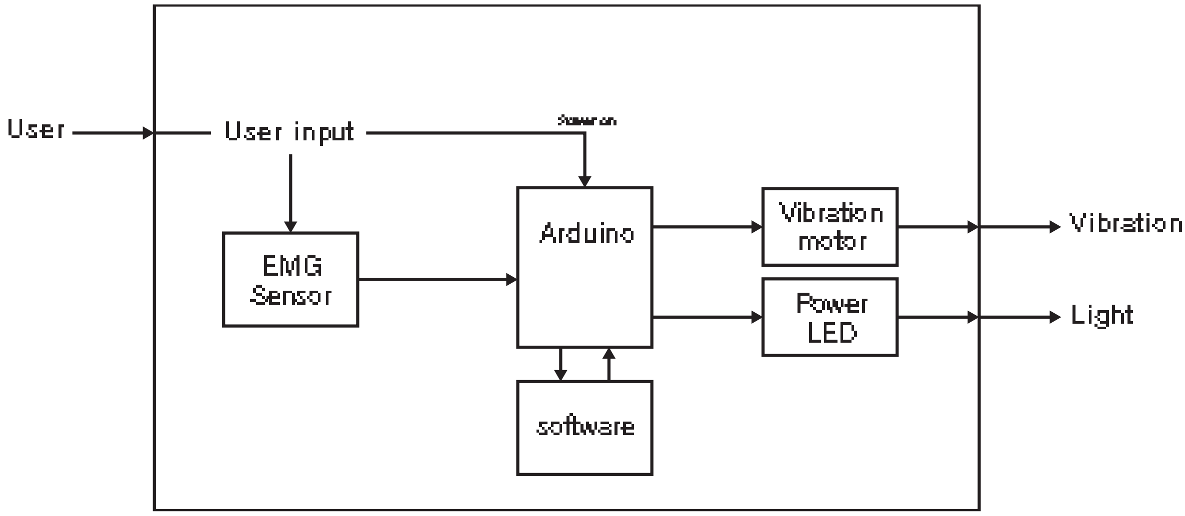


Fig. 5.2. *Functional system diagram.*

First, the actions that the user takes before the device is enabled are shown. These steps include reading the instructions, applying the CoreMnemo and turning it on. The user will likely only need to use the instructions during the initial few uses. Once the device is enabled, it starts continuously sensing the EMG values of the user's transversus abdominis (TrA) muscle. This is one of the previously identified muscles responsible for tilting the pelvis and stabilising the lumbopelvic region. Out of the three identified muscle groups, the TrA is the only one that the user may be able to reach themselves and was therefore selected as the best point of measurement. The device continuously compares the incoming values with a threshold value that indicates whether the muscle is engaged or not.

While the user is dancing with the device enabled, there is a continuous feedback cycle where the user's actions influence the CoreMnemo's responses, as shown in the diagram. The user may lose control of their core (e.g. by forgetting to tilt their pelvis), leading the device to read EMG values that are below the activation threshold. The device notices this and gives the user vibrotactile feedback by turning on the vibration motor. The user now feels the CoreMnemo vibrating on their stomach and is reminded to engage their core (e.g. by tilting their pelvis). The device (which continues to read and analyse the EMG values of the TrA and is still vibrating) notes that the values are above the threshold again, leading it turn the vibration motor off. The user notices that vibration has stopped, informing them that they have successfully reengaged their core. This process continues while user is actively using the CoreMnemo. Once the user has completed their training session, the user disables the device, stopping the feedback cycle. As a last step, the battery of the CoreMnemo is charged in preparation for the next use.

5.4 Requirements

The processes of developing user personas, scenarios and functional architecture, have led to a better understanding of the solution's functionality and the requirements that need to be met in order to achieve a successful outcome. This makes it possible to now specify a final list of functional and non-functional requirements, which are needed for the realisation and evaluation of the final prototype. The requirements have been prioritised following the MoSCoW analysis method [105] which has been outlined in more depth in section 3.2 of this report. The priority level of each requirement gives clarity on which requirement should be prioritised in the further development and realisation process. Apart from guiding the process, this ensures that the intended outcome is achievable within the given timeframe.

5.4.1 Functional Requirements

Functional requirements define the functionality of a system and what it does on a technical level. The functional requirements that have been defined for the final prototype of this project, including their priorities, are listed in table II.

TABLE II

FUNCTIONAL REQUIRMENTS ORDERED BY MOSCOW PRIORITY

Nr.	Functional requirement	MoSCoW Priority
1	Reads TrA (Transversus Abdominis) muscle EMG values accurately.	Must have
2	Vibration motor turns on when the EMG values of the TrA are below *the threshold value.*	Must have
3	When the EMG values of the TrA are above *the threshold value* the vibration is stopped.	Must have
4	Can be worn on the body in the abdominal region.	Must have
5	Can operate under normal dancing conditions (e.g. spinning motions, fast movement, etc.).	Must have
6	Is sweat resistant i.e. it does not malfunction with the influence of sweat.	Must have
7	Is safe to use i.e. does not critically endanger the user.	Must have
8	Is impact resistant.	Must have
9	Can cope with potential noise in the incoming EMG signal.	Should have
10	Battery/charge of the device lasts for the duration of an entire dance class (approximately 60 minutes).	Should have
11	Vibration motor starts “pulsing” when the EMG values of the TrA are above *a certain value.*	Could have
12	Stores data for further analysis by the user.	Won’t have
13	Vibration motor vibrates more intensely the further the EMG value drops below the threshold value.	Won’t have
14	Indicates power bank is half empty by vibrating in a pattern of 3 long pulses and 3 short pulses.	Won’t have

The “must have” requirements are essential to the functionality of the device. In order to function properly, the device needs to be able to correctly and accurately read the EMG values of the TrA (first requirement). In response to this data, the device needs to be able to turn the vibration motor on and off adequately based on the threshold value (second and third requirements). The device is only able to perform these actions if it can be worn on the body, and continue operating while the user is dancing (fourth and fifth requirements). As dancing leads to sweating, it is essential that the device is able to operate in sweaty conditions and does not malfunction from this (sixth requirement). The next essential requirement (seventh requirement in the list) is that the device needs to be safe to use and does not endanger the user. As the humans conduct electricity and the electrodes are connected to the skin, especially the risk of electrical shock is on that needs to be considered in operation of the device. Lastly, some styles of dancing include floorwork, in which dancers perform different types of movement (e.g. rolling over stomach or slides) on the floor. The stomach often makes contact with the floor during these movements. The device should ideally be designed to withstand this impact and allow for continued functionality in such conditions (eight requirement).

Two “should have” requirements were identified. The EMG data may contain noise from, for example, neighbouring muscles. The device should be able to account for this in the way it handles the EMG data so that the device’s functionality isn’t impacted (ninth requirement). Additionally, it would be ideal if the device is able to function for the entirety of a dance class for the best results (tenth requirement). While this may not be more challenging to implement, impact resistance (eleventh requirement) would be of added value to the device.

A feature that could be favourable to include is listed as a “could have” requirement. This feature (tenth requirement) is providing additional feedback regarding high engagement of the muscle through differently patterned vibration feedback. This could enrich the users experience by providing extra insight into their performance.

Last are three “won’t have” requirements, which will not be addressed in the scope of this project. These include options for new interaction ideas and functionalities for CoreMnemo.

5.4.2 Non-functional Requirements

Non-functional requirements define how a system is supposed to behave, focusing on aspects such as performance and user experience. The final list of non-functional requirements is presented, including its priority levels, in table III.

TABLE III

NON-FUNCTIONAL REQUIRMENTS ORDERED BY MOSCOW PRIORITY

Nr.	Non-Functional Requirement	MoSCoW Priority
1	Helps the dancer to stay mindful of their pelvic alignment.	Must have
2	Stays in place while dancing, taking factors such as sweating, impact and vigorous movement into consideration.	Must have
3	Can be applied/put on by the dancer without external guidance.	Must have
4	Feedback feels intuitive to the dancer.	Must have
5	Is adaptable to dancer's physiological and anatomical differences (i.e. applicable for all body types).	Should have
6	Does not restrict range of movement.	Should have
7	Does not distract the dancer from the task of dancing.	Should have
8	Is comfortable to wear while dancing.	Should have
9	Interaction with the device feels intuitive and is easy to understand.	Should have
10	Is visually appealing and does not look weird or embarrassing to the dancer i.e. it integrates well with dancer's fashion choices and requirements.	Could have

The essential non-functional ("must have") requirements ensure that the device achieves its desired goals in the desired way. The main goal of CoreMnemo is to help dancers stay mindful of their pelvic alignment (first requirement). In order to achieve this goal, the device needs to function according to the functional requirements in Table II, which is only possible if the device stays in place (second requirement). As different individuals may sweat to a different degree, for example, this might differ from user to user. It is important to account for this. In order to achieve its desired functionality and application by dancers as individuals, it is essential that the device can be put on and operated autonomously (third requirement). Additionally, feedback needs to be intuitive in order to be effective for the user (fourth requirement)

The other important ("should have") requirements are mainly directed at ensuring wearability. The device should be comfortable and not restrict movement (eight and sixth requirements). It should also not distract the dancer from dancing (seventh requirement) as this would be the opposite of what CoreMnemo aims to do: staying mindful of alignment while also focusing on dancing. Additionally, different dancers have different bodies, the device should be wearable by these different bodies and functional for these different body types (fifth requirement). In order to allow autonomous use of the device, interactions with the device should also be easy to understand (ninth requirement). A final requirement, which could potentially enhance the user experience, is the visual appeal of the device. Ensuring this is also wearable with dancers own fashion choices could also improve the overall user experience.

Concluding notes

In this chapter, the interactions and functionality of CoreMnemo were specified. The concept is now developed sufficiently to start the realisation of a prototype for the CoreMnemo device. It is now clear in which ways CoreMnemo may potentially be used, and what requirements a protype should meet in order to achieve its goals. It has already been identified that apart from the device itself, likely some additional instructional resource needs to be developed that will ensure the ease of use as the device. This will be taken into account in the following realisation phase.

Chapter 6 – Realisation

The goal of the realisation phase is to develop a fully functioning prototype. This involves identifying the required components and integrating them into a final product which is ready for further evaluation. The process of developing the final prototype for the CoreMnemo is described in this chapter. The first section will focus on identifying the required components to create a successful outcome. The second section will then go further into the development of each of these components and how they are integrated into a complete system. In the final section, the protype is evaluated based on the previously specified functional requirements.

6.1 Identifying Components

After specifying CoreMnemo's functional architecture and interaction scenarios, it is now possible to define the required components that will form the final prototype. These components and their purposes will be introduced in this section.

6.1.1 Main components

There are two main hardware components which need to be considered: The sensing and feedback mechanism and the Application system. These components need to be combined in some way in order to form a functional end-product, which meets the specified requirements. The sensing and feedback mechanism is the electronic hardware element of the CoreMnemo, as introduced by the functional block diagram in Fig. 5.2 of the previous chapter. This mechanism is responsible for reading TrA muscle activation levels (using EMG), processing this, and administering vibrotactile feedback to the user when the activation levels drop below a certain threshold value.

The Application system is the wearable component of the CoreMnemo, which allows the user to wear the CoreMnemo on their body. It needs to house the sensing and feedback mechanism, while protecting and keeping all hardware parts together, as well as acting as some form of application mechanism that allows the user to mount the hardware components to their body and keep them in place.

6.1.2 User Guide

A third component that is separate from the final prototype is a user guide. This user guide is intended to clarify and explain the use and purpose of the CoreMnemo, as well as explaining how CoreMnemo is properly set up and applied. The purpose of this guide is to provide autonomy to the user and inform them properly, allowing them to use the CoreMnemo device without external guidance or supervision.

6.2 Development of Components

Having identified the main components of the CoreMnemo, the realisation and building process of the prototype was continued. The required parts and tools for each component were identified, after which they were integrated through iterations into a functional product. The process of developing each of the components, including the parts and tools used, will be discussed in this section.

6.2.1 Sensing and feedback mechanism

Parts and tools

The sensing and feedback mechanism has a few tasks that it needs to fulfil. It needs to read EMG values of the TrA muscle, process this data and adequately determine when to administer feedback, give vibrotactile feedback and it needs to be powered in some way. An Arduino Nano [111] was chosen as the microcontroller board for the system, to which the hardware components are soldered. Its small size and accessible software system make it suitable for creating a wearable prototype. For initial prototyping and testing purposes, an Arduino Uno [112] (which has the same layout as the Arduino Nano) in combination with a breadboard and prototyping kit (including prototyping cables, LED’s and resistors) was used to develop the final system. In order to measure EMG data, a MyoWare 2.0 muscle sensor [113] was used. The MyoWare muscle sensor is an all-in-one EMG sensor which is Arduino compatible. It has built in hardware filters, allowing for use of either Raw sensor output, rectified output or envelope (20 - 500 Hz) output. The sensor is directly snapped onto three traditional single-use snap electrodes for EMG and ECG measurements, specifically 24 mm Kendall H124SG electrodes by the brand “Cardinal Health” [114] were used. These are very small sized soft foam electrodes, with a solid conductive gel core, allowing them to adhere closely to the skin. An extended MyoWare reference electrode cable is used to increase the accuracy of the readings, which plugs into the MyoWare muscle sensor and snaps onto a fourth electrode. A small (unbranded) vibration dc motor module, 3.7-5.3V, with a mounting hole [115] is used to administer vibrotactile haptic feedback. For final integration of the electronic and logic components, a small piece of solderable PCB breadboard was used, in combination with solid core wires, paracord, a few pieces of heat-shrink tubing and a TX3 connector cable that was originally used to power a computer fan. A visual overview of components can be viewed in Fig. 6.1.

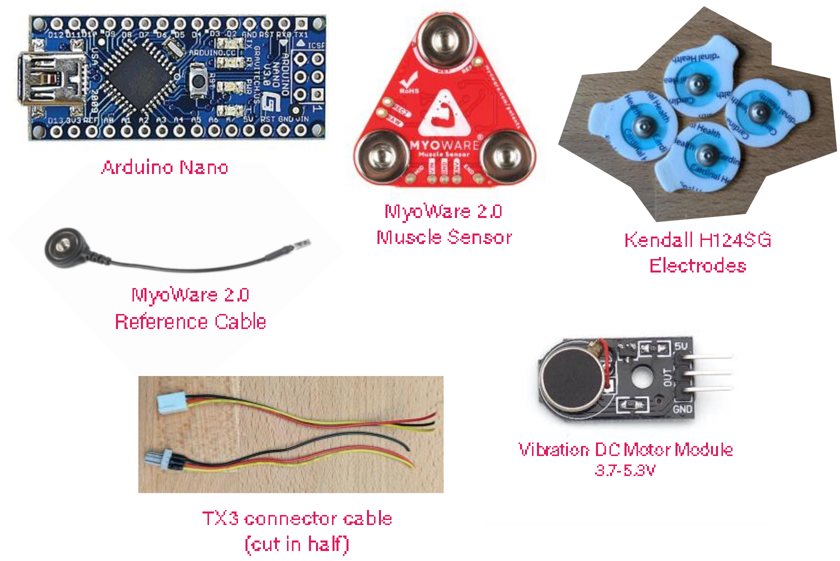


Fig. 6.1. *Overview of main components.*

Sensor setup and placement

The first step that was taken in developing the hardware was to create a working sensor setup. This was achieved by first connecting the MyoWare muscle sensor to the Arduino Uno and running the basic setup code provided by MyoWare [116]. For this, the Arduino was connected to the computer. In order to enable easier prototyping with the MyoWare sensor, three pin headers were soldered to the VIN, GND and ENV (envelope data) pins of the MyoWare sensor. Prototyping cables were soldered onto the RAW (raw data) and RECT (rectified data) pins. The code instructs the Arduino to read the sensor data and print it to the serial port. The data can be viewed using the Arduino serial plotter, showing a moving plot of the EMG values read by the sensor. The precise values can be observed using the Arduino serial monitor. With this setup, several experiments with varying placements of the sensor on different muscle groups, different signal types and using/not using the extended reference electrode were conducted in order to determine functionality, proper placement and which signal (envelope, rectified or raw) is best suited for use in the final solution. During these experiments movement exercises tilting the pelvis back and forth as well as consciously engaging and relaxing the muscles were performed to view their influence on the signal read by the sensor. The ENV signal, when used with the extended reference electrode showed the most accurate and clear representation of muscle engagement.

The MyoWare advanced setup guide [117], SparkFun guide [118] and several academic sources [119]– [120] were used to determine proper placement of the electrodes and the sensor on the abdomen to measure TrA activity. Sources suggested various placement methods. The most frequently suggested location was the bottom right/left of the abdomen near the hip bone. The most logical and suitable neutral location for the extended reference electrode in this case being the hip-bone, as suggested by [117]. Some sources [117], [120]–

[121] suggested horizontal placement, whereas others [119], [122] suggested diagonal placement (Fig. 6.2). Further tests reading the envelope signal and reference electrode at both horizontal and diagonal placement were therefore needed to determine the most suitable orientation. The diagonal orientation seemed to show the clearest signal with the least amount of noise (Fig. 6.3) and was therefore chosen for this project. The final placement of the sensor and reference electrode can be seen in Fig. 6.4.[2]

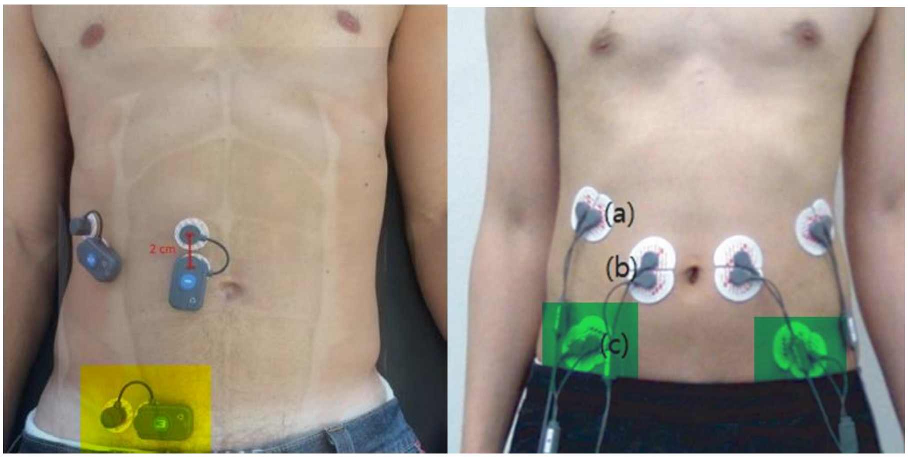


Fig. 6.2. *Examples of horizontal (highlighted yellow)* [120] *and diagonal (highlighted green)* [119] *electrode placement to measure TrA activity.*

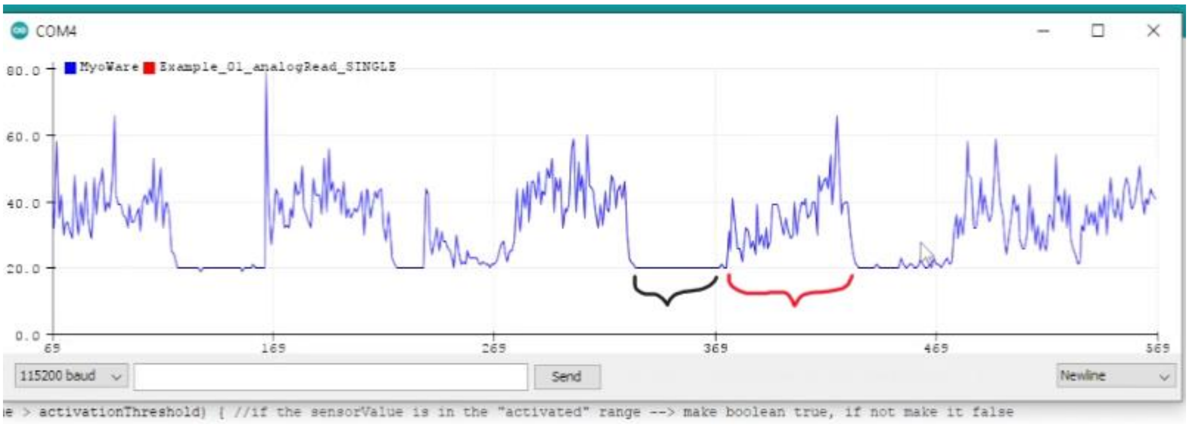
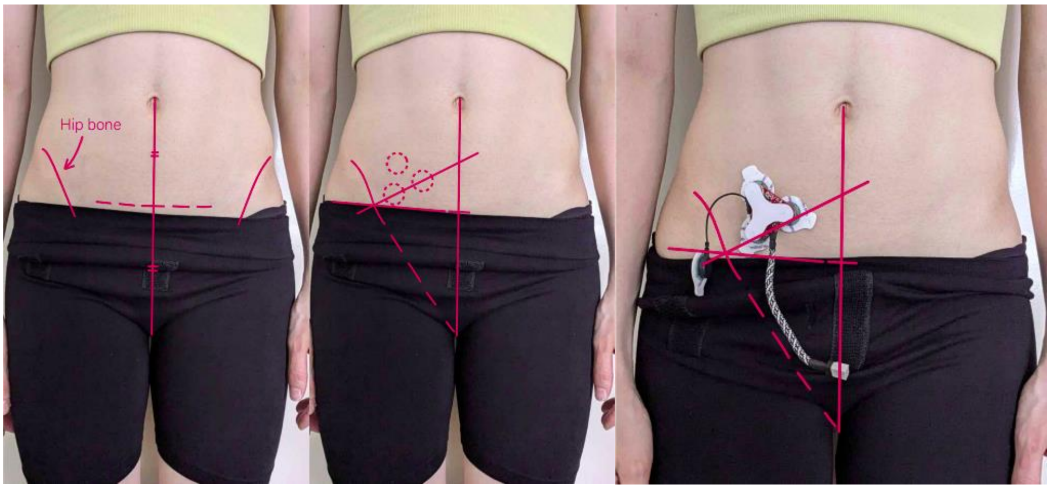


Fig. 6.3. *EMG signal of the TrA muscle. Anteriorly tilted pelvis with unengaged TrA muscle (indicated in black) versus neutrally aligned pelvis with engaged TrA (indicated in red).*

[2] During the user evaluation stages, an additional guide to place the MyoWare muscle sensor was developed. This is further described in Ch. 7.2.1.



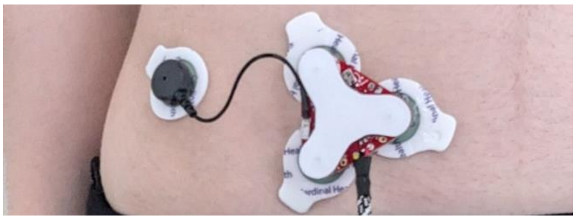


Fig. 6.4. *Final MyoWare muscle sensor electrode placement for measuring TrA activity.*

A setup with a green LED with a resistor on a solderless breadboard added to the setup thus far, adapting the code to switch on the LED when the incoming sensor values were below an arbitrary threshold, was used to test out different threshold values. The sensor setup still showed a certain level of noise on the incoming signal, causing the LED to flicker. In order to determine a logical threshold value, and to allow for a noise-free haptic feedback experience, this noise needed to be reduced. The Arduino movingAVG [123] library was used to calculate the moving average of the incoming signal over the past 10 measurements. This created a significantly more noise free, as seen in Fig. 6.5. Observing the plotted signal (while tilting and relaxing the pelvis), the threshold between muscle engagement and relaxation seemed to be somewhere between 25 and 30. After testing out different values within this range, the value that most accurately switched on the LED when the pelvis was released (tilting anteriorly or relaxing the TrA muscles), and off again when the pelvis was tilted into neutral position (or engaging the TrA muscles), was 28. EMG values seemed to be mostly universal across different individuals, which was tested by trying the same threshold value on three other persons. Therefore, 28 was selected as the final threshold value.

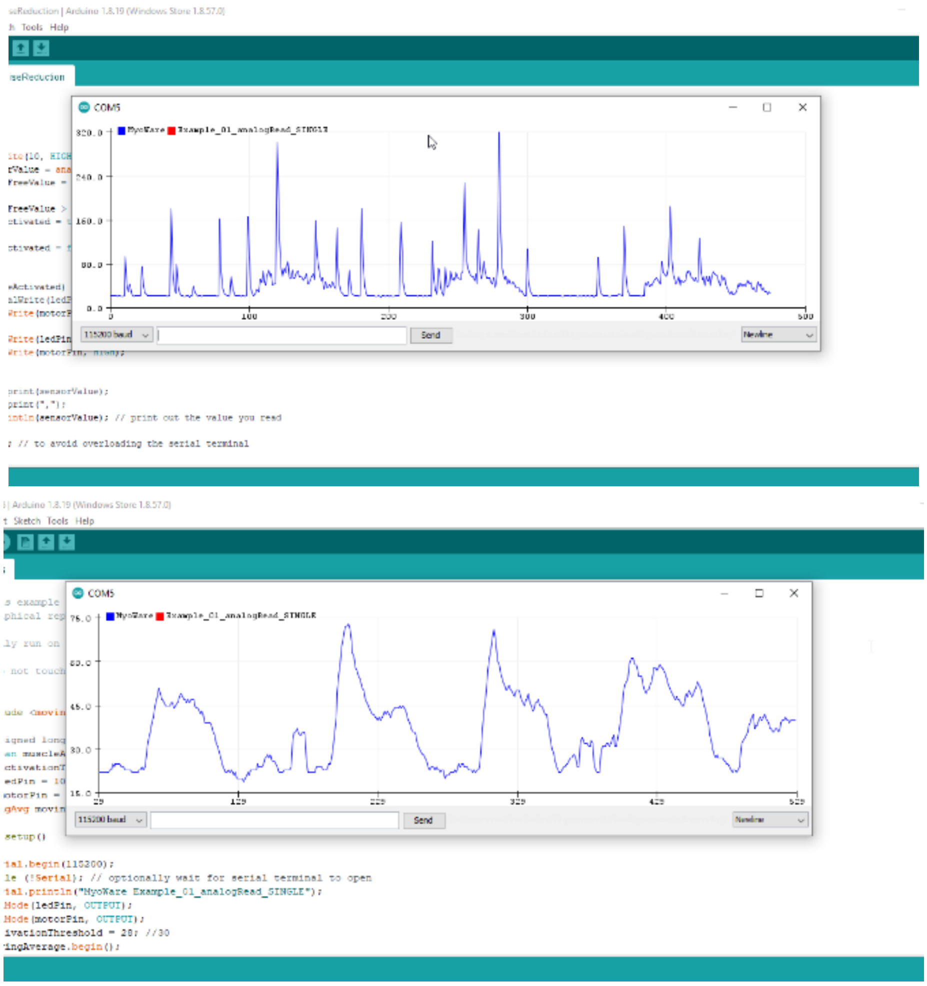


Fig. 6.5. *Top: Sensor signal examples before (min. value 20, max. value ±320) and Bottom: after applying moving average to reduce noise (min. value 20, max. value ±73).*

Feedback mechanism

Having configured the sensor hardware, as well as determined the electrode placement and threshold value, the next step was the integration of the small vibration DC motor module. This module (as introduced at the beginning of this section, and shown in Fig. 6.1) was first tested on its own, connecting it to the Arduino Uno and uploading a piece of test code that simply powered the motor on and off in bursts. After this test was successfully completed, the LED in the setup was replaced by the small vibration DC motor module and the code was adapted to include the DC motor instead of the LED. The first prototype of the electronic hardware was now completed. This prototype consisted of the Arduino Uno, together with the MyoWare muscle sensor and vibration DC motor module, connected via prototyping cables.

Programming

The final program that is uploaded to the Arduino is straightforward. First the relevant variables and movingAVG were initialised and the relevant pins are assigned in setup. The main loop consists of reading the sensor value, taking the moving average of this value and assigning them to variables. This is followed by an if-statement that checks whether the muscle is above/below the threshold value. Depending on the value the motor is turned on or off. Lastly, the value is printed, in order to plot or observe the data if needed. A short delay of 50 is added to prevent the serial terminal from overloading. The full code is shown in Appendix I.

Final configuration

A prototyping setup as mentioned above is not suitable for use inside a wearable device, as it is too large and fragile. In order to withstand the impact of body movement, components needed to be connected as efficiently and sturdily as possible. Permanent wires were soldered to both the MyoWare muscle sensor and the vibration DC motor module, according to the circuit diagram shown in Fig. 6.6. The motor module initially had pin headers attached to the pins, which were first desoldered. Three wires were then soldered to the pins. To improve the durability of the wires and achieve a more polished result, the wires were inserted into a piece of paracord of which the core strands were removed. This resulted in a three-core braided cable. A similar procedure was completed for the sensor. First, the pin headers and prototyping cables were desoldered from the MyoWare muscle sensor. Using a cable with a detachable connector allows for more flexibility of the sensor, adding the possibility to easily disconnect the sensor from the rest of the electronic hardware. This also allows the length of the cable to be extended with an additional cable if needed. To achieve this, the TX3-connector cable was cut in half and each half was wrapped with a piece of paracord in the same way as the wires of the motor module. The three wires of the female connector half were soldered onto the pins (VIN, GND and ENV) of the sensor. The male connector half was soldered to the Arduino logic components as described in the following paragraph.

The small portion of solderable PCB breadboard was used to create 4 traces (using LED-legs) for each of the pins used by the Arduino. Small wires were each soldered to a row on the breadboard piece, as seen in Fig. 6.7. The GND pins of the MyoWare muscle sensor and vibration DC motor module are connected to the GND row. The VIN pin of the sensor and the 5V pin of the motor module are connected to the 5V row. The ENV pin of the sensor is connected to the A0 row and the IO pin of the motor module to the (unlabelled) D6 row. After connecting the wires, the pieces of heat-shrink tubing which were threaded onto the cables prior to soldering, were shrunk onto each end of the cables, securing the paracord and wires into place. As a final step, the solder joints were reinforced with small dollops of hot glue as shown in Fig. 6.8. The final setup of the electronic hardware configuration is shown in Fig. 6.9.

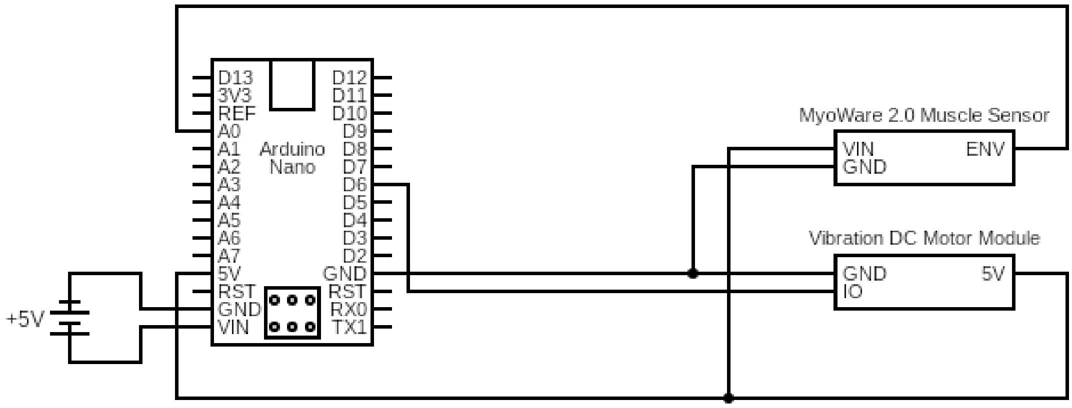


Fig. 6.6. *Circuit diagram of CoreMnemo electronic hardware.*

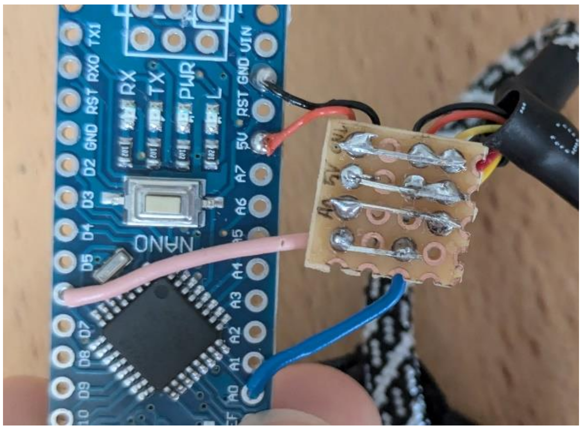


Fig. 6.7. *Final wiring consisting of a piece of PCB breadboard with traces forming four intraconnected rows.*

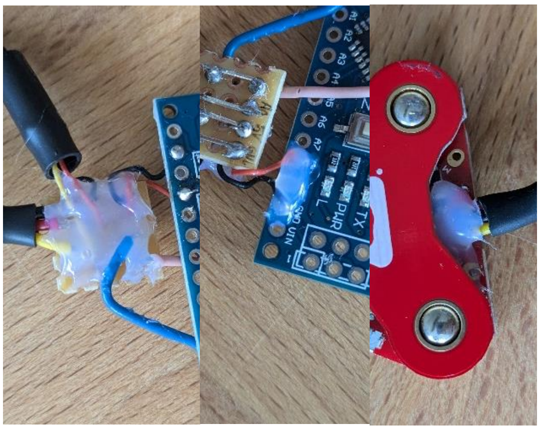


Fig. 6.8. *Soldered connections reinforced with hot glue.*

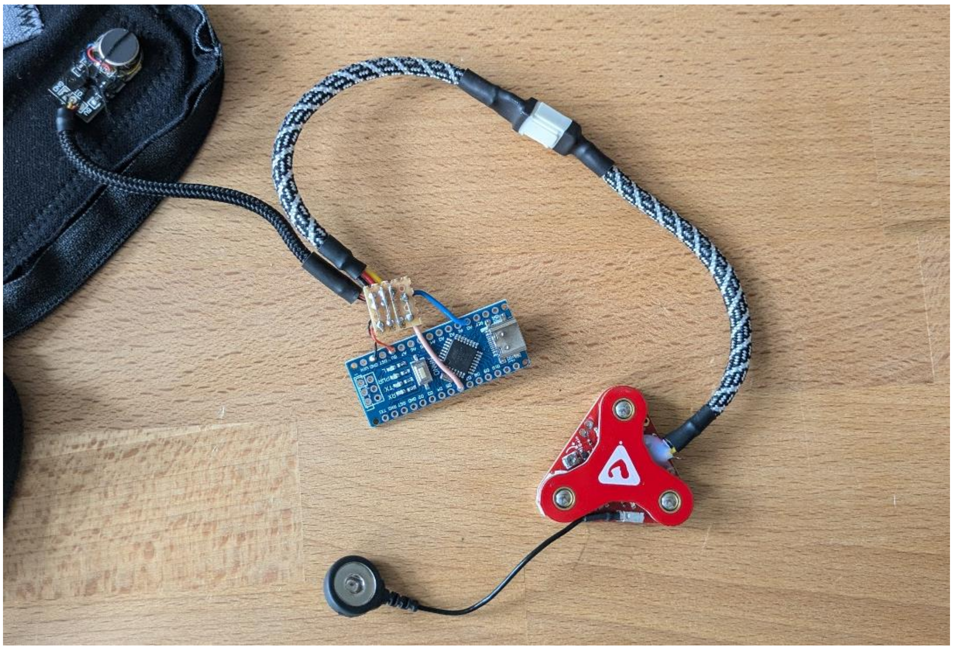


Fig. 6.9. *Final CoreMnemo electronic hardware setup, including Arduino nano, MyoWare muscle sensor, MyoWare reference cable and vibration DC motor module.*

Finding a suitable external power source required testing of a few portable power banks. The power bank had to be small enough in physical size to not make the device bulky and have a battery capacity that is large enough to sustain the device for the duration of an entire dance class. A small power bank that supports wireless charging was first tested. This seemed to work at first, but the power bank stopped powering the device as soon as it went into standby mode. The same problem occurred with multiple other power-banks. Some power banks are “intelligent” and require a certain amount of current to be drawn in order to continue powering the device. The CoreMnemo porotype does not draw enough current to achieve continuous powering of these types of power banks. After trying several portable battery packs, a Hema power bank [124] was found to be of the “less intelligent” type that continuously powered any plugged-in device. Another way to mitigate this problem using an “intelligent” power bank, is to plug a small device that does draw enough current into another port of the power bank.

6.2.2 Application system and wearability

Development process

The development of the application system component, i.e. the mechanism that makes the CoreMnemo prototype wearable, was one of the main challenges during the realisation phase. The MyoWare muscle sensor requires direct connection to the skin, while the electronics must be contained and held in place in a way that can withstand dance movement and meets all other functional and non-functional requirements.

Initial sketches and ideas involved the attachment of some form of pouch housing the electronics to the hip region, connecting to the muscle sensor that was separately attached to the abdomen with the adhesive electrodes. This pouch would contain all components in one location. Various attachment mechanisms were sketched out and inspected via paper prototypes, aiming to design a pouch that is as small and flat as possible. One concept involved a pouch housing the electronic hardware components, made of layers of kinesiology tape (sweat and movement proof), that could be directly stuck to the users abdomen. Combined with kinesiology tape used to reinforce the sensors[3] (Fig. 6.10). Another concept involved a zipper pouch (easy access of components) with perforations, through which the adhesive electrodes could be snapped to the muscle sensor contained inside. The adhesive electrodes would then also serve as the attachment mechanism with which the device is attached to the user (Fig. 6.11). Each of these concepts has advantages and disadvantages. A combination of aspects of these concepts and further sketches led to the development of the final design which was then constructed for final integration with the electronic components.

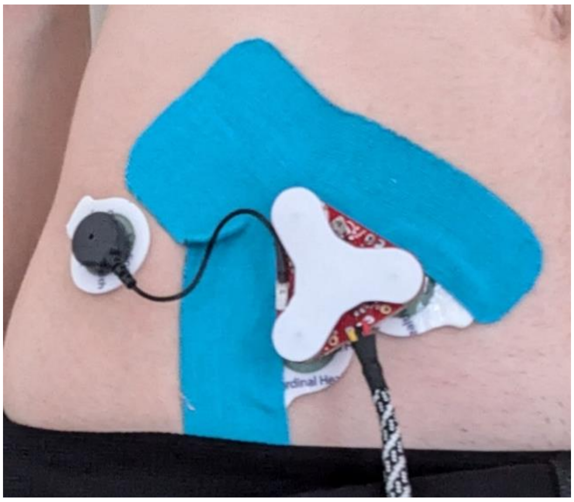


Fig. 6.10. *Kinesiology tape electrode and sensor reinforcement concept.*

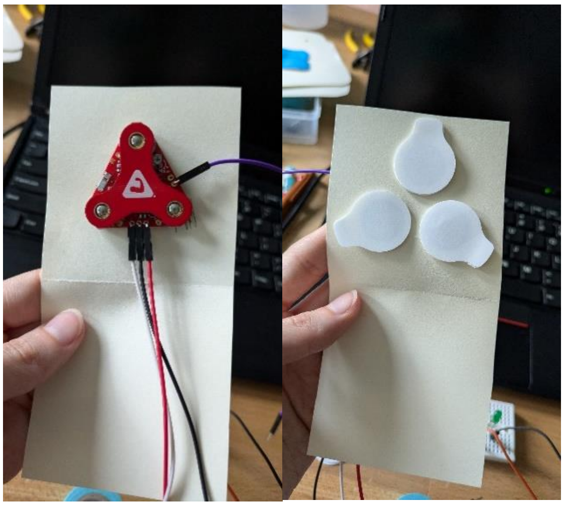


Fig. 6.11. *Paper prototypes of alternative attachment concept.*

Final design

The final design of the application system consists of two components: a pair of tight-fitting shorts and a pouch, as seen in the sketch in Fig. 6.12. The pouch is intended to house all electronic components and vibration motor, except for the muscle sensor, which is placed in its intended position with the adhesive electrodes directly on the skin. The shorts' purpose is to hold the pouch in place and the tight fit provides support to the muscle sensor, keeping it in place snugly.

The pouch is detachable from the shorts via Velcro strips, which allows for more flexibility and an easier application process. One benefit of this system is washability. With sweating and continuous wear, it is preferable that the shorts are washable, which would not be

[3] Placing Kinesiology tape over the electrodes for reinforcement seemed to interfere with measurements during testing, it is yet to be determined whether this is a feasible solution for additional sensor support.

possible if the electronic components were permanently attached. Multiple pairs of shorts may also be acquired in order to rotate clean pairs in between washes. Another benefit is the flexibility of sizing, as the shorts are universal and the same pouch design can be used with different sizes of shorts. If a user changes sizes, the shorts could also easily be replaced with a pair in a different size without needing to replace the pouch and electronic components. The sensor connects to the electronic components in the pouch via its detachable cable. Both the pouch and the shorts have a buttonhole through which the muscle sensor cable can be fed into the pouch. A zipper is placed around three edges of the pouch, allowing to be opened fully and enable easy access to its contents.

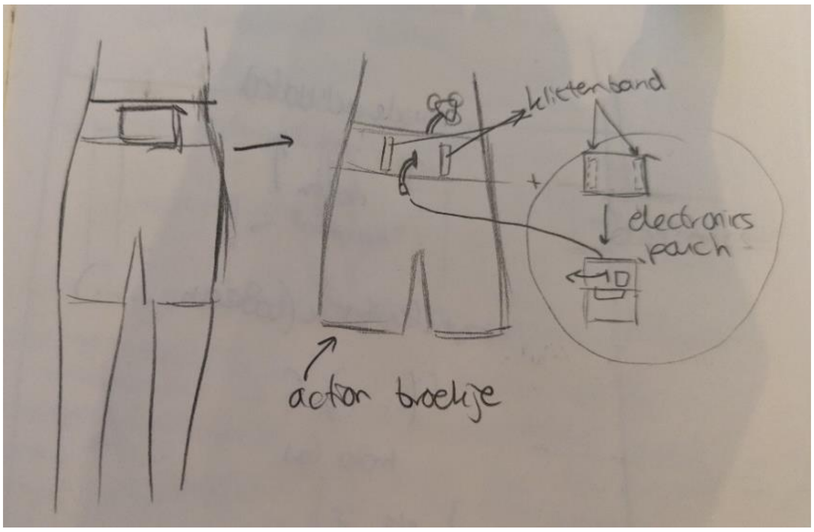


Fig. 6.12. *Sketch of final application system design.*

Construction process

The pouch and shorts were assembled using a sewing machine, a selection of sewing materials, elastic Velcro, pre-made bike shorts and repurposed fabric. The base of the shorts consists of a pair of basic bamboo bike shorts, onto which the Velcro was attached and a buttonhole was sewn into. Using the location of the muscle sensor, the correct placement of the buttonhole for the sensor cable was determined using a safety pin. Several test buttonholes were sewn onto a piece of test fabric, of which the results showed that the fabric of the shorts needed to be reinforced to achieve a clean outcome. A piece of grey synthetic fabric from an old pair of sports leggings (stretchy, but with a firmer texture) was placed onto the inside of the shorts as a backing (Fig. 6.13). Afterwards, the final buttonhole was sewn into the shorts using the sewing machine.

Fig. 6.13. *Reinforcement fabric and buttonhole.*

Next, the electronics pouch was created. The fabric of an old shapewear dress, which was made from a black synthetic knit fabric, was used to fashion the pouch. This fabric was selected because it has a decent amount of stretch, allowing for comfort and flexibility, but not so much stretch that components may sag too much inside the pouch. The size of the pouch (approximately 10 x 16 cm) was determined based on the dimensions of the power bank with its cable plugged into it. A rectangular piece was cut from the fabric which, when folded in half, fit these dimensions (taking seam allowance into account). Using the placement of the buttonhole in the shorts and the placement of the sensor, the location of the buttonhole in the pouch was marked out. After placing another piece of the previously used grey synthetic fabric on the pouch as a backing, the buttonhole was sewn on using the sewing machine. Next, a strip of the hook side of the elastic Velcro was sewn vertically to each side of the pouch. Elastic Velcro was chosen to allow more flexibility of movement and sturdier adhesion during movement. Next, the zipper was sewn around the edges to complete the pouch. As a final step, a piece of elastic was sewn into the pouch to hold the electronic hardware components in place inside the pouch. The final pouch can be seen in Fig. 6.14.

Fig. 6.14. *Completed CoreMnemo electronics pouch, opened (Left) and closed (Right).*

The finished pouch was then used to determine the final placement of the elastic Velcro strips on the shorts. Lining up the buttonholes, the placement of the Velcro strips on the pouch was used to mark out the right location on the shorts. Two strips of the loop side (more comfortable for the wearer) were then sewn onto the shorts. The final pair of shorts can be seen in Fig. 6.15. Several pairs of these shorts were made in the sizes S-XL, each using the finished pouch to determine buttonhole and Velcro placement.

Fig. 6.15. *Completed shorts for mounting the CoreMnemo pouch.*

Integrating the electronic hardware

To complete the prototype, the electronic components were placed into the pouch, behind the sewn in support elastic. The vibration motor module was then hand-sewn onto the pouch using its mounting hole, as can be seen in Fig. 6.16. The motor module was sewn through one of the Velcro strips (the one closest to the middle of the users stomach), as the fabric is very sturdily reinforced in this place. The Velcro strips also sit closest to the users skin, allowing the vibration to be felt more easily. The solder joints and traces on the piece of breadboard and Arduino had a tendency to catch onto the fabric of the pouch. Small pieces of electrical tape were stuck onto these components to resolve this problem (Fig. 6.17).

Fig. 6.16. *Vibration DC motor module sewn into pouch.*

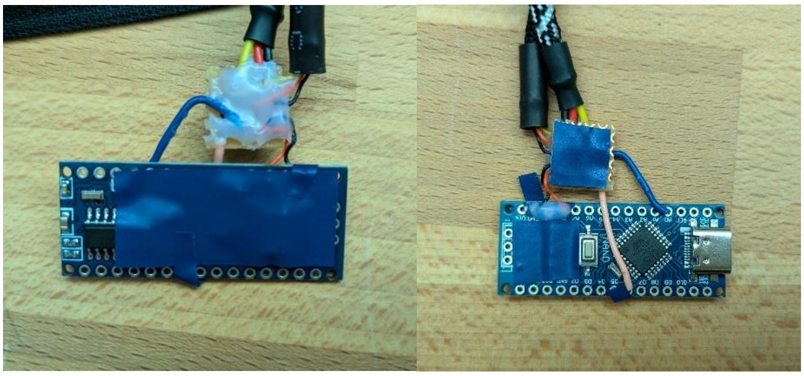


Fig. 6.17. *Arduino Nano and PCB breadboard covered in electrical tape.*

6.2.4 User guide

The main component of the user guide is a PDF file manual (created in Adobe illustrator [125]), designed for mobile viewing, that can be accessed via a QR-code. This QR-code was generated using a free QR-generator [126], and is provided to the user via a printed card (Appendix J). The visual identity and language use of the manual were designed to reflect a sense of playfulness and accessibility, while remaining clean and informational. There are four main sections that make up the manual. A section introducing the CoreMnemo, a section covering how CoreMnemo should be used and two sections covering how the CoreMnemo should be put on and taken off. The full user manual can be viewed in Appendix K.

The introduction section starts with a cover page, before starting with an introduction and explanation of what pelvic alignment is and its relevance for dancers. This explanation includes an illustrated demonstration of proper and improper alignment, as well as reasons why CoreMnemo may be suitable solution for the user. The next subsection covers what CoreMnemo is and what it does, including illustrations. In the final subsection it is explained how CoreMnemo works, providing a brief explanation of electromyography (EMG).

The second section is titled “Using CoreMnemo” and starts with an overview of the components that together make up the CoreMnemo device, before explaining how the device is used, how to turn it on and its relevant safety warnings. Images are used for further clarification. The following subsection provides a brief explanation of how to engage your core and what the user could do if they are having troubles with this. The final subsection explains the recommended frequency with which CoreMnemo is used and how to gradually stop using the device again. Here it is also emphasised that everyone is different and that the process does not define the users value, to aim at reducing stress that the user may feel when learning how to use the device.

The third section shows step by step instructions, including images (examples shown in Fig. 6.18), of how the device is applied to the body and how the pouch and shorts are worn and connected. The first subsection explains the placement of the sensory and reference electrode, directing special attention to the specific location of the electrodes. Images combined with illustrations are used to clarify this process. The second subsection show the next steps of putting on the shorts and pouch. For additional guidance, a video (linked at the bottom of Appendix J) showing the process of putting CoreMnemo on is linked. The fourth and final section provides a similar link at the beginning, linking to a video (also linked at the bottom of Appendix J) that shows the process of taking CoreMnemo off. The rest of the section explains step by step how to take the device off again, including images for clarification where needed.

Fig. 6.18. *Examples of user manual visuals.*

6.2.5 Final CoreMnemo prototype

In summary, the CoreMnemo consists of electronic hardware components (MyoWare muscle sensor, Arduino Nano, Arduino Program, vibration DC motor module, power bank), an application system (shorts and pouch) and a user guide. The MyoWare muscle sensor is attached directly to the skin with adhesive electrodes in the location of the TrA muscle. The shorts are worn over top of this. The pouch is attached to the shorts via Velcro and houses all other electronic components. The Sensor connects to the other electronic components via a cable that is threaded through the buttonholes in the shorts and pouch. the user can wear their regular dancing trousers over the CoreMnemo. The device turns on as soon as the power bank is plugged into the Arduino and measures the users TrA EMG values. If the device registers that the muscle is too relaxed, the vibration motor is turned on to remind the user to tilt their pelvis and/or engage their core. The motor is turned off once the desired muscle activation levels are reached again. Images of the final prototype and how it is worn (detailed descriptions are given in the manual in Appendix K) are shown in Fig. 6.19-20. For further support to the components, it is optional (and recommended) for the user to wear dance trouser over the CoreMnemo device.

Fig. 6.19. *CoreMnemo shorts worn on the body (left) and CoreMnemo shorts with the electronics pouch attached (right).*

Fig. 6.20. *CoreMnemo items combined into a container with manual card for presentation to user study participants.*

6.3 Functional evaluation

Having completed the prototype, a final functional evaluation can be performed to determine whether the device meets all functional requirements and is ready for further evaluation with users. Each of the requirements was tested and requirements that were successfully implemented were marked as such. The outcomes of this evaluation can be seen in Table IV.

The evaluation was performed by the designer on themselves and involved various movement tests, while wearing the device, to determine whether the device was functional. As the final design of the device is intended to be worn on the abdomen, it can already be determined that the fourth requirement has been met. The first three requirements were tested by connecting the device to a laptop and observing the EMG data plot while worn. Test were conducted engaging the core and releasing it, as well as tilting the pelvis and releasing it, while observing the response of the plot and determining whether the vibration motor is responding adequately. Through this it could be determined that the requirements have been met. The requirement of safety (seventh requirement) is mainly a concern of adequate instruction in order to prevent any potential harm. This has been addressed in the user manual and therefore the requirement has been met. The other "must have" requirements were tested by wearing the device and performing various dance movements such as spinning, jumping and running, as well as floorwork movements to evaluate the eighth requirement. The device continued to function under sweaty and moving conditions. In the case of the test, the device also seemed to be able to withstand impact with the floor.

The recommended criteria ("should have" requirements) were evaluated by once again wearing the device and observing the feedback quality. As previously discussed in Section 6.2.1, moving average was used to reduce the noise level of the signal when comparing it to the threshold value. Combined with the observation that the vibration feedback did not seem particularly irregular, this requirement can be considered as met. Wearing the device for a prolonged period of time also showed that the device is able to function for a duration of at least an hour. The final four requirements have not been implemented into the final CoreMnemo prototype.

All "must have" and should have" requirements have been met, indicating that the device functions correctly at a basic level (meeting the essential criteria) and with enhanced performance (meeting recommended criteria). Requirement number 8, which is a "must have" requirement, has been tested for impact resistance, but it remains difficult to determine how the device will hold up during an actual user case, therefore it has been marked as only partially implemented. In conclusion, the device can be considered as fully functional and ready for user evaluations.

TABLE IV

FUNCTIONAL REQUIRMENTS ORDERED BY MOSCOW PRIORITY, INDICATING WHETHER THEY HAVE BEEN SUCCESFULLY IMPLEMENTED

Nr.	Functional requirement	MoSCoW Priority	Successfully implemented
1	Reads TrA (Transversus Abdominis) muscle EMG values accurately.	Must have	X
2	Vibration motor turns on when the EMG values of the TrA are below *the threshold value.*	Must have	X
3	When the EMG values of the TrA are above *the threshold value* the vibration is stopped.	Must have	X
4	Can be worn on the body in the abdominal region.	Must have	X
5	Can operate under normal dancing conditions (e.g. spinning motions, fast movement, etc.).	Must have	X
6	Is sweat resistant i.e. it does not malfunction with the influence of sweat.	Must have	X
7	Is safe to use i.e. does not critically endanger the user.	Must have	X
8	Is impact resistant.	Must have	/
9	Can cope with potential noise in the incoming EMG signal.	Should have	X
10	Battery/charge of the device lasts for the duration of an entire dance class (approximately 60 minutes).	Should have	X
11	Vibration motor starts “pulsing” when the EMG values of the TrA are above *a certain value.*	Could have	
12	Stores data for further analysis by the user.	Won’t have	
13	Vibration motor vibrates more intensely the further the EMG value drops below the threshold value.	Won’t have	
14	Indicates power bank is half empty by vibrating in a pattern of 3 long pulses and 3 short pulses.	Won’t have	

Concluding notes

The final prototype for the CoreMnemo has now been completed. Based on the functional evaluation, it seems at this moment that the device is functional and therefore ready to be further evaluated by users. Outcomes so far have been promising. Further evaluation will show if these seemingly positive results are carried through when tested with users.

Chapter 7 – Evaluation

Having developed a functional prototype, the final task that remains is to evaluate this prototype with users. During the evaluation phase, user tests were conducted to determine whether the prototype is usable and meets the previously specified non-functional requirements. Any flaws in the device that have been missed during the realisation phase may also be detected. Based on this knowledge, conclusions can be drawn regarding whether the developed CoreMnemo device addresses the previously identified challenge of training pelvic alignment awareness in dancers. This chapter will discuss the design and results of these user evaluations. The first section will provide a detailed description of the testing setup and evaluation procedures. Followed by this, the outcomes of the tests are summarised. In the final section of this chapter, the non-functional requirements are assessed, and conclusions are drawn based on evaluation outcomes.

7.1 Study design

The user test design consisted of two segments: an interaction segment and an evaluation segment. The majority of the test is taken up by the interaction segment, in which the participant wears and uses the prototype. This is followed up with the evaluation segment, in which the participant shares their experiences and answers questions about their interactions with the device. The complete information letter given to participants, which contains an in-depth description of the test procedures and duration, is presented in Appendix G. The informed consent form given to participants are presented in Appendix H.

7.1.1 Interaction segment

The interaction segment was designed to resemble a real-life use case, including three main components. First, the participant is given the box containing the CoreMnemo parts. They are then tasked with putting on the CoreMnemo device autonomously, using the provided user guide. As this requires the participant to expose their stomach, this portion of the test is not videorecorded, and written notes of observations were taken instead. Help and supervision are provided if needed to ensure that the device is properly put on before continuing to the next part of the interaction segment.

The second component was set up as a simulation of a modern/contemporary style dance class, in order to test the performance of the prototype in a realistic dance environment. This dance class was constructed as a shortened version of a regular dance class technical exercises (derived from both classical ballet and modern technique), learning & executing a small piece of choreography and improvisation. These elements are all commonly encountered in a dance class environment. A list of the included technical exercises (further elaborated in [127] and [128]), in order of instruction and execution, are listed in Table V. The choreography taught during the choreography section was designed to include extreme movements of the spine, turning movement, balancing and floorwork, touching upon areas in which core engagement/pelvic alignment is particularly important. During the improvisation exercise the participant is asked to improvise freely to a song of their choosing. The dance class component of the test is videorecorded for further in-depth observation.

During the final component of the interaction segment, the participant is asked to autonomously remove the CoreMnemo device again, using the user guide. Written notes with observation are taken and supervision or help are provided if needed, to ensure the device is handled appropriately.

TABLE V

TECHNICAL EXERSICES INCLUDED IN INTERACTION SEGMENT OF USER TEST

Mode	**Exercise**	**Steps**
Stationary in centre	Plié exercise (in first, second, fourth and fifth position, left and right)	Plié, grand plié, contraction, cambré, forward stretch, relevé balance
	Tendu exercise (left and right)	Tendu, flex foot, développé 45 degrees, coupé balance in plié and with straight leg, jeté
Moving across the floor	Turn exercise (modern jazz, in parallel, both sides)	Triplets/pas de bourrée, balance, half turn, single turn, double turn (or more)
	Emboîté exercise (both directions)	Emboîté
	Coupé jeté combination (modern jazz, both directions)	Piqué turn, coupé jeté, basic roll over floor
Floorwork across the floor	Floorwork crawling exercise (contemporary, both directions)	"crawling" facing the front while moving hands and feet separately, returning to a kneeling position.

7.1.2 Evaluation segment

The interaction segment is followed up by the evaluation segment, which is aimed at collecting information about the participants experiences to determine whether the CoreMnemo prototype meets the non-functional requirements. This segment is made up of two parts. The first part of the evaluation segment is a short semi-structured interview, designed to collect additional remarks that the participant may have regarding their experience using the device as well as perceived pros & cons from their perspective and any other relevant topic of feedback. The question guide used for this portion of the evaluation segment is listed in Appendix E.

The second part of the evaluation segment is a paper survey that the user is asked to fill in after the interview. This survey (Appendix F) consists of a list of statements about using CoreMnemo, for which the participant is asked to select to what degree they agree or disagree with these statements. These statements were formulated to specifically target the list of non-functional requirements and determine whether they have been met. After filling in the survey, the user test comes to an end.

7.2 Outcomes

Four dancers of different ages and with different backgrounds participated in the user evaluations. Participant 1 (age 17, female) completed pre-professional dance education, focusing on modern dance, ballet, character dance, and improvisation. She recently auditioned for professional higher education dance schools and aims to have a career in dance. She takes classes in various urban styles aside from her other training. Participant 2 (age 16, female) is enrolled in the same pre-professional dance education program. She also participates in recreational classes in various urban styles. Her aim is to become a professional dancer. Participant 3 (age 19, female) just returned from a dance hiatus. Her main focus is K-pop and Hip Hop and before taking a break from dancing used to take regular weekly ballet and contemporary classes, but has not built a lot of experience in this area. She takes dancing seriously but is not aiming for a career in dance. Dancer 4 (age 22, female) is a second-year contemporary dance student, preparing for a career in dance. The main focus of her degree is contemporary dance, supported with ballet lessons, but she also has experience in various urban styles.

7.2.1 Observations

Several noteworthy observations were made during the evaluations. The first session (participant 1) formed a baseline and led to insightful observations that were immediately implemented before the following evaluation sessions. A first observation was that reading the user manual takes a significant amount of time. In the following tests participants were therefore given more time to read the manual before formally starting the test. The instruction video for putting the CoreMnemo was placed before the written instructions on sensor placement in the manual. This lead to confusion with the participant and misunderstandings about correct sensor placement. The reading order of the manual was updated to improve clarity for the following sessions. The third observation made during the first test leading to changes in the design was that placing the muscle sensor, even with the inclusion of pictures, was perceived as difficult. This led to the development of a physical placement template (described at the end of this section), to aid the user in placing the muscle sensor correctly. With assistance the participant was still able to successfully apply the device. During the choreography portion of the test the power cable of the power bank unplugged once due to not being inserted into the Arduino all the way. Sweating caused the electrodes to be somewhat loose when taking of the device, with the reference electrodes being almost completely detached.

Participant 2, taking part in the second session, seemed to be of a more detail-oriented nature and took a more thorough approach when reading the manual. She also seemed to be more hesitant in the application process, being afraid to make a mistake. With the addition of the placement template and the instructions, she was successful at autonomously putting on the CoreMnemo and turning it on. Once the device was put on, she remarked that it felt funny. It took her a few minutes to adjust to the device, but quickly discovered how to use it. During the initial stages of the test the participant seemed to be somewhat distracted due to the new experience of dancing with the device. This gradually reduced during the first technical exercise. Participant 2 felt somewhat clumsy during the process of removing the adhesive electrodes from her skin, due to the sticky conductive gel.

The third session took longer than the first two sessions, due to participant 3 having less experience with contemporary dance and needing more instruction. Apart from forgetting to remove the adhesive backing from the electrodes, she was also able to autonomously put on CoreMnemo without additional help. Due to sweating, the electrodes very easily came loose of the skin when taking off the device. The third participant seemed the least determined to respond to the feedback, and seemed to ignore vibrations during times between dance exercises.

The fourth participant (fourth session) was initially more hesitant with using the device. While the first three participants adapted to the CoreMnemo easily, viewing it as a part of themselves, the fourth participant perceived the device more as a foreign body. She frequently commented about the device feeling funny or weird. She commented that the device vibrated quite a lot, and initially it was difficult for her to stop the CoreMnemo from giving vibration feedback by engaging her core. She mentioned at this point that she has scoliosis which could be a potential cause for this. The adhesive electrodes adhered very well to the participants skin, causing her some discomfort when removing them from her skin again.

The functional state of the CoreMnemo prototype was studied after every user session. Even with reinforcement of the wires, there seemed to be slight damage done to the connections with every session. The insulation around the wires would start tearing and some areas of exposed core would start fraying. Additional upkeep, adding more hot glue, was needed to prevent failure. Additionally, as briefly touched upon in the previous paragraph, different sweating conditions influenced the adhesion of the electrodes. This could lead to different outcomes in the future, possibly coming loose during use for some, while they may adhere too well for others. Additionally, while the electronic components in the CoreMnemo pouch are not very heavy, they did seem to weigh down the pouch to some extent during use. This caused the pouch to not fit completely snugly against the stomach of the wearer, forming a small gap between the pouch and shorts. While the pouch adhered well to the shorts, this did lead to more movement of the pouch than needed and also a less snug fit of the vibration motor on the stomach.

Placement template

The physical placement template (Fig. 7.1) described earlier in this section, was designed to improve the ease of application of the MyoWare muscle sensor. The template was made out of a transparent plastic sheet, out which a triangular shaped hole with indents was cut, in the same orientation as the sensor should to be placed on the body. Black permanent marker was used to indicate the orientation of the sensor cable. An oval shaped mark was drawn on the template to indicate where the template should be lined up with the hip bone. A small notch in the top right corner of the template indicates the corner that should face the navel.

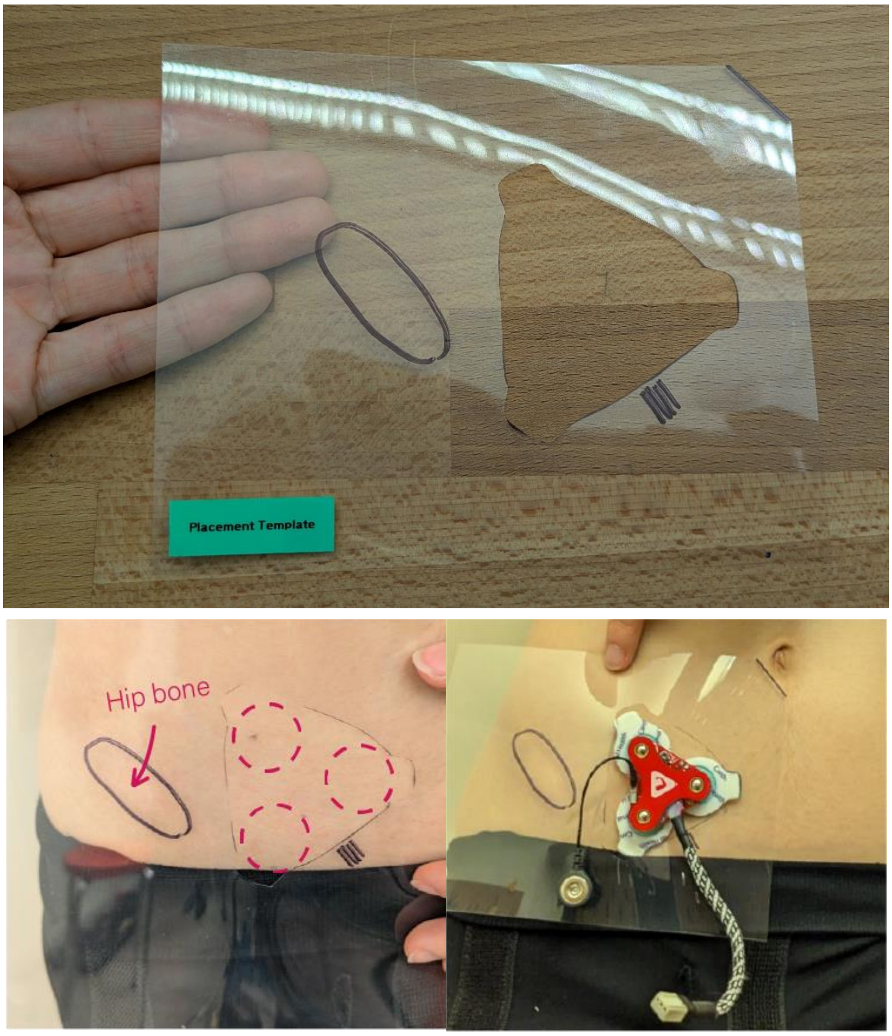


Fig. 7.1. *Placement template for the MyoWare muscle sensor.*

7.2.2 Interview component/feedback

Participants gave both overlapping and individually differing responses to the questions asked during the interview. Participant 1 mentioned that she enjoyed using the prototype and that it helped her to be conscious of engaging her core. She also mentioned that she thought that the device felt comforting, like there was a small animal or something of the sort on her stomach. When discussing points that she felt were difficult she mentioned the placement of a sensor, and that maybe something like a temporary tattoo guide or something similar might help her with placing the sensor more easily. She noted that, even during floorwork, the device wasn't really in her way and that it didn't really catch her attention in any particular way or cause her pain. She also suggested putting something on the outside of the pouch to see whether the device is on or not, due to the incident of the cable slipping out. In terms of using the product, she felt it was easier to do certain moves with the device, due to her increased core engagement, and that using it felt a little bit like a game to her. She did not personally clearly notice any false positives or negatives and overall thought the device was helpful to her.

Participant 2 also mentioned enjoying the experience of trying out CoreMnemo prototype. She mentioned that she thought putting on the sensor was quite difficult, but that it was "well explained, which made it not so difficult anymore". When asked about downsides of the CoreMnemo device in her opinion, she mentioned the Velcro attachment mechanism because she felt it didn't connect the pouch to the shorts very strongly. In terms of false positives/negatives, she noticed very brief short vibrations in between periods of no vibrations relatively often, especially during the plié exercise. She overall thought that the device worked well because it was sensitive to her engaging and relaxing her core as well as tilting her pelvis. In line with participant 1, participant two also felt that using the device felt a bit like a game, where she was trying to "win from the device".

The third participant first mentioned that she thought the use process of the CoreMnemo prototype was very clear because of the level of detail in the guides. She mentioned that personally reading things is difficult for her, but that the video made this process easier for her. She thought that maybe some people would find it scary to wear some sort of machine on their body, but then expressed that it felt very gentle and that it stayed in place well. There weren't any steps of the process that she expressed as particularly challenging. She added that "the manual said that finding the right spot was a bit difficult, but actually it was not too difficult at all". Regarding points she did not like about using the prototype, she included that she would like to see something that can pause the device. When not doing anything, the device was vibrating for her, and she felt it would tire her out if she were to keep trying to engage her core this entire time. As a closing remark she mentioned that she thought that device worked well overall, but that she sometimes chose to ignore it because she was tired.

Participant 4's described her overall experience as very interesting. She remarked that the device actually works. At first, she thought it was really weird to put on, especially the jelly electrodes felt peculiar to her and that the buzzing felt very odd to her at first. She also noted in relation to this that it was quite easy to put the device on due to the video. Because she noticed buzzing frequently even when she felt she was engaging her core enough she sometimes questioned herself whether she was wrong or whether the device was wrong. She also reiterated that she has scoliosis and that her posture is therefore "wonky", leading her to suggest that maybe it wouldn't fully work for her because of this. When asked about changes she would make to the device, she suggested that the overall pouch could be more compact. Currently the pouch creates a visible bump underneath dance trousers, which she thought would be a little embarrassing in a dance class. Overall, she thought the device was helpful and that it did help her be more mindful of her pelvic alignment and core engagement. She also felt that it potentially could help dancers, as many of them suffer from lower back problems.

7.2.3 Survey

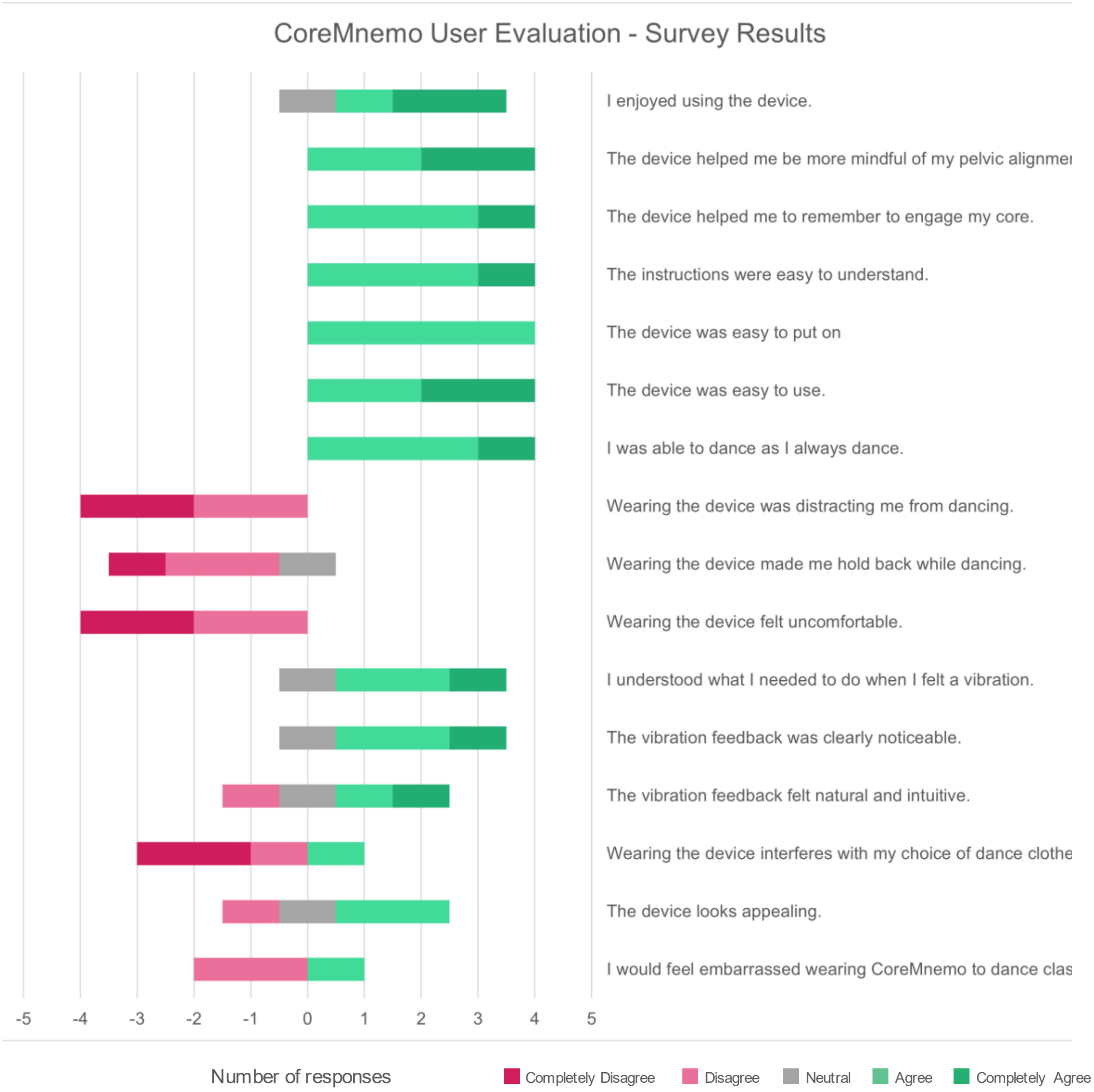


Fig. 7.1. *Survey results.*

Throughout the survey, participants' responses were mostly in line with each other. All but one dancer either agreed or completely agreed to the statement about the level of enjoyment they experienced using the device ("I enjoyed using the device") with one dancer responding neutral.

The most consistent results were observed about the main functionality and usability. The statements regarding the CoreMnemo's main functionality ("the device helped me to be more mindful of my pelvic alignment" and "The device helped me to remember to engage my core") and usability ("the instructions were easy to understand", "the device was easy to put on" and "the device was easy to use") received only "agree" or "completely agree" responses, as can be seen in Fig. 7.1. All but one of the statements received either one or two "completely agree" responses. Only the statement about the ease of putting on the device received four "agree" responses.

The statements with the most consistent responses after this were those regarding the way in which the CoreMnemo prototype influenced dancers' comfort and ability to dance. This group includes the statements: "I was able to dance as I always dance", "wearing the device was distracting me from dancing", "Wearing the device made me hold back while dancing" and "wearing the device felt uncomfortable". All dancers responded that they were able to dance as they always dance, with one "completely agree" response. The other three statements received mostly "disagree" or "completely agree" responses. Only the statement regarding whether the device made them hold back while dancing received one neutral response.

In relation to the statements revolving about the vibration feedback ("I understood what I needed to do when I felt a vibration", "The vibration feedback was clearly noticeable" and "The vibration feedback felt natural and intuitive") received more mixed responses. Regarding the perceived intuitiveness of the feedback, every participant responded differently, ranging from "disagree" to "completely agree". The other two statements received identical responses, with two "agree", one "completely agree" and one neutral response each.

The final category of statements, regarding visual appeal and fashion compatibility ("Wearing the device interferes with my choice of dance clothes", "The device looks appealing" and "I would feel embarrassed wearing CoreMnemo to dance class"), also had more polarised responses. Each statement had at least one response from both the agree and disagree sides of the spectrum. All except one dancer did not think that wearing CoreMnemo to dance class would be embarrassing. Only one participant responded with "agree" to this statement. The same is true regarding the notion that CoreMnemo interferes with their choice of dance clothes, where two of the disagreeing participants even responded with "completely disagree". The most spread apart answers in this category were regarding the visual appeal of the device. Half of the dancer considered it to look appealing ("agree") whereas the other half responded with "neutral" or "disagree".

7.3 Evaluation of non-functional requirements and conclusions

Having discussed the outcomes of the user evaluations, it can now be evaluated whether the previously specified non-functional requirements have been met. This is presented in Table VI. First, the "must have" requirements will be evaluated. The survey results convey that the device helps the dancer to stay mindful of their pelvic alignment and remembering to engage their core. Therefore, the first requirement has been met. The device stayed in place throughout every test, with the influence of the forces of movement and turning as well as rolling over it on the floor. The second requirement has therefore also been met. However, this comes with a critical note that individuals might sweat more or differently than what has been observed in these four user tests. Depending on the circumstances, this could potentially lead to slipping of the sensor. The requirement that the device can be put on by the dancer without external guidance has also been met. Based on the observations, all participants were able to apply the device successfully without additional help. This does, however, require the use of the placement template and updated manual, as the first participant was not able to apply the device by themselves without these components. The final “must have” requirement requires more deliberation in order to determine whether it has been met. Half of the participants agreed that the feedback felt intuitive, whereas the other half disagreed or had no opinion on this matter. It can therefore not be said with conviction that the requirement has been completely met and is marked as partially met.

Next the “should have” requirements will be evaluated. The fifth requirement, regarding its adaptability to dancers’ physiological and anatomical differences can not be marked as fully met. While the device was wearable by all dancers and functioned in the basic level, one of the participants mentioned receiving multiple false positives. She expressed about this that she thought this was caused by her imbalanced posture from scoliosis, which the observations from the session support. As it is not yet determined whether this is in fact the cause, it is likely that this does influence the functionality of the device to some extent and the device is not able to adapt to this in its current form. Therefore, the requirement can only me marked as partially met. Based on survey responses, interview responses and observations, it can be said that the device does not restrict the dancers’ range of movement, and therefore the sixth requirement has been met. The responses to the statement whether the device distracted them from dancing were all positive (disagree or completely disagree) and therefore it can be said that the seventh requirement has also been met. This is also supported by the responses to the statement whether the participants were able to dance as they always dance. The eighth requirement has also been met, as all dancers responded positively to the wearing comfort in the survey and also commented about the comfort of the device during the interview. When looking at the responses to the two statements from the survey about the clarity of the feedback and whether it was clear to them what they needed to do when receiving feedback, the responses are almost all positive. The same is true for the statement about the device being easy to use. From the observations and interviews, it also seemed that the interaction with the device was easy to understand, as participants quickly found their way in this. The ninth, and final “should have” requirement, has therefore also been met.

The tenth and final requirement, regarding the visual appeal of the device and how well it could be integrated with dancers’ fashion choices, was a could have requirement. Based on the responses from the interview and survey, this requirement can be partially marked. Some dancers did not think the device looked appealing or had a neutral opinion regarding its appearance, and one dancer commented feeling somewhat embarrassed by the way it would look in class as well as influencing their choice of dance clothes. However, the other participants did not feel this way about the device and did not think it looked unappealing. Therefore, this requirement has only been partially met.

TABLE VI

NON-FUNCTIONAL REQUIRMENTS ORDERED BY MOSCOW PRIORITY, INDICATING WHETHER THEY HAVE BEEN MET

Nr.	Non-functional requirement	MoSCoW Priority	Has been met
1	Helps the dancer to stay mindful of their pelvic alignment.	Must have	X
2	Stays in place while dancing, taking factors such as sweating, impact and vigorous movement into consideration.	Must have	X
3	Can be applied/put on by the dancer without external guidance.	Must have	X
4	Feedback feels intuitive to the dancer.	Must have	/
5	Is adaptable to dancer's physiological and anatomical differences (i.e. applicable for all body types).	Should have	/
6	Does not restrict range of movement.	Should have	X
7	Does not distract the dancer from the task of dancing.	Should have	X
8	Is comfortable to wear while dancing.	Should have	X
9	Interaction with the device feels intuitive and is easy to understand.	Should have	X
10	Is visually appealing and does not look weird or embarrassing to the dancer i.e. it integrates well with dancer's fashion choices and requirements.	Could have	/

Overall, all of the non-functional requirements have been either met or partially met, indicating a successful first iteration of the CoreMnemo device. The visual appeal of the device, intuitiveness of the feedback and adaptability to different physiologies and anatomic builds should be further investigated and improved on. Longer term testing, with larger number of more diverse subjects, including observation of different dance styles, would be needed to also evaluate the long-term outcomes of using CoreMnemo.

Chapter 8 – Discussion and Future Work

8.1. Discussion

From the findings of the evaluation, it can be concluded that CoreMnemo shows potential as tool for improving pelvic alignment and core engagement in dancers. It effectively provided real-time feedback that test subjects mentioned helped them become more aware of their pelvic alignment and to remember to engage their core. This was the main objective that CoreMnemo was designed to achieve and it potentially offers promising solution to the ongoing challenge many dancers face in trying to master pelvic alignment. The device was generally well received, with users finding it comfortable to wear and easy to use after getting familiar with the device and its instructions. The use of core engagement as an indirect measure of pelvic alignment, as derived from the conducted background research, seems to have been an effective way to measure pelvic alignment in a real-time manner.

CoreMnemo sets itself apart from existing technology applications in dance, as one of the first wearable technology devices specifically designed for dancers to be used in training rather than for creative applications. CoreMnemo could be defined as an automated version of the feedback training techniques already applied in current dance education and could potentially inspire a shift in the way dancers view their training. Within traditional dance training techniques dancers heavily rely on their instructors and dance education system to learn about the importance of pelvic alignment. When first training to apply this knowledge, they are often completely dependent on their teachers to be reminded if they lose control and receive feedback on their performance. Very few dancers take personal initiative to train this outside of dance classes in order to improve. CoreMnemo has the potential to move this reliance into the dancer's own hands, providing them with the tools to be able to improve by themselves without being dependent on others.

This could have broader positive implications not only for dancers, but also dance teachers and education, as well as other areas of sport. For dance teachers, they may be able to deploy CoreMnemo to discover new innovative ways of teaching, allowing for more efficient use of class time. By taking away one aspect to be monitored, it may allow them to focus on other aspects of dancing in their students and spread their attention more effectively. Simultaneously, the importance of pelvic alignment and core engagement is not solely limited to the field of dance. Other sports in which the core and lumbo-pelvic stability is crucial may also benefit from application of the CoreMnemo, potentially adapting the device to fit different needs in different sports. The same is true for applications in physical therapy.

8.2 Limitations and recommendations for future work

One of the main limitations in the current work is that the CoreMnemo has only been tested short term. The vibration cueing system has shown promising results with immediate use. However, an important goal of CoreMnemo is to “make itself redundant”, as is serves as a tool in the process of training automatic core engagement and pelvic alignment. In order to determine whether CoreMnemo is actually able to achieve this goal, it would need to be tested over a longer period of time. An important aspect to consider in this further study, would be the risk of dancers building reliance on the device. Additionally, to determine the results of longer-term studies more accurately and more decisively, it would be valuable to implement the ability to store EMG data for evaluation. This could provide more concrete evidence of the effects of CoreMnemo, clearly showing whether dancers are improving over time. Additionally, this is needed in order to further investigate the occurrence of false positives or missed cues and the specific qualities (e.g. when and how often the occur) of these events.

A larger variety in subjects should also be included in these evaluations. All participants that evaluated CoreMnemo were female, between the ages of 16 and 22, were all around the same height and of average weight. Three out of four dancers also aimed at a career in dance. Including a larger number of subjects, with more diverse characteristics could lead to more accurate results. Particularly a larger variety in body types should be included to further determine how applicable CoreMnemo is to bodies that do not fit the “norm” in terms of body fat and anatomical build. One of the evaluation participants had scoliosis, which seems to have influenced her experience using CoreMnemo and its accuracy. Additionally, while EMG values and the determined activation threshold value seem to function across all subjects, several sources [129] – [130] suggest that these values are in fact not universal. Differences in body fat, gender, and anatomy all cause different individuals to have varying EMG measurements. While these are very small differences, this likely impacts the experience and functionality of CoreMnemo from person to person, as was displayed by the user test with participant four. Therefore, it needs to be Investigated how to address these differences accurately.

Another aspect of CoreMnemo that should be further analysed and developed is the level of intuitiveness of the vibration feedback. The outcomes of the user evaluation indicate mixed results regrading this, warranting further analysis of the reasons for this and how it may be improved. Additionally, the way in which the sensing and feedback mechanism is currently setup is very simplified. Currently, the device simply keeps vibrating if the user is not engaging their core and does not vibrate if they are engaging it. Furthermore, user evaluation participants commented sometimes feeling brief jitters of vibrations. In further work, this might be addressed to further streamline the user experience and performance of the CoreMnemo device.

The conducted user evaluations brought several flaws in the wearability of the device to the surface as well. While the overall design of the shorts and detachable pouch seems to be functional and practical, there are still aspects in the designed that could be further improved. The first is the way in which the pouch attaches to the shorts. While the Velcro strips were strong enough to keep the pouch in place, two strips alone were not enough to prevent the pouch from being weighed down to some degree. Other factors such as material choice and pouch size could be further considered in this in order to develop a better fitting pouch. The second is the adhesion of the surface electrodes. While the electrodes stayed in place throughout the user evaluations, observations suggest that the point where they may fall off is within the close realm of possibilities. In previous low fidelity prototypes (section 6.2.2) the electrodes have been reinforced kinesiology tape. Investigating the effects of this tape on the electrodes, and exploring other ways to mitigate the risk of electrodes becoming detached from the body, would be needed in order to prevent potential incidents. Further improvement of individual components, including the electronic hardware construction, is also recommended to create a more put-together end-result. This could be done considering topics such as modularity and sustainability.

Several additional functionalities could also be developed to improve CoreMnemo. Some of these potential functions have already been introduced in section 5.3.1 in the form of “won’t have” requirements. These include adding different levels vibration intensity to communicate different levels of engagement, indicating battery level with vibrations, and storing EMG data for further analysis by the user via an external application. The latter should always be carefully considered regarding privacy. Another functionality, which was suggested during the user evaluation, is the addition of an indicator that the device is powered on and working. As there were several mentions of user test participants perceiving using CoreMnemo almost like a game, further exploration into the field of gamification may also be considered.

Chapter 9 – Conclusion

The aim of this Research project was to develop an interactive tool that can form a supplement in dancers training, helping them to become more aware of their pelvic alignment. This project was guided by the research question:

***RQ**: How can interactive technology be developed into a tool for training awareness of pelvic alignment in dancers?*

The process of answering this question, which is described in this thesis report, has led to the development of CoreMnemo: a wearable core engagement memory aid for dancers. By measuring core engagement of the transverse abdominal muscle via EMG measurements, and providing vibrotactile feedback cues to the wearer if their core is no longer engaged, it serves as a tool to help dancers be more mindful of their core and pelvic alignment.

First, relevant literature was studied regarding the topics of pelvic alignment and dance, as well as state of the art and opinions of relevant experts & target audience members. With this knowledge, a process of ideation (including stakeholder analysis) was completed to develop initial requirements and concepts. Subsequently, a final concept was selected and further developed by specifying the user experience, as well as final functional and non-functional requirements to be met by the final design. This specification was used as a foundation to develop the final CoreMnemo prototype, including the sensing and feedback mechanism (Arduino, sensor and actuator), application system (shorts and pouch) and user guide (information and instructions). The prototype was evaluated in a user study with four participants, who tested the prototype in a simulated dance class before providing their opinions on this experience via a short interview and survey. The outcomes of this were analysed conclusions were drawn on whether the prototype was able to meet its requirements. Last, the implications of CoreMnemo in the context of dance and sports training were discussed and limitations and recommendations for future work were given.

In conclusion, CoreMnemo seems to have reached its goal of helping dancers become more aware of pelvic alignment by creatively applying interactive technology. Outcomes of the user evaluation show promise, but further research is needed to determine the full effects and implications of CoreMnemo on dancers and the dance world as a whole. The main limitations that need to be addressed in this are the limited sample size and subject diversity, as well as the limitations and application of EMG technology, intuitiveness of feedback and wearability. Additionally, the occurrence of false positives and missed cues has not yet been explored due to a lack of data logging functionalities. While CoreMnemo in its current state has certain limitations, it shows potential as an inspiration for change in the field of dance training and wearable technology in dance. It could potentially change the way in which dance training is approached and has opened the path for further research and development in this field and outside of it. Additionally, the project has helped to shed a light on a problem that is not explicitly addressed in dance education spaces, yet occurs very frequently both inside and outside of dance. As further research and development continue, CoreMnemo has the potential to grow into a training tool that has the ability to help dancers in achieving healthier, happier, movement.

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Appendix

A. Overview of pelvic alignment measurement techniques and training approaches

Pelvic alignment measurement techniques	**Measure**
Reflective markers attached to the subject's body (commonly the ASIS and PSIS) and capturing this via visual recordings (dynamic, static) following by drawing lines through the captured markers and determining their angles and positions (manually or via software).	Pelvic angle
Wireless inertial sensor device to measure pelvic tilt kinematically by sensing the angle of the wearer during movement, rather than observing it visually.	Pelvic angle
The AlignaBod posture assessment method, taking a side-view of the subject in front of the AlignaBod grid screen (seen in Fig. 2.9) and drawing a plumb line of the spine, followed by analysis.	Lumbo-pelvic alignment
Reflective markers attached to various anatomical landmarks recorded via video camera(s). The relative locations of the markers were used to determine alignment using software.	Lumbo-pelvic alignment
Physical stability tests, involving observation (execution quality or execution ability) of exercises that test the strength and control of the muscle groups relating to lumbo-pelvic stability.	Lumbo-pelvic stability

Pelvic alignment training methods	**Category**
Guided training programs involving core strengthening exercises and general trunk exercises. (Shah and Kubal [46])	Exercise alone
Techniques focusing on stability and muscle activation, with personalised and supervised lumbar control exercises. (Smith [47])	Exercise alone
Gluteus maximus activation exercises & spinal stabilisation exercises, combined with interferential therapy (IFT). (Kaushika et al. [39])	Multimodal
Exercises focusing on gluteus maximus activation and spinal stability (lumbopelvic control), hamstring and mobility exercises combined with manual therapy and massages. (Mendiguchia et al. [5])	Multimodal
Individualised tutoring intervention next to regular dance technique classes, including informational sessions on pelvic alignment and anatomy and training-based sessions focusing on posture awareness while performing ballet, Pilates and relaxation exercises. (Deckert et al. [41])	Multimodal

Pelvic alignment workshop including information about Pilates and anatomy followed by coached Pilates classes on both the mat and Pilates apparatus. (Ahearn et al. [43])	Multimodal
Training program consisting of individually coached Pilates exercises including pre-Pilates breathing exercises, pelvic tilt centering exercises, deep abdominal and pelvic floor muscle activations. (Huang et al. [42])	Multimodal
The Dynamic Neuro-Cognitive Imagery (DNI) technique (focuses on understanding and embodiment of correct pelvic alignment, combining imagination exercises and connected physical exercises). Abraham et al. [44]	Experimental
Somatic training intervention focusing on body awareness and movement education, including concepts of imagery. (Gamboian et al. [45])	Experimental
Feedback method, directing attention towards the body, via a remotely activated vibrating pager. (Holt et al. [40])	Experimental

B. Expert Interviews question guides

Dancers

how old yare you and how long have you been dancing?

what styles of dance do you practice? How frequently do you take dance classes? (Level of dancing (prof, amateur))

What is your main goal of dancing i.e. why do you dance?

Would you consider your body to be healthy? Do you have any Injuries or frequent pain?

> If so what, when, how long, sought out help etc.

Have you ever received feedback regarding your posture during dance classes/rehearsals?

In your dance education, have you ever learned about anatomy? Could you tell me a little bit about that?

(Have you ever learned anything about pelvic alignment) What do you know about pelvic alignment? Why do you think pelvic alignment is important?

How did you first learn about pelvic alignment?

How much attention to pelvic alignment was given in your dance classes to pelvic alignment throughout your dance education? (specify depending on dancer's age, education, and experience)

What are your opinions on the way you were taught about pelvic alignment? (Do you think that the amount of attention given to pelvic alignment is enough?)

How aware do you feel you are of your pelvic alignment during dance and outside of it?

> If dancer has good understanding and awareness: At what point do you think you started really understanding how pelvic alignment works? What caused this?

What are the things you find most challenging surrounding maintaining proper pelvic alignment? (depending on answers to previous question, ask further depending on dancers' answers, e.g. about differences across styles, choreography class, performance, etc.)

Are there things that you feel are (or used to be) lacking during training or that you would personally like to work on regarding pelvic alignment and awareness? (Provide examples if needed, e.g. stretches, awareness and mobility exercises, core & muscle strengthening, learning how to engage the correct muscles, anatomy instruction, etc.)

Do you think there is a need for more pelvic alignment awareness and training in dancers?

Would you (if you had the right tools e.g. extra class, technological tool) work on your pelvic alignment awareness outside of your regular dance classes in your free time?

Depending on answer: What are things that would prevent you from doing so? Ask about training routine, combinations with work/school etc.

Dance teachers

What is your dance background? How long have you been teaching and what styles, ages and levels do you teach? How often do you teach?

Did you study to become a dance teacher, how did you become a dance teacher?

Do you see a lot of students struggling with pain or injuries?

To what extent (in your studies) have you learned about anatomy and physiology? (elaborate)

What do you know about pelvic alignment? Why is pelvic alignment important?

Do you address pelvic alignment in your dance classes? In what ways do you address this?

Depending on previous answers/teacher:

Do you address it differently based on style, age, and level?

Do you feel that you give it enough attention?

What factors limit you in the amount of effort and time you put into teaching about pelvic alignment?

Do you think in general that enough emphasis is put on the importance of pelvic alignment in dance education? (ask about amateur and professional)

To what extent do you think that you understand how to teach pelvic alignment?

Depending on answers:

Were you taught in your education about how to teach pelvic alignment?

Are there things that you would like to know in order to understand this better?

Do you (often) notice students struggling with their pelvic alignment? If so, what are the things they struggle with?

Depending on answers:

What are the things you see them struggling with?

What are the things you do to help such a student?

Are there things preventing you from helping students? If so: what are those things?

Do you think that more space in class or additional classes specifically about pelvic alignment and training for would be beneficial? Do you think dancers would actually use possibilities like that?

If there were tools/methods both live and digital that could help in class with training specific problems regarding postural alignment, would you use them?

Physiotherapists

What is your background as a physiotherapist, do you specialise in a particular field?

Do you have experience working with dancers?

> What are common injuries dancers experience?

What do you understand under pelvic alignment/tilt?

Why is pelvic alignment important?

Are pelvic alignment problems common?

Do you notice any specific problems with dancers and their pelvic alignment?

How do you asses pelvic alignment?

What are common causes of pelvic tilt?

> What types of issues do you see most commonly?
>
> How are these issues usually treated?

What methods do you use to treat injuries that are caused by pelvic tilt? How do you notice that pelvic tilt is the cause?

What are your opinions on the methods used and their effectiveness?

> How do you stay up to date on the latest research and developments regarding treatment methods?

Do you think that people in general are aware of their pelvic alignment?

> Depending on answers:
>
> Do you think this is enough?
>
> Where do you see room for improvement?

Do you think that awareness of pelvic alignment and how to engage the correct muscles alone is enough to learn correct pelvic alignment?

Are there any common misconceptions about pelvic alignment?

What would you say are good practices for anyone wanting to maintain or improve healthy pelvic alignment? Are there things specifically good for dancers?

Like in many other sports, dancers need to focus on a lot of things at the same time while dancing. When treating athletes or dancers, are there techniques that are used to help people remain conscious of body alignment while actively engaging in sports or dancing?

C. Expert Interviews information letter

18-3-2024

Understanding Pelvic Alignment Awareness in Dancers

Interview Information Letter

This information letter contains any necessary information for potential participants taking part in the Interviews for this research project.

This research project has been reviewed by the Ethics Committee Information and Computer Science.

Background

The pelvis is considered to be the cornerstone of skeletal alignment. This is especially important for dancers, as correct neutral alignment of the pelvis allows for proper use of the related muscle groups and healthy rotation of the joints[4]. Particularly in classical ballet and modern styles, neutral pelvis alignment is also essential to achieve correct technical execution and visual quality of moves[1], as well as playing a significant role in injury prevention[5]. However, many dancers struggle with maintaining proper alignment of the pelvis and awareness of their pelvic posture.

In this research project, a tool is being developed which aims to help dancers gain awareness of their pelvic alignment, forming a supplement in their training towards healthy and joyful movement. To form a better understanding of the context around the topic of pelvic alignment in dancers, Dancers', dance educators' and expert opinions are required. In order to collect these opinions interviews are being conducted.

Practical information

You will be invited to a 1 on 1, semi-structured interview, where you will be asked questions about the topic of pelvic alignment in dancers and your experiences related to this topic. You may refuse to answer any question without needing to give a reason. The interview will take up to 60 minutes and you can either take part via an online videocall or an in-person meeting at the UT-campus or dance/work related location of your choice. Your answers will be

[4] https://www.jenniferdeckert.com/uploads/1/2/6/6/12665879/10_bulletin_for_teacherst-resumepaper.pdf
[5] https://pubmed.ncbi.nlm.nih.gov/38391038/

recorded via audio recording software. These recordings will be pseudonymised (numbered randomly and named accordingly) and stored (for the duration of this project) in a OneDrive cloud folder which will only be accessible to the researcher. After your interview session, you may be invited for a follow-up session. Attending a follow-up session is not mandatory and you may decline the invitation without any reason.

Your answers will be analysed and compared to answers of others and any findings from this will be used to form a better understanding of pelvic alignment awareness in dancers and detect problems surrounding it. Your words may be directly quoted within the (publicly available) bachelor thesis report, but any personal information such as name or contact information will not be mentioned or shared with anyone but the researcher.

It is possible to withdraw from the study and request for your data to be deleted at any point in time without any specific reason. This can be done by contacting the researcher and requesting to withdraw from the study or asking for deletion of your data. Any information that has been collected at that point in time will be deleted. You may also request access to your data. If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee Information & Computer Science: ethicscommittee-CIS@utwente.nl.

For any other questions regarding the study, please contact the researcher:
[redacted]

D. Expert Interviews informed consent form

Consent Form for Understanding Pelvic Alignment Awareness in Dancers Interview

YOU WILL BE GIVEN A COPY OF THIS INFORMED CONSENT FORM

Please tick the appropriate boxes	Yes	No
Taking part in the study		
I have read and understood the study information dated [18/03/2024], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	○	○
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	○	○
I understand that taking part in the study involves participating in an audio-recorded interview. I understand that the recordings will be pseudonymised.	○	○
Use of the information in the study		
I understand that information I provide will be used for a (publicly available) bachelor thesis report.	○	○
I understand that personal information collected about me that can identify me, such as [e.g. my name or where I live], will not be shared beyond the study team.	○	○
I agree that my answers can be quoted in research outputs.	○	○
I understand that information I provide will be stored in a OneDrive cloud folder, which is only accessible to the researcher, for the duration of this project.	○	○

Signatures

______________________	______________________	________
Participant:	Signature	Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

______________________	______________________	________
Researcher: Elise Schut	Signature	Date

Study contact details for further information: Elise Schut, [redacted]

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E. User evaluation Interview guide

CoreMnemo User Study – Interview Guideline

How old are you and how long have you been dancing?

What styles of dance do you practice? (how frequently, what level)

Tell me about your experience, how did you experience using the device during this test?

Further question depending on answers and other points to potentially discuss:

- putting on
  - With practice, do you would quickly get the hang of how to use the device?
- using
- taking off
- Pros and cons, difficult points
  - Is there anything specifically about the instructions that you thought was unclear?
  - If there is something you would change, what would that be?

Did you notice any false positives? How many?

Do you think there were false negatives? Please explain.

F. User evaluation survey

CoreMnemo User Study - Survey

Participant: _______________ **Date:** _______________

Please rate how much you agree or disagree with the following statements.

	Completely Disagree	Disagree	Neutral	Agree	Completely Agree
The device looks appealing.	o	o	o	o	o
The instructions were easy to understand.	o	o	o	o	o
The device was easy to put on.	o	o	o	o	o
Wearing the device was distracting me from dancing.	o	o	o	o	o
The device helped me be more mindful of my pelvic alignment.	o	o	o	o	o
Wearing the device felt uncomfortable.	o	o	o	o	o
The device helped me to remember to engage my core.	o	o	o	o	o
Wearing the device made me hold back while dancing.	o	o	o	o	o
The device was easy to use.	o	o	o	o	o
I was able to dance as I always dance.	o	o	o	o	o
The vibration-feedback was clearly noticeable.	o	o	o	o	o
I understood what I needed to do when I felt a vibration.	o	o	o	o	o
I enjoyed using the device.	o	o	o	o	o
The vibration-feedback felt natural and intuitive.	o	o	o	o	o

Please turn page

Wearing the device interferes does not interfere with my choice of dance clothes.	○	○	○	○	○
I would feel embarrassed wearing CoreMnemo to dance class.	○	○	○	○	○

G. User evaluation information letter

29-5-2024

Evaluating a Pelvic Alignment Training Tool for Dancers

Information Letter

This information letter contains any necessary information for potential participants taking part in the user study for this research project. This user study has been reviewed by the Ethics Committee Information and Computer Science.

Background

The pelvis is considered to be the cornerstone of skeletal alignment. This is especially important for dancers, as correct neutral alignment of the pelvis allows for proper use of the related muscle groups and healthy rotation of the joints[6]. Particularly in classical ballet and modern styles, neutral pelvis alignment is also essential to achieve correct technical execution and visual quality of moves[1], as well as playing a significant role in injury prevention[7]. However, many dancers struggle with maintaining proper alignment of the pelvis and awareness of their pelvic posture.

In this bachelor thesis research project, a wearable device (worn in the abdominal region) is being developed which aims to help dancers gain awareness of their pelvic alignment, forming a supplement in their training towards healthy and joyful movement. The device analyses the dancer's pelvic alignment and gives the dancers feedback in the form of vibrations if their pelvic alignment is out of range. In order to evaluate the functionality and usability of a prototype of this tool, user tests are being conducted.

Practical information

If you choose to participate in this study, you will be invited to join a short (up to 45 minutes) or full-length (up to 90 minutes) user-testing session. The goal of these sessions is for you to interact with the prototype and share your opinions about your experiences using it. The session(s) will take place in a dance studio with you, the researcher and up to 1 dance instructor present. If you are uncomfortable in participating in the session alone, it is possible to discuss this with the researcher and potentially (if resources allow it) invite up to 2 other

[6] https://www.jenniferdeckert.com/uploads/1/2/6/6/12665879/10_bulletin_for_teacherst-resumepaper.pdf
[7] https://pubmed.ncbi.nlm.nih.gov/38391038/

dancers to participate alongside you. These dancers will not be testing the prototype. After your session, you may be invited for a follow-up session. If you first attended a short session the second session will be a full-length session and vice versa. Attending a follow-up session is not mandatory and you may decline the invitation without any reason.

The session will begin with a briefing and the opportunity to ask any questions you may have before starting the test. The full-length session will start with you being tasked to put on the device by yourself with the help of provided instructions. Once the device has been successfully applied you will take part in a short simulated commercial or contemporary dance class while wearing and using the prototype. In this class an instructor will guide you through a warmup exercise, a technical exercise and teach a small piece of choreography. There will be water drinking breaks in between segments. Next, if you feel comfortable doing dance improvisation, you will be asked to improvise freely to a song for the duration (about 3-5 minutes) of the piece of music. This is optional, and you can choose not to partake in this if you do not feel comfortable improvising. Afterwards, you will be asked to take off the device again with the provided instructions. With this, the interaction phase of the test is over, and a short interview and questionnaire will begin. First there will be a short semi-structured interview (1 on 1 with the researcher) in which you will be asked to share comments you have on your experience using the prototype. After this you will be asked to fill in a questionnaire on paper. This questionnaire contains more questions about your opinions on specific aspects of the interaction with the prototype. Topics you can expect questions about here may include comfort, ease of use, quality of the feedback and your perception of effectiveness.

If you participate in a short session, you will only take part in a single segment of the previously mentioned interactions. You may, for example, be asked to only put on/take off the device with the provided instructions or only participate in the guided technical or choreography exercise (with appropriate warmup). It will be communicated to you which aspect of the interaction will be addressed. After this you will participate in the short semi-structured interview mentioned before. In a short session, you will not need to fill in the questionnaire.

Recording and data processing

The researcher will be taking written notes in online word file (only accessible by the researcher and pseudonymised) during the application/taking off processes. The interaction segment of the session will be videotaped. This includes the simulated dance class and optional improvisation session. These videos will be pseudonymised (numbered randomly and named accordingly) and stored (for the duration of this project) in a OneDrive cloud folder which will only be accessible to the researcher. You can additionally request for your face to be blurred in the recordings. The EMG sensor data, read by the sensors in the prototype during the interaction segment, will be recorded and stored under your pseudonym for later analysis. Your answers in the interview segment will be recorded through audio recording software. These recordings will also be pseudonymised and stored in the same way. The questionnaire will be filled out on paper, which will not contain your name and will be numbered the same as the video and audio recordings. This data will only be viewed by the researcher. Your data will only be stored for the duration of the project and will be deleted afterwards.

The video recordings, your interview answers and questionnaire responses will be analysed by the researcher. The goal of this is to observe the interaction with the prototype, evaluate the quality of the prototype and find potential weaknesses, as well as determining whether the protype meets the researcher's requirements. Conclusions that are drawn from this will be used to further develop the prototype and suggest future changes. Your words from the interview or questionnaire may be directly quoted within the (publicly available) bachelor thesis report, but any personal information such as name or contact information will not be mentioned or shared with anyone but the researcher. With your permission, pictures (in which your face will not be visible) may be taken for use in within the same report.

It is possible to withdraw from the study and request for your data to be deleted at any point in time without any specific reason. This can be done by contacting the researcher and requesting to withdraw from the study or asking for deletion of your data. Any information that has been collected at that point in time will be deleted. You may also request access to your data. If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee Information & Computer Science: ethicscommittee-CIS@utwente.nl.

How to prepare

It is recommended you come to the session in comfortable clothes to dance in or bring them to change into. At the location of the test, there is a changing room to get changed into these clothes. It is also advised you bring a water bottle. During the test you will either need to apply/put on the prototype yourself or with the help of the researcher. As the prototype is worn in the lower abdominal and hip region, it is important for you to consider if you are comfortable with showing your stomach in the presence of the researcher or potentially having brief minor physical contact with the researcher during the application process. You can of course request to have the application process take place off camera and adaptations to the process can be worked out with the researcher in case of any discomfort.

For any further questions regarding the study, please contact the researcher:

[redacted]

H. User evaluation informed consent form

Consent Form for Evaluating a Pelvic Alignment Training Tool for Dancers User Study

YOU WILL BE GIVEN A COPY OF THIS INFORMED CONSENT FORM

	Yes	No
Taking part in the study		
I have read and understood the study information dated [29/05/2024], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	O	O
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions or participate in activities, and I can withdraw from the study at any time, without having to give a reason.	O	O
I understand that taking part in the study involves participating in a videotaped interaction study requiring my interaction* with a prototype. I understand that afterwards I will take part in an audio-recorded interview and, in case the case this is a full-length session, will fill in a questionnaire on paper. ** This interaction involves putting the device on [and/or] wearing and using it during simulated dance class [and/or] wearing and using it during an optional dance improvisation [and/or] taking the device off again.*	O	O
I understand that the recordings and questionnaire will be pseudonymised. I understand that I can request that my face is blurred in video recordings.	O	O
Use of the information in the study		
I understand that information I provide will be used for a (publicly available) bachelor thesis report.	O	O
I understand that personal information collected about me that can identify me, such as [e.g. my name or where I live], will not be shared beyond the study team.	O	O
I agree that my answers can be quoted in research outputs.	O	O
I understand that information I provide will be stored in a OneDrive cloud folder, which is only accessible to the researcher, for the duration of this project and will be deleted after the project has been completed.	O	O

Signatures

Participant: [printed] Signature: ____________________ Date: ________

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

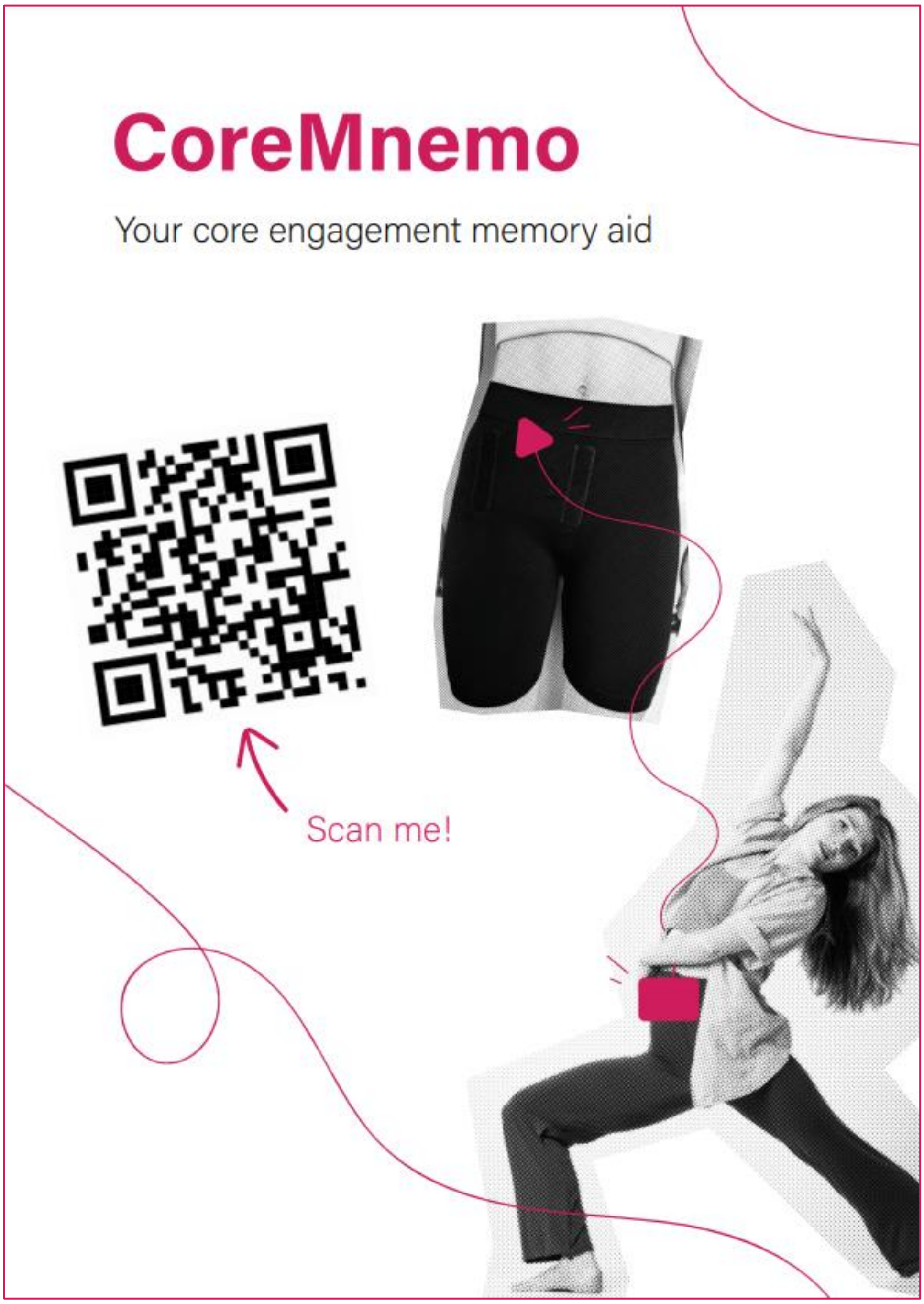
Researcher: Elise Schut Signature: ____________________ Date: ________

Study contact details for further information: Elise Schut, [redacted]

I. CoreMnemo Arduino code

```
/*
  Graphical representation is available using Serial Plotter (Tools > Serial Plotter menu).
  *Only run on a laptop using its battery. Do not plug in laptop charger/dock/monitor.
  *Do not touch your laptop trackpad or keyboard while the MyoWare sensor is powered.
*/

#include <movingAvg.h>

boolean muscleActivated;
int activationThreshold;
int ledPin = 10;
int motorPin = 6;
movingAvg movingAverage(10);

void setup()
{
  Serial.begin(115200);
  while (!Serial);
  Serial.println("MyoWare analogRead_SINGLE");
  pinMode(ledPin, OUTPUT);
  pinMode(motorPin, OUTPUT);
  activationThreshold = 28;
  movingAverage.begin();

}

void loop()
{
  digitalWrite(10, HIGH);
  int sensorValue = analogRead(A0); // read the input on analog pin A0 and assign it to variable
  int noiseFreeValue = movingAverage.reading(sensorValue); // take moving average of sensorValue to reduce noise

  //if the sensorValue is in the "activated" range --> make boolean true, if not make it false
  if (noiseFreeValue > activationThreshold) {
    muscleActivated = true;
  } else {
    muscleActivated = false;
  }

  //if the muscle is activated, turn of motor off, if not turn it on
  if (muscleActivated) {
    digitalWrite(motorPin, LOW);
  } else {
    digitalWrite(motorPin, HIGH);
  }

  Serial.println(noiseFreeValue); // print the noiseFreeValue

  delay(50); // to avoid overloading the serial terminal
}
```

J. CoreMnemo manual card



Instructional videos – hyperlinks:

Applying CoreMnemo: https://youtu.be/RegOJJ2ttj4

Removing CoreMnemo: https://youtu.be/GhZeBAYr8j4

K. CoreMnemo user manual

CoreMnemo

Your core engagement memory aid

Pelvic alignment?

If you are a dancer, it is likely that you have at some point heard about tilting your pelvis and engaging your core. You might have heard your teacher say that you should be tilting your pelvis "forward" or to a neutral position. This is important because tilting your pelvis to a neutral position engages your core muscles.

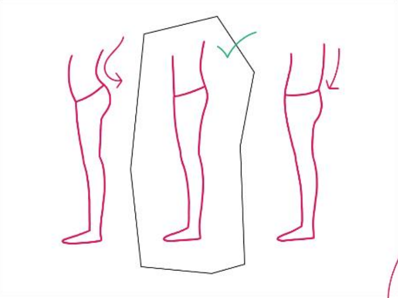
There are af few reasons why this is relevant for dancers:

1 control of your core and enagaging it properly is what holds your spine in place and gives it stability. This helps to prevent injuries and back pain.

2 Engaging your core by tilting your pelvis helps you maintain a stable centre of gravity, which is in particular important for your dancing. Being able to constantly maintain your centre of gravity allows you to execute dance moves properly and more effortlessly. Ever struggled with turns or balancing? Maybe you fall out of moves sometimes or feel clumsy with floorwork? Engaging your core might be something you need to work on!

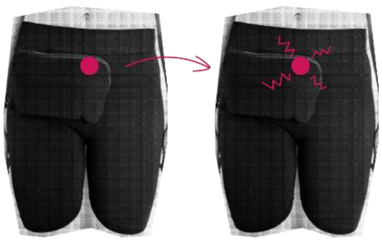
L.

While plenty of dancers already subconsciously engage their core, this doesn't come as easily to everyone. It can be difficult to remember to keep your core engaged while you are dancing, and teachers aren't always able to give you all the reminders you need. It could be that you have only recently learned about the importance of core engagement or that you only recently started dancing, maybe you just want to get better at it. Whatever situation you may be in, the CoreMnemo might be able to help you!



What is CoreMnemo?

CoreMnemo is an interactive wearable device for dancers, that is designed to help you stay mindful of your core engagement and pelvic alignment so that you eventually become able to do this automatically. The CoreMnemo measures your core muscle engagement and if it notices that you are no longer actively engaging your core, it will vibrate to remind you that you need to engage muscles again!



How does it work?

The CoreMnemo uses an EMG sensor. When your brain wants to activate a muscle, small electrical signals travel via your nerves into the muscle. In response to these signals the muscle activates. The EMG or electromyography sensor measures these electrical signals of the transverse abdominal muscle, which is one of the main core muscles that you need to engage while dancing. The CoreMnemo device analyses this data and determines whether your muscle is active enough. If your values are too low, the device will vibrate to remind you to engage your core. It will stop vibrating once you have re-engaged your core.

Using CoreMnemo

How to use CoreMnemo?

There are several parts to the CoreMnemo:

A. Shorts with velcro strips, in your preferred size
B. EMG sensor and reference cable
C. Single use electrodes
D. Electronics pouch with velcro strips
E. Electronics components
F. Power bank + USB-C cable

How you put these items on together is explained in the "Putting CoreMnemo on" section below. You can choose to wear the shorts and pouch on their own, but it is recommended that you wear your regular dance trousers/bottoms over it to provide additional support.

After you have put on the device, all you need to do before you start dancing is turn it on. You do this by plugging the electronics components into the power bank as instructed below. As soon as you plug it in, the CoreMnemo will start working and you are ready to go! If you are done using the device, you can turn the device off by unplugging it again.

! Saftey warning !
Never plug the CoreMnemo device into a phone charger, charging power bank or other device (e.g. a computer) that is plugged into an electrical socket!
If you neglect to do so there is risk of **electrical shock**!

How to engage your core?

Once the device is on, it may be useful to first play around with it a bit before you jump into a dance class. Try engaging your core muscles and tilting your pelvis to see how the device responds. To properly engage your transverse abdominal muscle, try placing your fingers just below the belly button. Then, contract the muscle by pulling down and away from your fingers. It may also help to envision pulling your bellybutton in and up. You will notice that you automatically need to tilt your pelvis in order to achieve this. If you are struggling to figure out the right technique, it may be useful to ask your dance instructor or physical therapist for advice.

How often should I use CoreMnemo?

It is recommended that you do not use the CoreMnemo during every single dance class, the goal is that you learn to engage your core automatically on your own after all. This however depends on your dance schedule and how many hours a week you dance. If you are a more casual dancer, and take class about 1-2 times a week, it is acceptable to use the device during every class if you wish to do so. If you, however, take multiple (3 or more) classes a week, it would be a good idea to incorporate at least one class where you do not use the device. This is important so that you give yourself room for free dancing and so you don't become reliant on the device.

After some time, you might notice that you are becoming better at automatically tilting your pelvis and engaging your core muscles. This could be after some weeks or maybe months, depending on the person. How long this takes does not define your ability and is completely personal. Do not become discouraged if your process feels slower than what you envisioned! When you are starting to notice this change, you can start to slowly decrease the number of times a week that you use the device, reducing the number of classes you take with it about once every two weeks until eventually you are only using it once a week. You can choose to keep using the the device once a week at this point or stop using it completely. Once you have reached this point, it is always useful to use the device every once in a while to check whether you are still keeping up with what you have learnt.

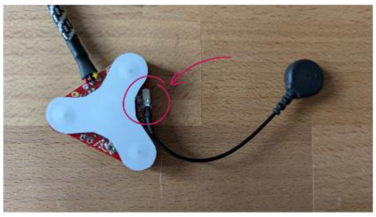
Keep in mind that regular and consistent use of the device is necessary to achieve a successful outcome! Only once you start noticing that engaging your core is becoming more automatic should you start slowly decreasing the number of classes you take while wearing the device for the intended results.

Putting CoreMnemo on

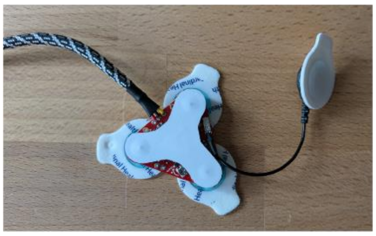
Please closely read the instructions before watching the linked video guides for support.

Placing the EMG sensor and reference electrode

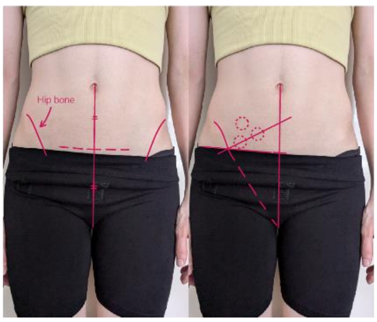
Step 1:
Make sure that the reference cable is attached to the EMG sensor as shown.

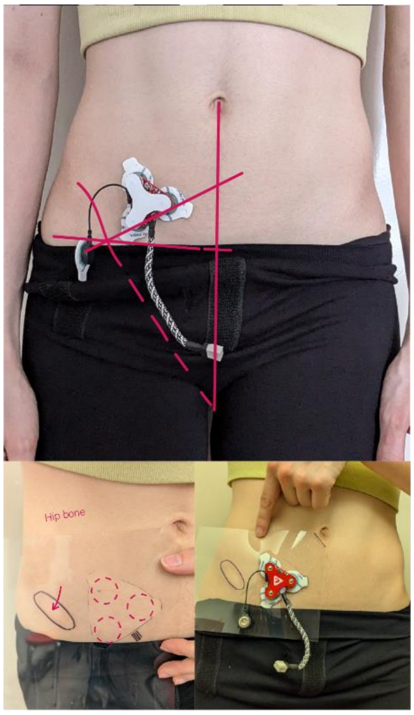


Step 2:
Click the single use electrodes onto the EMG sensor and reference cable as shown.



Step 3:
Determine the right position for the sensor. This step can be a bit tricky so make sure you closely read the instructions and view the images! The device has three electrodes, the placement of the two electrodes at the bottom of the triangle is most important. The goal is to line these electrodes up on the right side (from your perspective) of your abdomen below the belly button. The precise location will line up in the middle of your groin and belly button, as indicated by the lines in the image, close to your hip bone. It might help to engage your core muscles and feel where the muscle hardens on your stomach with your fingers.
To find the right angle and positioning there is a placement guide template included in the box. Use it by lining up the oval on the guide with the point where your hip bone sticks out the most, as shown in the images below. The notch cutout in one corner of the guide indicates the direction of your bellybutton. The triangular hole in the template indicates where to stick the sensor. The black marks one one side of the triangle indicate where the cable of the sensor should be, to help you find the orientation of the sensor.





Step 4:
Once you have found the right location, make sure the area is clean and free of grease and adhesive.

Step 5:
Remove the adhesive backing from the electrodes attached to the sensor and stick the sensor to the right location as shown. Push on the sensor and rub over the electrodes to ensure that they are properly stuck to your skin.

Step 6:
remove the adhesive backing from the electrode attached to the reference cable and stick it onto your hip bone as shown.

Putting on the other CoreMnemo components

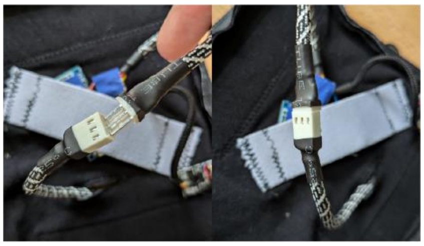
Step 1:
After attaching the EMG sensor, put on the included shorts.

Step 2:
Thread the EMG sensor cable through the buttonhole in the shorts.

Step 3:
Take the electronics pouch and thread the EMG sensor cable through its buttonhole from the backside (grey) that has the Velcro strips attached to it as well as shown.

Step 4:
Align the Velcro strips of the pouch with the Velcro strips on the shorts and attach the pouch to the shorts as shown.

Step 5:
Plug the EMG sensor cable into the matching cable attached to the electronics components as shown.



Step 6:
Place the power bank in the pouch, plug it in when you are ready to turn the CoreMnemo on and close the zipper on the pouch.

Step 7:
Put your regular dance clothes back on over the shorts and pouch and you are ready to start dancing!

Video guide:

Putting CoreMnemo on

Taking CoreMnemo off

Please closely read the instructions before watching the linked video guides for support.

Taking CoreMnemo off

Taking the device off after use

Step 1:
Open the pouch and unplug the power bank from the electronic components.

Step 2:
Unplug the EMG sensor cable from the electronics components.

Step 3:
Unthread the EMG sensor cable from the pouch and pull the pouch away from the velcro to remove it.

Step 4:
Unthread the EMG sensor cable from the buttonhole in the shorts. Then take the shorts off or pull them down in order to access the EMG sensor.

Step 6:
Pull away the EMG sensor and reference cable from your skin by pulling at the tabs on the electrodes.

Step 7:
Carefully pull the electrodes off of the reference cable and EMG sensor and discard them. It can help to place the adhesive backing back onto the electrodes before pulling them off.

Step 8:
Plug the power bank into a phone charger to charge it before the next use.

! Saftey warning !
Never plug the CoreMnemo device into a phone charger, charging power bank or other device (e.g. a computer) that is plugged into an electrical socket!
If you neglect to do so there is risk of **electrical shock**!