EMPOWERING DANCERS THROUGH MIXED REALITY

Designing Tools that Help Dancers Explore Movement Qualities in Solo Learning Environments

Willow Yiliu Hong

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CONTENTS

Thesis Abstract

Movement quality is defined as the way humans execute movements with respect to time and space. In the field of dance, movement quality is the expressive part of movement that allows dancers to communicate emotions with others.

Within the circle of dance learners, one of the challenges is the difficulty of exploring a variety of movement qualities of dance moves. Learners wish to easily find different ways of executing one dance move, and be able to understand new movement qualities so that they can learn and expand the expressive power of their own body. However, existing dance learning environments prevent learners from either (a) see enough quality variations, (b) compare two movement qualities, or (c) focus on self movement and progress. Unfortunately, all three are required for a fruitful movement quality exploration.

My thesis project explores opportunities for mixed reality technology to help dancers explore a variety of movement qualities in solo learning environments. Based on the derived design insights and principles from research, I designed a desktop application with an armband controller to help dancers (a) discover new movement qualities via both crowd-sourced collection and body awareness (b) easily understand the relations between the body and movement qualities via 3 types of feedback, and (c) increase exploration efficiency via a seamless practice flow.

Process Overview

Research Process

- *Literature Review*

15+ papers and articles that are related to dance learning, movement study, and mixed reality technologies.

- *Observation Study*

Observed 2 Salsa dance studio classes that have 20+ dance learners.

- *Interview*

40+mins in-depth interviews with 7 dance learners; among them 5 are salsa dance learners.

- *Exploratory User Workshop*

1 hr dance activity with 5 dance learners.

- *Competitive Analysis*

Researched various existing dance practice products and new mixed reality products and summarized their pros and cons.

Design Process

- *Concept Speed Dating*

Speed dated feedback typologies and 3 initial system concepts with 4 dancers using storyboards and interactive prototypes.

- *Journey Mapping*

Mapped out user experiences for the system.

- *Low-fidelity Sketches & Prototypes*

Sketched out the app interfaces with relevant functionalities, and made 1 armband model.

- *Mid-fidelity Wireframes & Models*

Detailed out a portion of the entire proposed system with wireframes, and tested the wireframes and the armband prototype with 4 dancers.

- *Hi-fidelity Prototypes*

Iterated on the designed experience based on user testing result, and produced hi-fidelity animated wireframes as well as the 2nd version of the armband.

- *Working Demo*

Made an interactive demo using CMU's OpenPose to demonstrate feasibility of the proposed design.

PROJECT GOALS & SCOPE

In this chapter, I address my personal experience that inspired the intents of this thesis, which are: exploring new ways of representing movement-related information, helping dancers enhance body awareness and control, and creating tools that can inspire research in other motor learning fields. I also propose the research and design scope of this project.

Personal Experience

Movement is a fundamental component of our everyday lives. When we move through a space, we perceive and appropriate environmental features in relation to our bodies. This generates an awareness of not only the three-dimensionality of the environment, but also the capabilities of our own bodies (Proulx, M. J. et al., 2016). Most of us develop this awareness over time without much effort when we perform daily activities. Take walking as an instance: we know how far each step will take us and that continuously switching our legs propels us forward. However, when it comes to movements that we don't perform daily, or that our body fails to adopt as a norm, do we still know the capabilities of our body and how to move it as the way we want in our mind?

I encountered this question when I was practicing dance steps — the movements were completely new to my body. In my learning process, the instructor often divides the dance into multiple motion segments based on rhythm, demonstrating each segment for the students to observe and imitate. However, most of the information my senses gathered was about the end state of each segment, which was a static pose. I often had a hard time comprehending what happened to the body between each end state because the movements happened too quickly. So what if I slow down a dance video and map my body in space according to the pose presented in the video for every second? I realized that while I am able to see what the instructor is doing and control my body to the specific trajectory in space, I don't know how my body should feel like and act like when I want to dance in a certain way: I don't understand how to move my body from one location to another over time in order to dance in a jerky way, a smooth way, or a soft way.

Thesis Intent & Scope

In motor theory, this understanding of the “how” is defined as an understanding of movement quality, that is, the way humans execute movements with respect to time and space (Alaoui, S. F. et al., 2012). One way to understand movement quality is to extract and represent movement-related information. Existent methods range from a simple video recording, to position mapping of specific body parts, to animations of polygonal imageries. While these approaches are effective in communicating the spatial trajectories of movement over time, they provide little information about the relations between dancer’s body movement and the movement quality the dancer produces.

For this thesis, I approached the issue of “understanding movement quality” through bodily awareness. I was interested in exploring new ways of representing movement-related information that allow dancers connect their body with movement qualities in an easy and natural way. I aimed to help dancers enhance their awareness of their body capabilities and develop the ability to precisely control their own body with their mind. I also created tools that can inform other movement-quality-related studies or be implemented to other motor learning fields.

The primary research and design focuses of this thesis are (1) finding target user group among dancers; (2) confirming and updating audience’s needs in relation to movement qualities; (3) designing representations of movement-related information in a meaningful way; (4) designing accessible and delightful user experiences for the proposed tool. In the next chapter I will discuss how I decided to focus on the topic of movement quality in dancing with literature review.

LITERATURE REVIEW

In this chapter, I discuss my literature review process on movement and motor learning, and address the increasing interest and need in exploring movement qualities in many motor-learning fields such as performing arts, fine arts, physical health, etc. Then I discuss the concept of movement quality in the context of dancing, and point out the significance of understanding “movement quality” in dance education.

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Significance

I started my thesis with extensive literature reviews on movement and motor learning. What I found is that there is an increasing interest and need in exploring movement qualities in many fields such as performing arts, fine arts, physical health, etc.

In the theatrical arts, many theories and techniques have been developed to help performance artists understand the qualities of movement in order to maximize the expressive ability of their bodies.

The Chekhov Technique revolves around the use of the imagination to understand four types of movement qualities; molding, floating, flying, and radiating (Chenard, J., 2010). However, performers might have a hard time translating these abstract dynamics into a specific movement quality (Blom, L.A. et al., 1982). Labanotation (Figure 1) is a notation system developed by Rudolf Von Laban in 1928. Within the system, the Effort Graph (Figure 2) is used to visualize eight basic elements that constitute the quality of movement. While the graph symbols can be useful in clarifying and communicating the quality of a given movement, its complexity makes it very difficult to understand and be used by the general audience.

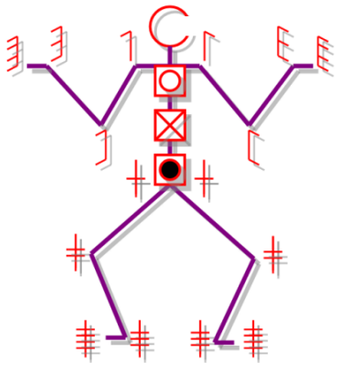

Figure 1: Signs for body parts in Labanotation

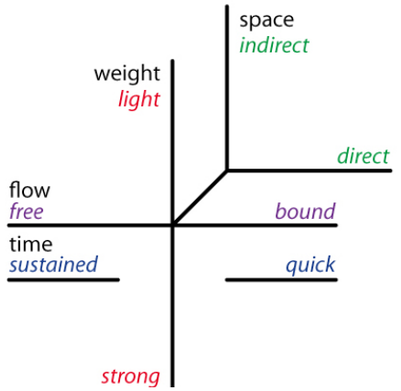

Figure 2: Laban's Effort Graph

Significance

In calligraphy learning, the writing movement is performed as a way to appreciate the aesthetic value of ancient master's writings. For example, when a learner is copying characters from the Lan Ting Xu by the Chinese calligrapher Wang Xizhi (Figure 3), whose work is believed to be the best in the last 1000 to 2000 years, he is trying to experience the actions of Wang Xizhi, to feel how Wang Xizhi feels in writing this work, thus becoming aware of the very subtle actions and changes in his writing (Xu, J. et al., 2015).

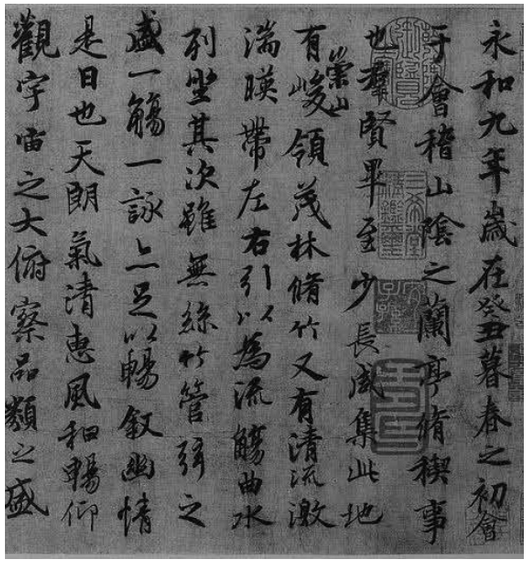

Figure 3: Copy of Lantingji Xu attributed to Feng Chengsu, preserved at the Palace Museum in Beijing

However, since there is no information about Wang Xizhi's movement characteristics but static pictures of written characters, the learner can only rely on two ways to understand the writing movement: (1) visual comparison between the learner's movement outcome and the written characters in Zi Tie (Master's calligraphic works), which contains no information about movement quality; (2) verbal and tactile feedbacks from the instructor, which contains passive and distorted information about movement quality. The learner therefore finds it difficult to identify all movement components that will produce the sense of rhythm, the stroke fluidity and other movement qualities.

In the field of senior care, movement quality is monitored as indicators of change in elderly's health status. For instance, daily-life gait characteristics is used as predictors of falls (van Schooten, K. S. et al., 2016). By using wearable sensors to assess elder people's walking speed, stride length, stride frequency, intensity, variability, smoothness and symmetry (Figure 4), researchers are able to develop prediction models that identify the persons who are at high risk of falling, thus preventing the devastating consequences of potential fall incidents.

While the prediction model proves to be effective in helping the elderly population, the way it represents movement qualities can be understood by no one other than the research scientists themselves. If individuals want to self-monitor and understand the changes in the qualities of their movements over time, they are powerless due to the lack of intuitive representation of gait qualities provided to them.

	Mean (SD)	First fall (HR [95% CI])
Walking speed	0.83 (0.20)	0.84 [0.70–1.00]
Stride frequency	0.86 (0.08)	**0.83 [0.70–0.98]**
Stride length	1.07 (0.20)	0.89 [0.75–1.06]
Root mean square VT	1.75 (0.51)	**0.78 [0.65–0.95]**
Root mean square ML	1.21 (0.27)	0.93 [0.78–1.10]
Root mean square AP	1.26 (0.28)	**0.78 [0.65–0.93]**
Range VT	11.36 (2.88)	0.86 [0.72–1.03]
Range ML	8.79 (2.80)	0.92 [0.77–1.09]
Range AP	8.55 (2.43)	**0.82 [0.68–0.99]**
Walking speed variability	0.07 (0.02)	1.09 [0.92–1.29]
Stride time variability	7.53 (4.09)	1.08 [0.94–1.25]
Stride length variability	0.06 (0.02)	1.08 [0.91–1.27]
Autocorrelation at dominant period VT	0.45 (0.16)	**0.82 [0.69–0.97]**
Autocorrelation at dominant period ML	0.34 (0.11)	1.01 [0.85–1.20]
Autocorrelation at dominant period AP	0.40 (0.11)	**0.84 [0.70–1.00]**
Magnitude of dominant period in frequency domain VT	0.62 (0.21)	**0.83 [0.70–0.98]**
Magnitude of dominant period in frequency domain ML	0.37 (0.16)	**1.18 [1.01–1.38]**
Magnitude of dominant period in frequency domain AP	0.52 (0.12)	**0.94 [0.79–1.12]**
Width of dominant period in frequency domain VT	0.76 (0.20)	1.09 [0.95–1.25]
Width of dominant period in frequency domain ML	0.77 (0.08)	0.89 [0.74–1.08]
Width of dominant period in frequency domain AP	0.72 (0.06)	**1.24 [1.09–1.40]**
Percentage of power under 0.7 HZ VT	0.19 (0.19)	1.04 [0.92–1.18]
Percentage of power under 0.7 HZ ML	8.29 (6.86)	1.07 [0.92–1.24]
Percentage of power under 0.7 HZ AP	8.48 (5.96)	1.11 [0.97–1.28]
Index of harmonicity VT	0.70 (0.15)	**0.84 [0.72–0.98]**
Index of harmonicity ML	0.49 (0.22)	**1.21 [1.02–1.44]**
Index of harmonicity AP	0.72 (0.09)	1.16 [0.98–1.39]
Harmonic ratio VT	2.19 (0.59)	**0.81 [0.68–0.96]**
Harmonic ratio ML	1.85 (0.35)	0.97 [0.82–1.16]
Harmonic ratio AP	1.82 (0.42)	**0.76 [0.63–0.91]**
Mean logarithmic rate of divergence VT	1.49 (0.29)	**1.21 [1.01–1.44]**
Mean logarithmic rate of divergence ML	1.73 (0.20)	1.00 [0.84–1.19]
Mean logarithmic rate of divergence AP	1.65 (0.22)	**1.21 [1.01–1.45]**
Mean logarithmic rate of divergence per stride VT	1.76 (0.40)	**1.23 [1.04–1.45]**
Mean logarithmic rate of divergence per stride ML	2.04 (0.30)	1.10 [0.93–1.30]
Mean logarithmic rate of divergence per stride AP	1.94 (0.31)	**1.29 [1.09–1.54]**
Sample Entropy VT	0.25 (0.07)	1.04 [0.92–1.18]
Sample Entropy ML	0.35 (0.06)	0.88 [0.74–1.06]
Sample Entropy AP	0.27 (0.08)	1.07 [0.93–1.23]
Duration of locomotion	1.23 (0.55)	0.97 [0.81–1.15]
Number of strides	6407 (2971)	0.95 [0.79–1.13]
Number of locomotion bouts	405 (144)	1.05 [0.88–1.25]
Maximum duration of locomotion bouts	313 (239)	0.95 [0.79–1.14]
Maximum number of strides in one locomotion bout	565 (508)	0.94 [0.78–1.13]
Median duration of locomotion bouts	6 (1)	0.94 [0.79–1.12]
Median number of strides in one locomotion bout	7 (1)	0.89 [0.75–1.06]
Duration of lying	9.65 (2.52)	0.96 [0.81–1.14]
Duration of sitting	9.12 (2.38)	1.04 [0.87–1.24]
Duration of standing	2.62 (0.96)	1.12 [0.95–1.32]
Number of transfers	136 (58)	1.13 [0.96–1.32]
Duration of unclassified activities	0.36 (0.15)	1.00 [0.85–1.18]

Hazard ratios (HR) with 95% confidence intervals (95% CI). VT: vertical, ML: mediolateral, and AP: anteroposterior direct significant at $p<0.05$. All mean (SD) values are in Standard Units (m, sec, m/sec), except total durations of activities, whic

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Figure 4: Univariate associations between gait quality and physical activity with time-to-fall

Movement Quality in Dancing

In the field of dance, movement quality is the expressive part of movement that allows dancers to communicate emotions with their audiences. Therefore it is deemed by dance experts (von Laban, R., 2011) as an essential concept to understand in dance learning. Movement quality in dancing is often used interchangeably with the term “style”. Throughout history, some dancers have created distinguished and systematic combinations of movement patterns and qualities, which later became different dance style categories, such as “Street Dance” or “Latin Dance”. Other dancers followed conventional movement patterns (dance steps) under each dance style category, such as a “Stanky Leg” in street dance, but danced in a different movement quality, thus creating personal dancing styles that reveal individuality (see example in Figure 5).

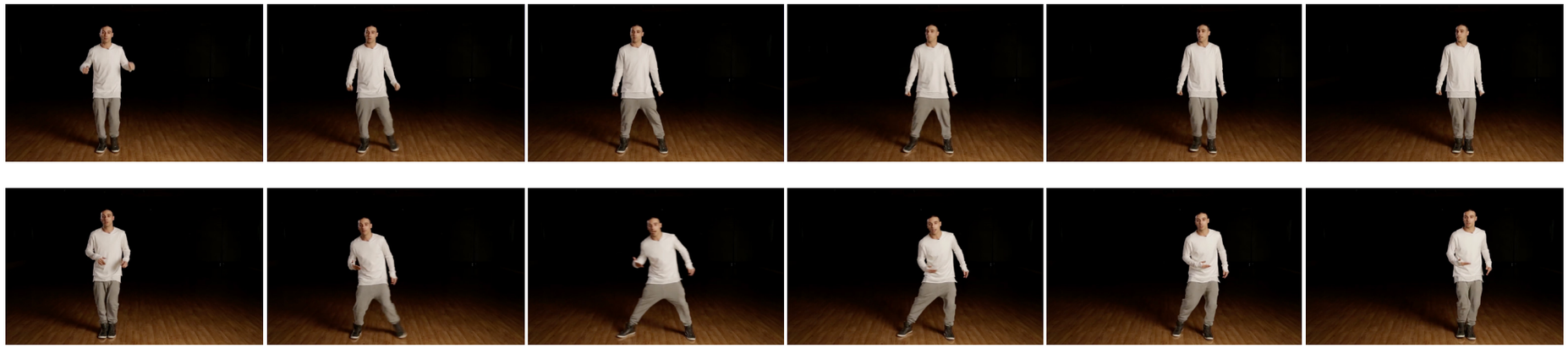

Figure 5: A dancer performs “stepping to the left” with 2 different movement qualities: top row is stiff and even; bottom row is dragged and choppy

EXPLORATORY RESEARCH

In this chapter, I cover the exploratory research conducted to

(1) understand movement quality's role in the current dance learning process using observation studies and interviews;

(2) identify intermediate dancers as my target users, and synthesize their fundamental needs in relation to movement quality, which then become my design objectives; :

need 1 - increase exposure to unfamiliar movement qualities

need 2 - find a better tool to understand movement qualities

need 3 - practice movement qualities in solo environments

(3) test the effectiveness of using prompts to discover new movement qualities through a dance workshop that uses the theory of Somaesthetics & the "making strange" methodology as its framework. (4) discover design principles from the workshop, which are "providing multi-modes" of discovery, "comparative feedback" and a "seamless experience".

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Step 1: Choose Sample Study Group

After the literature review process, I became particularly interested in movement qualities in the context of dancing. In order to understand how exactly movement quality is playing a role in the current dance learning process, I worked with a group of Salsa dancers from Carnegie Mellon University's ballroom dance club as a sample group for dance learners. The diagram on the right illustrates my scoping process.

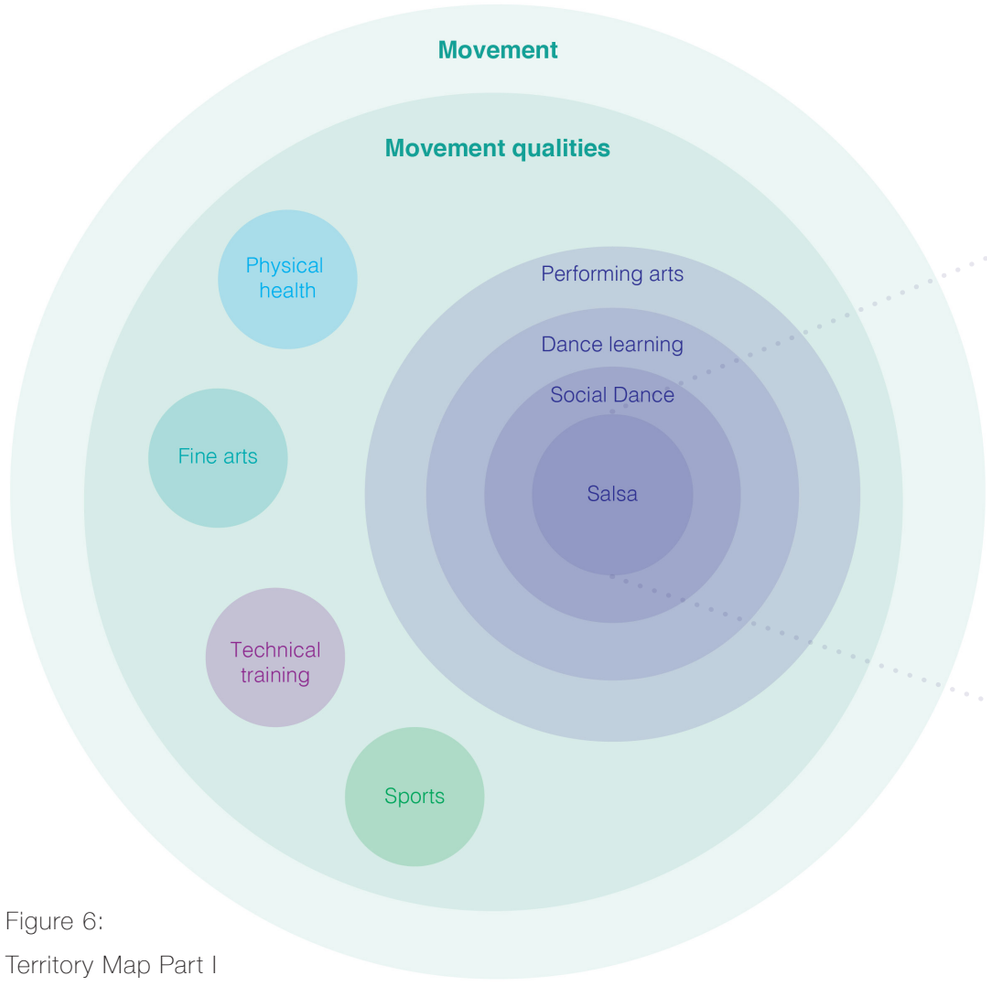


Figure 6:
Territory Map Part I

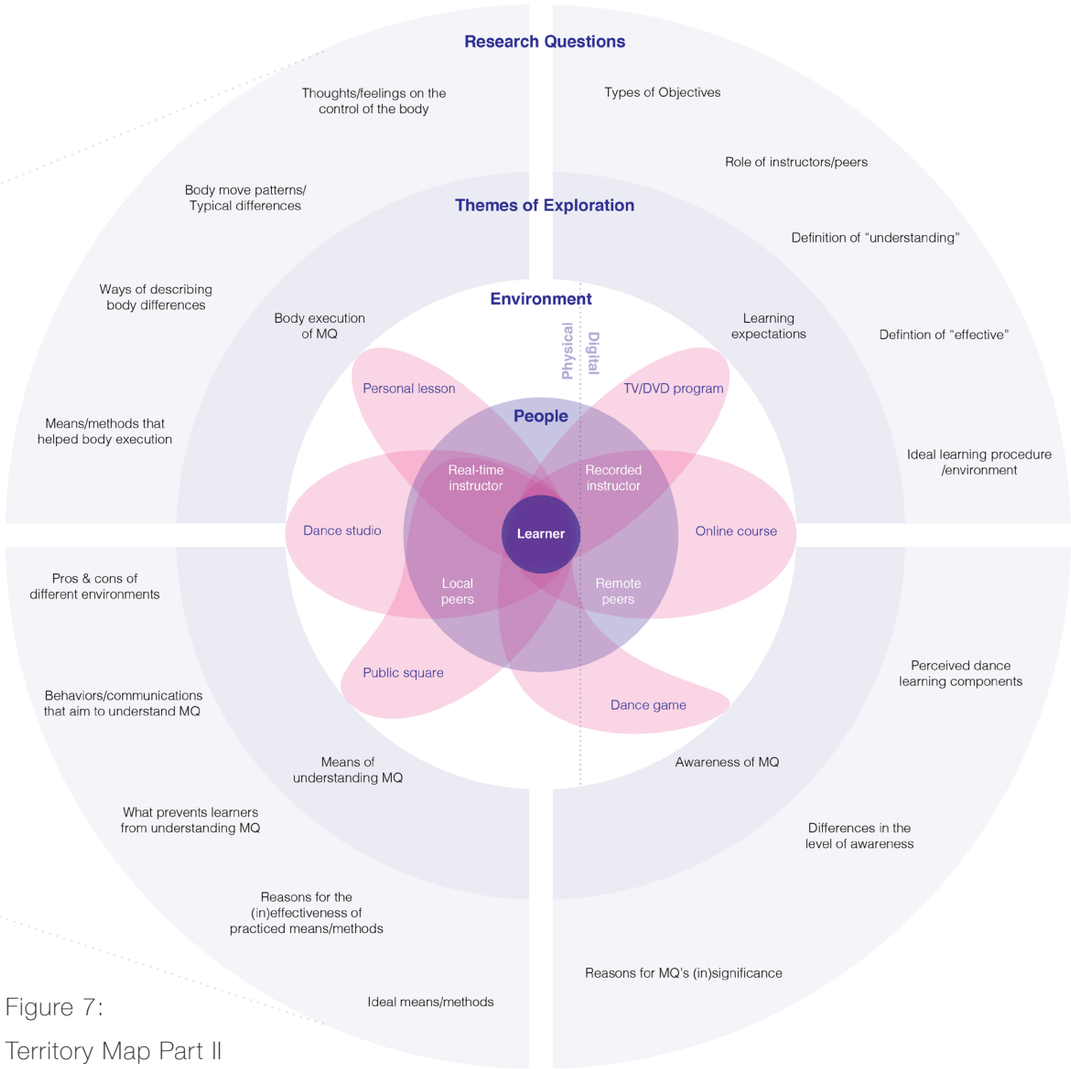


Figure 7:
Territory Map Part II

Step 2: Determine Research Methods & Questions

I chose "observation study" and "in-depth interviews" as my research methods in that observation study helped me to uncover dancer's unconscious attitudes toward movement quality, and in-person interviews can reveal dancer's opinions and desires in a more intimate and direct way. I considered the following four research themes to guide the creation of my research questions to be used in the observation study and interviews with Salsa learners:

- *Learning Expectations*
- *Awareness of Movement Quality*
- *Means of Understanding Movement Quality*
- *Body Execution of Movement Quality*

Step 3: Conduct Observation Studies & Interviews

I observed two salsa classes with more than twenty learners, and conducted seven in-depth interviews.

Below are photo of the observed Salsa class and some sample interview questions:

Figure 8: Observation Study of Salsa Class

- *Why you decided to join this Salsa class? What is your learning goal?*
- *What are the different components in Salsa dance do you think you need to learn?*
- *Have you tried other ways of learning dance other than dance class? What do you like/dislike about it?*
- *Do you see any differences between how your body moves versus how the instructor's body moves? Can you describe them ?*

Identify Target Users & Needs

From observation studies and interviews, I synthesized three main insights.

Insight 01 - Studied dancers wish to find a variety of ways to execute movement in order to expand the expressive range of their bodies.

As studied dancers become more experienced and gain more interest into dancing, they no longer just want to have fun and dance comfortably. Instead, they want to discover as many style variations as possible so that they know how to move their body when they want to communicate certain messages. They believe that by increasing exposure to unfamiliar movement qualities, they will have a clearer picture of the relationship between the physical body, the dance music and the quality of their movement.

On the one hand, this insight aligns with what I found in literature review about the significance of movement quality in dance learning, on the other hand, this insight rvealed the group of audience that I targeted for my project: once beginner dancers have memorized the dance steps, they start to shift their focus from sequence of movements to the execution of the sequence, and raise a series of needs that are specifically relating to movement quality. Therefore this group of dancers can be said to reach an intermediate level in dance learning.

The diagram below illustrates this identified user group: beginner-to-intermediate dancers who have a high degree of familiarity with the sequence of dance steps. The diagram also lists some of this user group's subgoals, which all lead to one larger goal: enhancing the expressiveness of body movement through discovering new movement qualities.

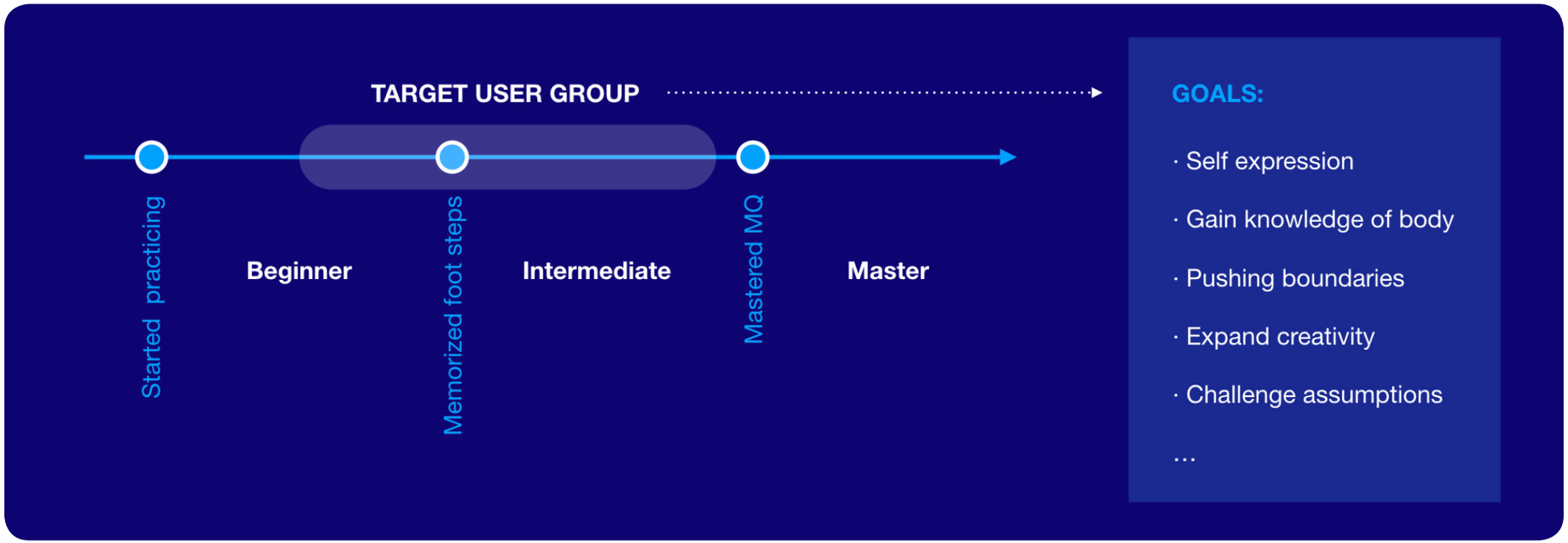


Figure 9: Target Users

Identify Target Users & Needs

Insight 02 - Existing ways of finding and understanding new movement qualities are very limited.

The studied dancers have directly or indirectly expressed the difficulty of discovering new movement qualities. In a typical dance studio learning environment, the instructor can only provide a few ways to dance a certain move, and students have to go to dance clubs or watch online videos to see more possibilities. However, it is very hard to understand new movement qualities from these venues. Obstacles include singling out a specific dance move, copying and repeating the desired movement quality, etc. Below are some quotes from interviews that support this insight:

- *"I see other's demonstration but then I don't quite remember it. When I practice on my own, I don't know what to do."*
- *"I go to dance clubs a lot to see different styles. But it is almost impossible to follow. People will improvise with other dances."*
- *"I don't want to copy the instructor because his moves are very muscular. I watch tons of videos to see more possible ways of doing a move."*
- *"I need to pause, play and rewind the video over and over to understand what is going on. It is really tedious."*

Insight 03 - Dancers finds it hard to practice movement qualities in group learning environments.

Dancers believe that when they dance in pairs, such as in social dances, they should collaborate with their partners instead of thinking about themselves and ignoring the energy flow between them. Thus it is almost impossible to focus on practicing the qualities of their own movement.

Dancers also said that when they dance in a group, they find it uncomfortable practicing their own movement qualities in front of others because the in-process movements are not presentable. In addition, if there is an instructor, his or her movement quality is often presented in a fragmented and distorted way due to demonstration purposes. Therefore, they wish to have non-disruptive access to the desired movement quality as it is performing in solo learning environments. B

Below are some quotes from interviews that support this insight:

- *“I prefer to practice my movement qualities at home alone. I feel more comfortable and can focus on myself.”*
- *“When you dance with others, you should be less conscious about yourself and focus on the connection with your partner.”*

Identify Target Users & Needs

- *“It is embarrassing to practice hip motion in class. I prefer to practice my styles at home alone. I feel more comfortable and can focus on myself.”*

- *“When the teacher breaks down a movement and demonstrates it, his movement quality is a simplified version. I don’t gain much knowledge about the actual movement quality.”*

Based on these three insights, I determined the design goal of my thesis:

How can we help dancers explore a variety of movement qualities in solo learning environments?

Step 1: Search Relevant Theories & Methods

With this design goal in mind, my next step was to search for existing theories and methods of movement quality exploration and test them with users to find out what works and what not, what are the expectations and concerns.

One theory I found is called Somaesthetics, which emphasizes the importance of bodily awareness. This theory's main contributor, Richard Shusterman, argues that a heightening of somatic consciousness would not only increase the perceptual awareness of meanings and feelings, but also enhance artistic appreciation and creation (Shusterman, R., 2012).

This theory offers two ways of viewing the body, one is viewing the body as an external machine that works independently from the mind, the other one is viewing the body as an internal vehicle that functions as the extension of the mind (Figure 10).

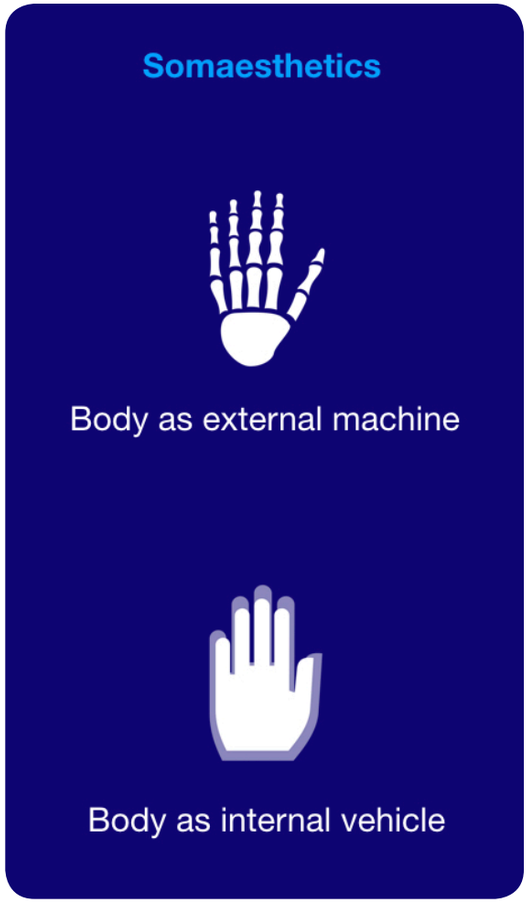


Figure 10: Theory of Somaesthetics

Test Existing Theories & Methods

One method I found is call the “making strange” methodology (Loke, L. & Robertson, T., 2013), which offers various analytical and experiential ways to de-familiarize the movements of the body. For example, “Finding Pathways” is identifying the specific part of the body that dancers use when they move, and changing the moving sequences of those parts. And “Imagery” is using descriptive metaphors to discover new movement qualities, such as “dance like you are climbing stairs” (Figure 11).

This methodology argues that these methods enable an investigation into the experience of movement, and can open up new spaces in the design of artifacts and technologies.

Figure 11: “Making Strange“ Methodology

Step 2: Design the Workshop

Based on these research, I came up with the activity framework for an exploratory user workshop, which is illustrated on the right.

I grouped variables that could effect movement quality based on the found concepts and methods, and created prompts that ask participants to sequentially experience the changes of these variables while dancing, and experience the resulting movement qualities with and without seeing themselves.

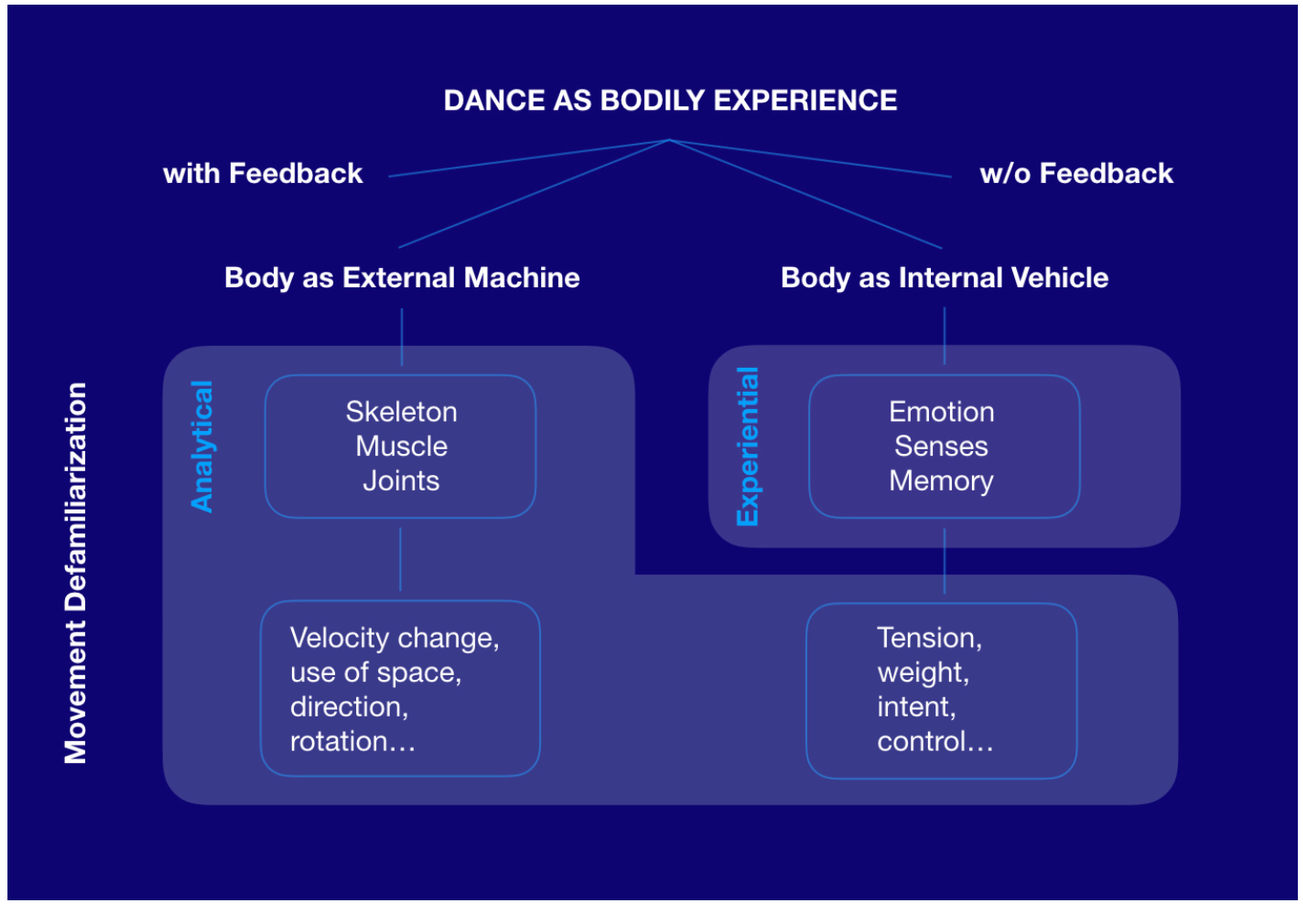


Figure 12: Workshop Activity Framework

Test Existing Theories & Methods

The major goal of the workshop was to test the effectiveness of these prompts as a way to heighten dancer's somatic consciousness and thus discover new movement qualities. Participants were asked to follow a series of analytical and experiential prompts that identify some of the variables summarized in the framework, then move their body accordingly. For example, an analytical prompt would ask participants to change the kinematic parameter of a specific body part (Figure13), and an experiential prompt would ask participants to dance with an imagery in mind (Figure14).

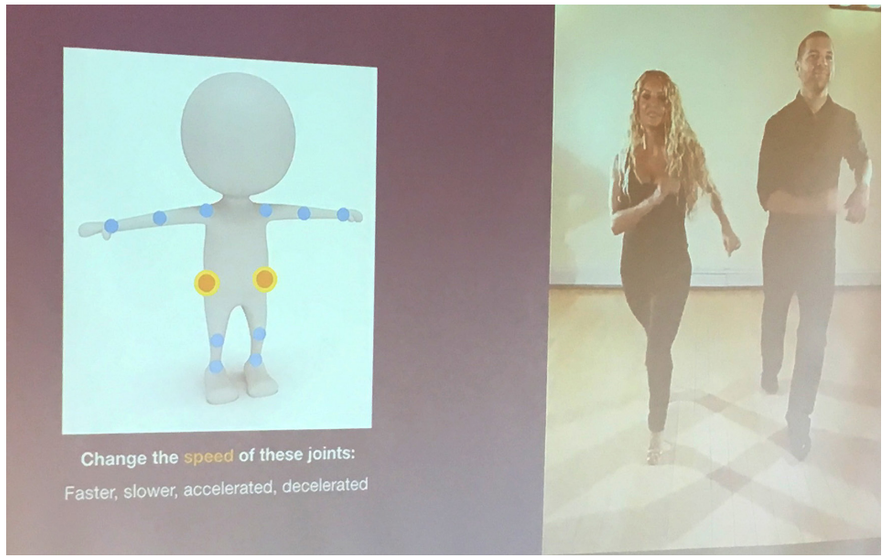


Figure 13: Analytical Prompt

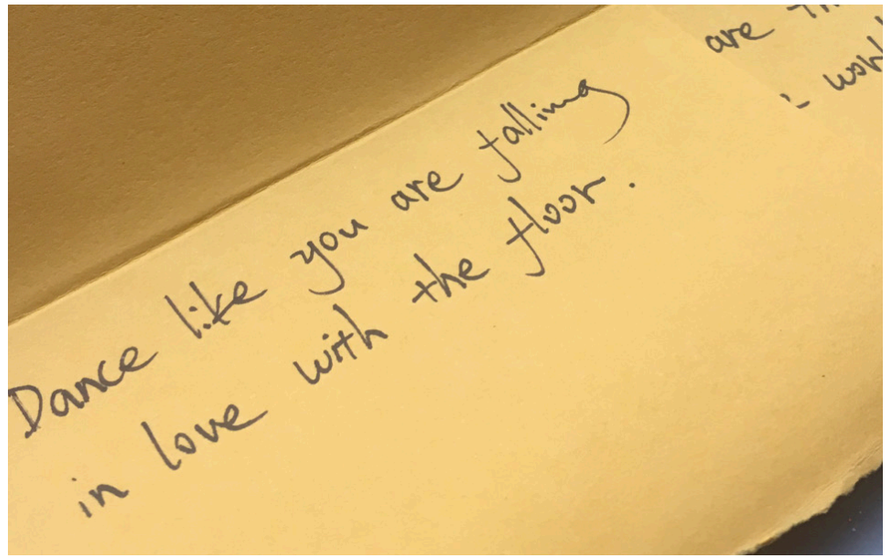


Figure 14: Experiential Prompt

Step 3: Conduct the Workshop

I recruited five Salsa dancers to participate in this exploratory user workshop. During discussion, participants are positive about the helpfulness of using different types of prompts to increase dancer's body awareness and discover new movement qualities. Compared to the conventional way of discovering new movement quality through other dancers, this approach embarks on a journey of self-discovery, which offers greater possibilities in understanding the relations between movement quality and the body, the mind and even the music, and thus expanding the range of body expressiveness.

Figure 15: Participants Dancing with Prompts

Figure 16: Participants Having Discussion

Test Existing Theories & Methods

From this workshop, I also derived three design principles:

Principle 01 - Multi Modes

In addition to learn from other dancers, it is promising for the proposed design solution to provide other pathways to discover new styles.

Principle 02 - Comparative Feedback

Dancers need to compare the motion of two different styles so that they can understand the relations between body and movement qualities. The solution needs to provide feedback that makes this comparison process easier.

Principle 03 - Seamless Experience

Dancers wish to spend more time on dancing itself rather than wasting time on the logistics. The solution needs to provide integrated functions and smooth interactions to ensure a continuous exploration flow.

DESIGN PROCESS

In this chapter, I cover the steps I took to develop research findings into the final design, which include:
(1) speed dating of feedback typologies with graphic and interactive prototypes, which results in 3 types of feedback to be included in my proposed system - “live + video split view”, “real-time visualization” and “motion difference data”;
(2) testing system design with storyboards and initial user experience design. Here I determined my system to be a desktop application accompanied with an armband;
(3) user testing with mid-fidelity prototypes and model. Here I discovered mismatches in the designed experience with user’s mental model and confusing interactions on both the interface and the armband;
(4) design iteration into final design, which is illustrated by high-fidelity animated prototypes and model;
(5) development of a functional prototype using OpenPose;
(6) competitive analysis with both current dance practice venues and relevant innovative works to confirm design originality.

4

Since one of the design principles I found was the importance of comparative feedback, the first step I took was to determine what types of feedback should be provided to aid movement comparison. I created graphic and interactive prototypes and tested them with dancers to hear their thoughts.

- *Body*
- *Motion*
- *Music*

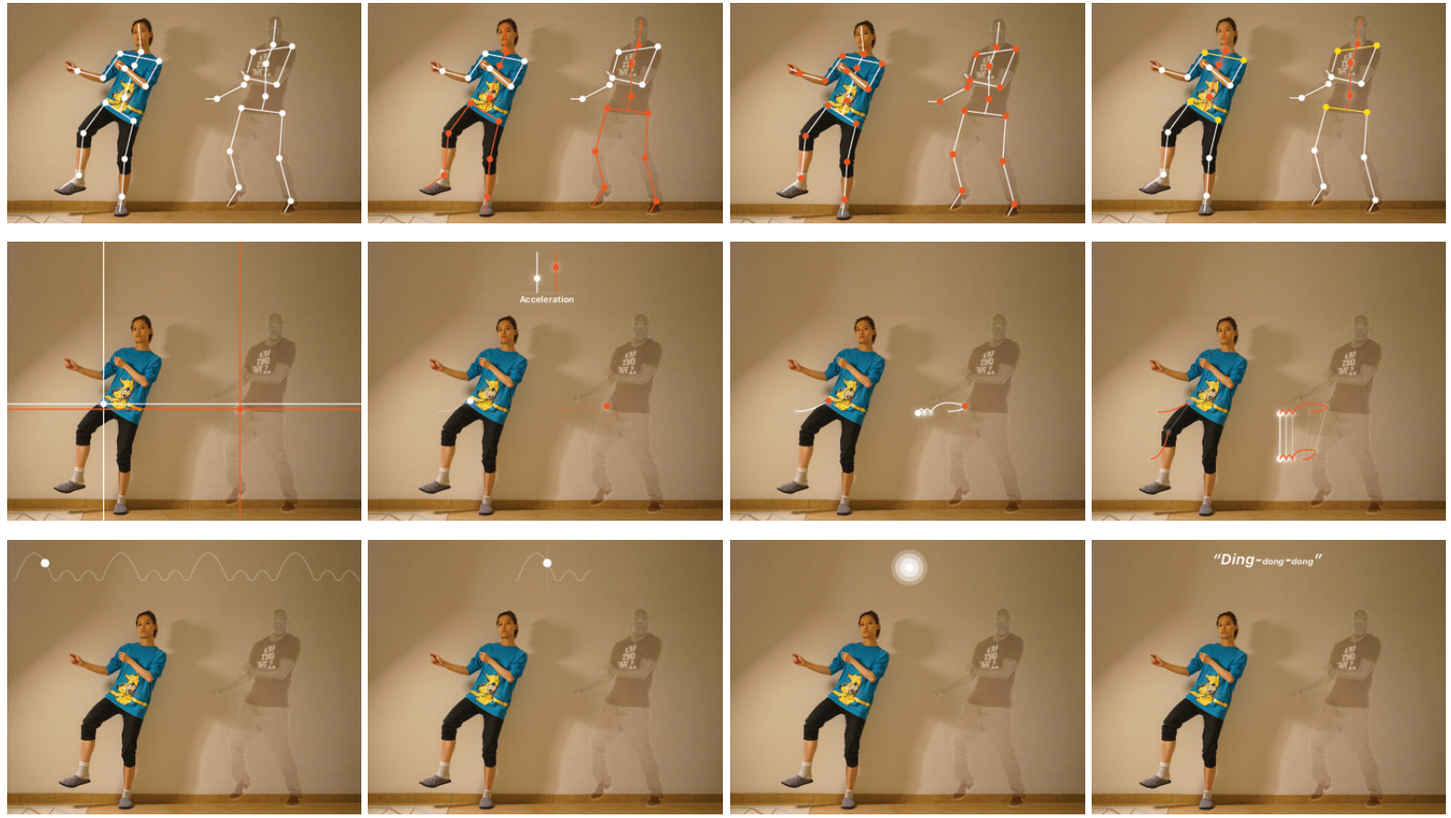
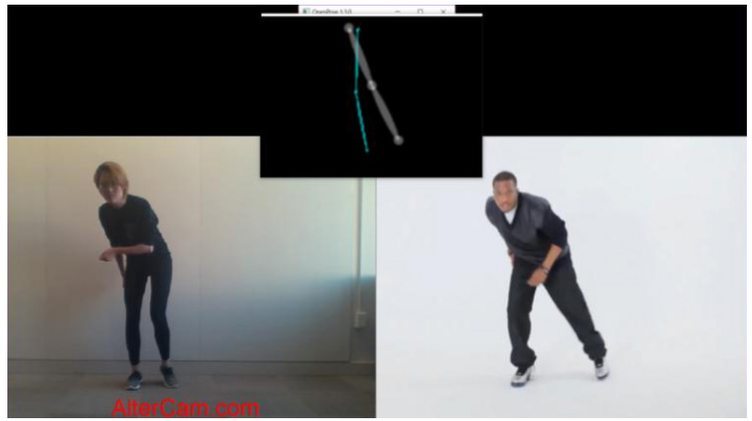


Figure 17:
Feedback Visualization Prototypes

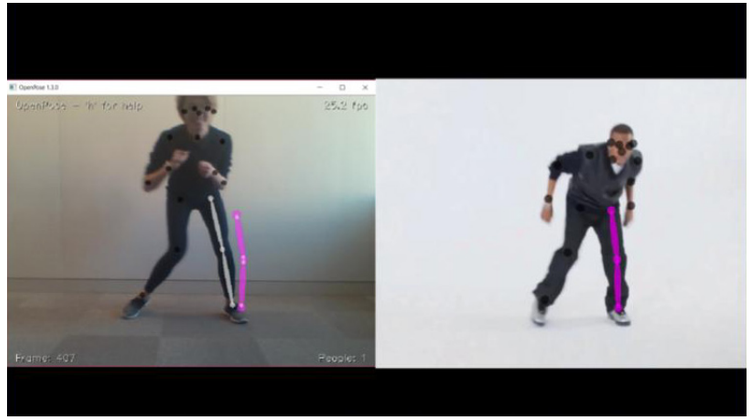
Speed Dating of Feedback Typologies

- *Compare via Grid Overlay*

- *Compare via Top Overlay*



- *Compare via Body Displacement Overlay*



- *Compare via Motion Trace Overlay*

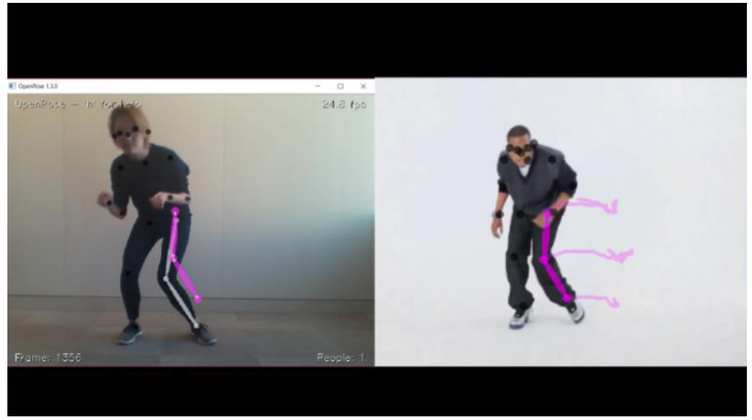


Figure 18:
Interactive Prototypes

Speed Dating of Feedback Typologies

Figure 19: Dancers Testing Prototypes

From conducting speed dating of feedback typologies, I found that 3 types of feedback are particularly useful for my target users:

- *Live + Video Split View*

The first feedback type is a split screen that allow dancers to see both themselves live and a video simultaneously.

- *Real-time Visualization*

The second type is real-time visual overlay augmented on the screen, which gives prominence to body motion itself.

- *Motion Difference Data*

The third type is data about motion differences, which can be recorded and reviewed later for further reflection.

Speed Dating of System Concepts

The next step I took was to design the overall system that helps dancers explore a variety of movement qualities in solo learning environments. I generated three concepts and illustrated my ideas using storyboards. I presented the storyboards (figure 20 & 21) to dancers and gathered their feedback.

What I learnt was that dancers are concerned about the usefulness and cost of the proposed systems. The usage of body suit or AR glasses would allow for haptic or three-dimensional feedback, but their cost might be very high, and they might also impede dancer's movements. Using a laptop is a good idea since it is fairly prevalent among dancers. However, its screen is too small for practicing dances; dancers wish to see feedback in real-life scale.

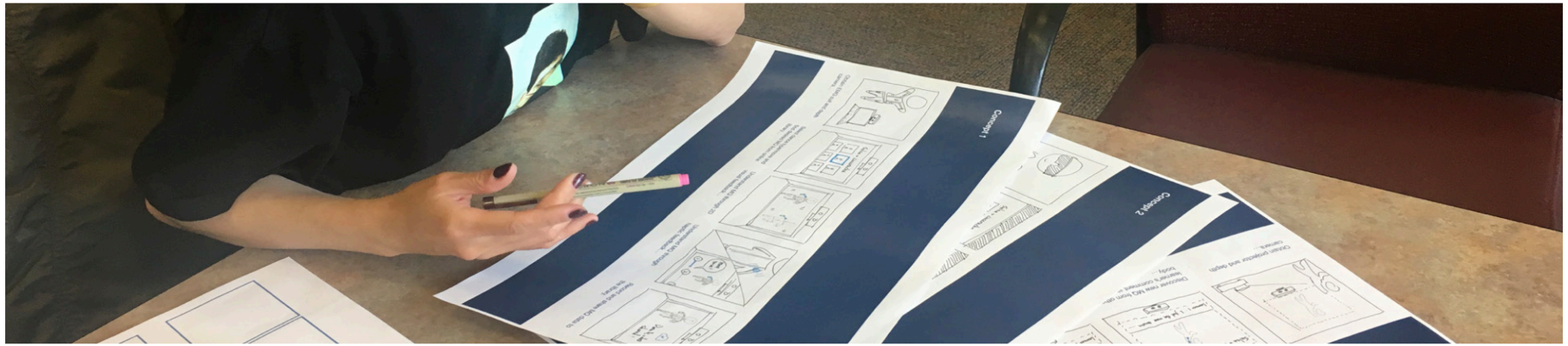
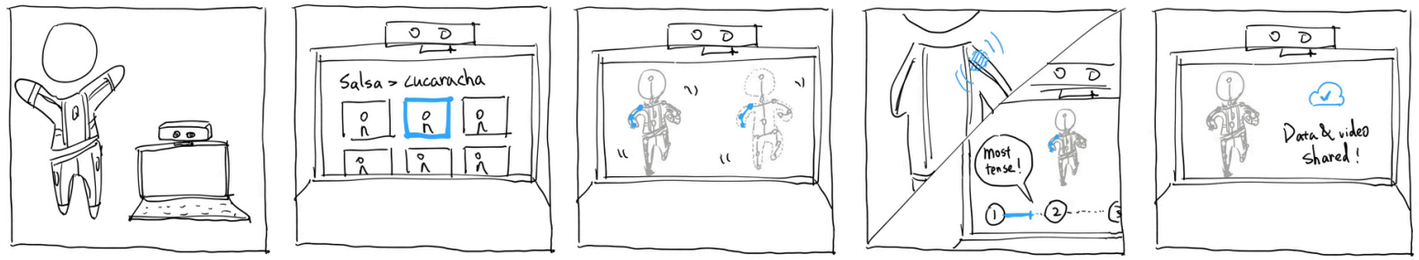


Figure 20: Speed Dating with Dancer

Speed Dating of System Concepts

- *Concept 1: Motion Tracking Suit+Computer*



Obtain EMG suit and depth camera…

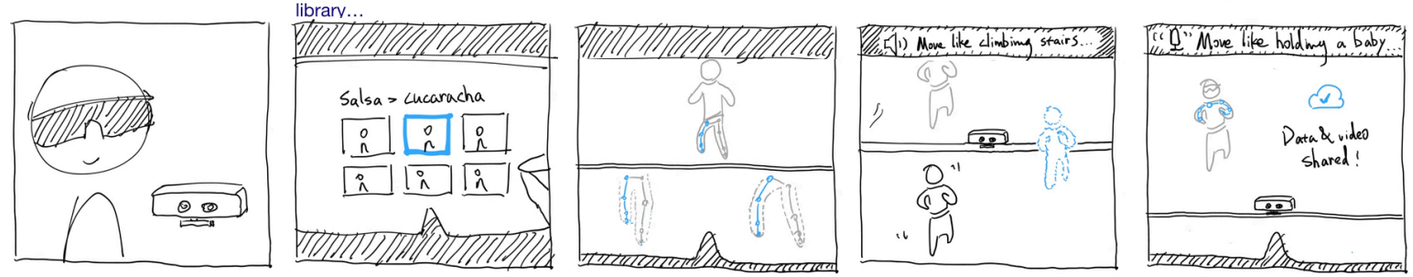
Select dance type/move and find desired MQ from online library…

Understand MQ through 2D visual feedback…

Understand MQ through haptic feedback…

Record and share MQ data to the library.

- *Concept 2: AR Glasses +Motion Tracking Device*



Obtain smartglasses and depth camera…

Select dance type/move and find desired MQ from online library…

Understand MQ through 3D visual feedback…

Understand MQ through experiential comments…

Share comments and MQ data to the library.

- *Concept 3: Projector +Motion Tracking Device*

Obtain projector and depth camera…

Discover new MQ from other learner's comment about the body…

Discover new MQ from other learner's comment about the music...

Select desired MQ from online library and talk to other learners in real time…

Share comments and MQ data to the library.

Figure 21: Concept Storyboards

Based on the result of concept speed dating, I decided to design a desktop application with an armband controller to empower dancers to explore movement qualities in solo learning environments.

The dancer first purchases the product from online channels and receives both an application program and an armband controller in one package via delivery. The dancer installs the application onto his or her computer (laptop or desktop), which can be connected to a projector or other output devices to see himself in real-life scale. The computer's webcam will track the dancer's movement and provide feedback. The dancer can use the armband to remotely control the application and explore movement quality.

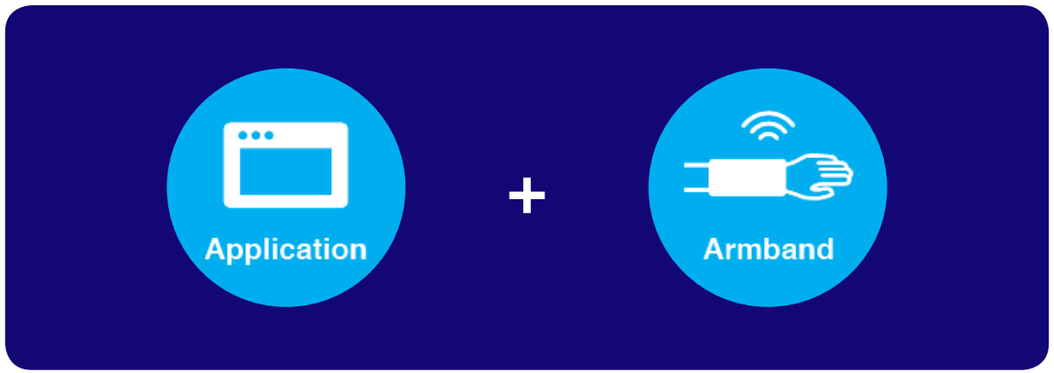


Figure 22: Product Package

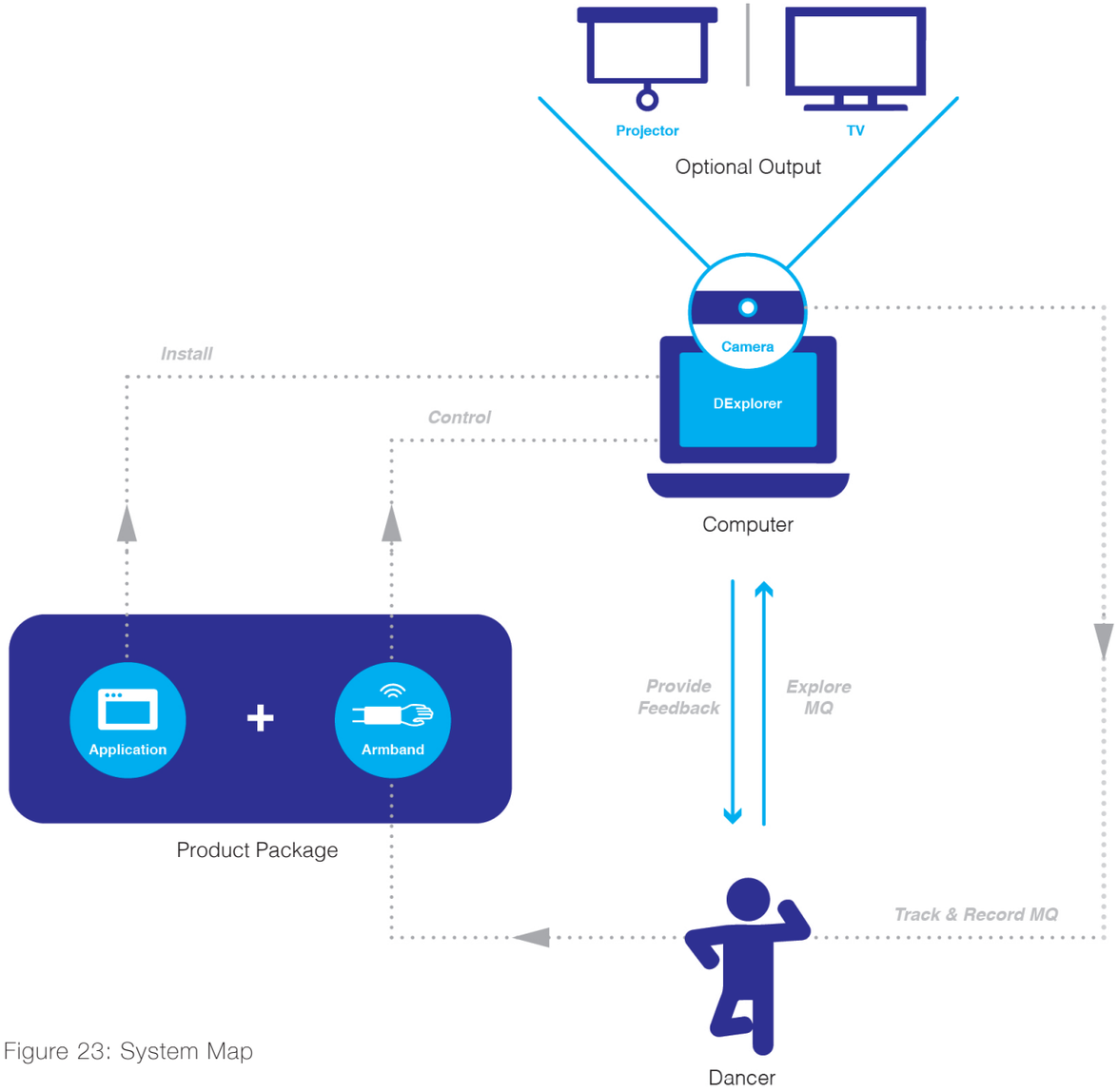


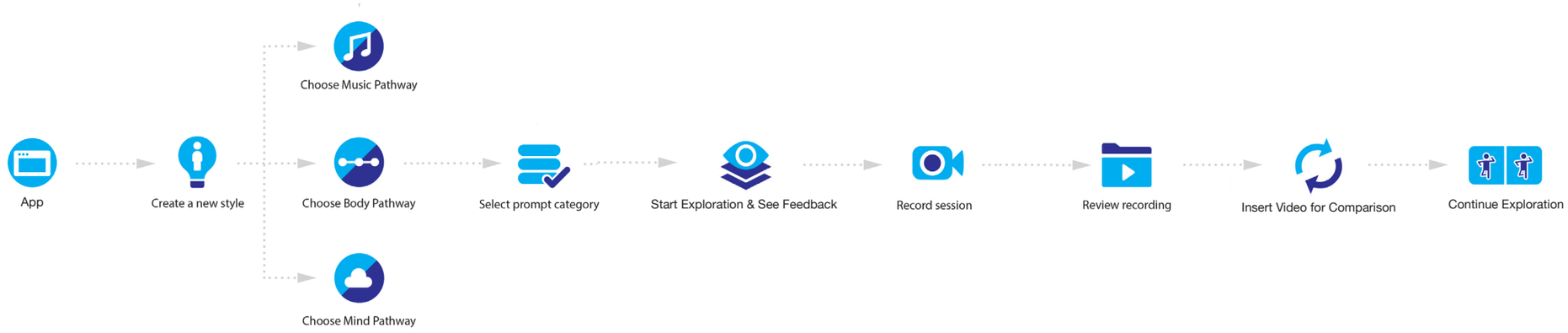
Figure 23: System Map

System & Experience Design

The application offers two modes of movement quality exploration: Create Mode, and Browse Mode. Under the create mode, dancers can choose to increase bodily awareness by investigating relations with the body itself, the mind, or the music, then follow prompts from interested categories to discover new dance styles. Under the browse mode, dancers can find desired new dance styles from crowd-sourced collections and practice from there. During exploration, dancers can use augmented visual overlays to compare style differences between themselves in real time and a recorded video of either themselves (Create Mode) or another dancer (Browse Mode).

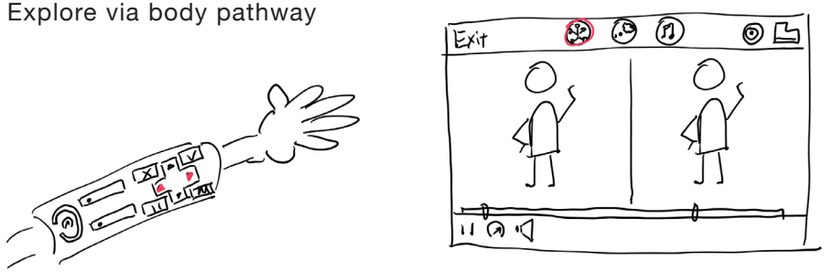
I mapped out the user journey for the proposed system, sketched out the application interfaces, then refined the sketches into mid-fidelity wireframes.

- *User Journey of the Create Mode*

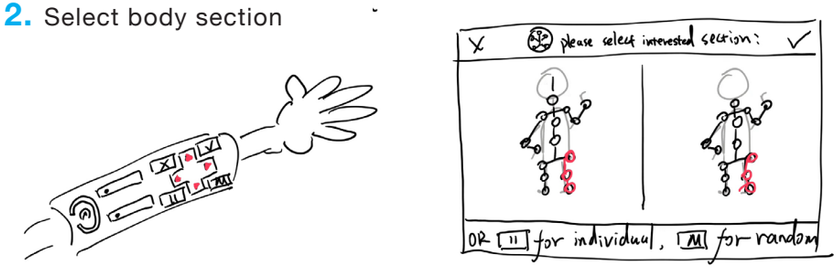


- *Selected Lo-fidelity Sketches for the Create Mode*

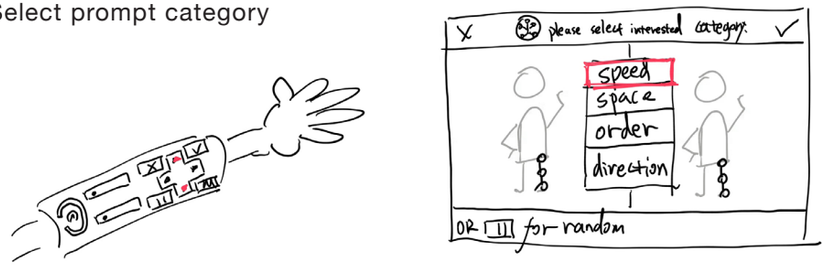
1. Explore via body pathway



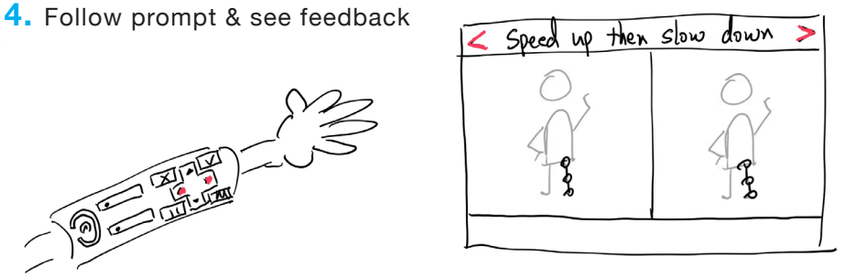
2. Select body section



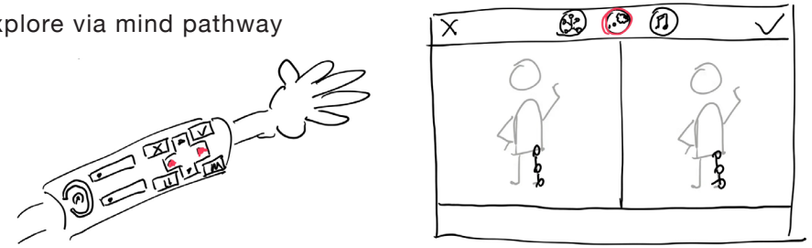
3. Select prompt category



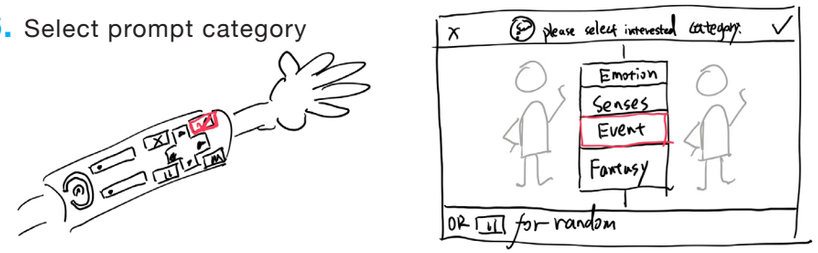
4. Follow prompt & see feedback



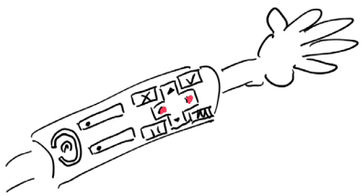
5. Explore via mind pathway

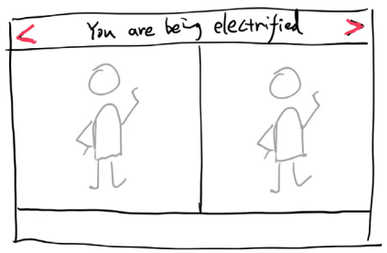


6. Select prompt category

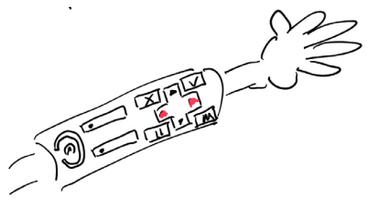


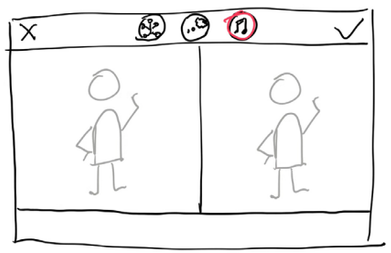
7. Follow prompt & see feedback



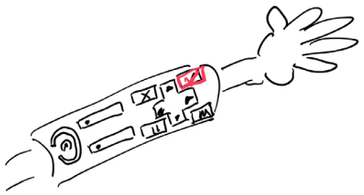


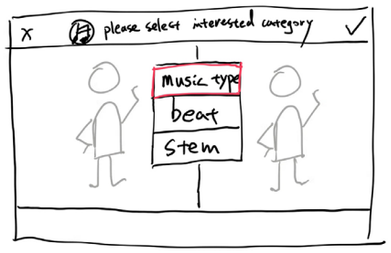
8. Explore via music pathway



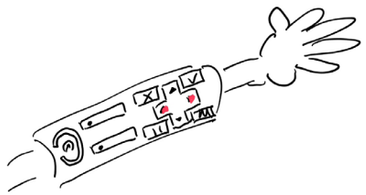


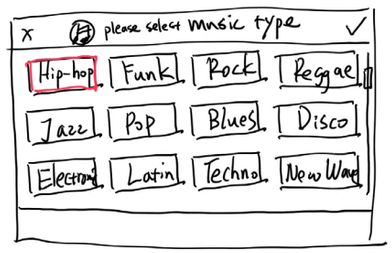
9. Select prompt category



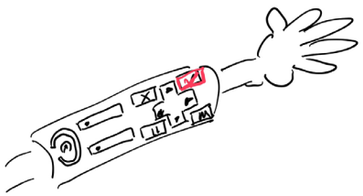


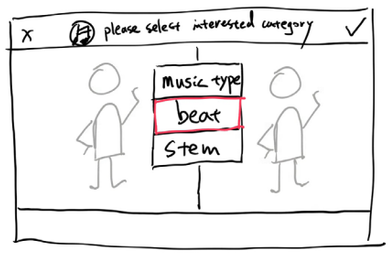
10. Select music type



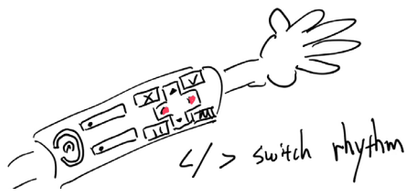


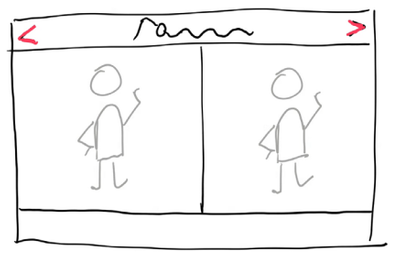
11. Select prompt category





12. Follow prompt & see feedback

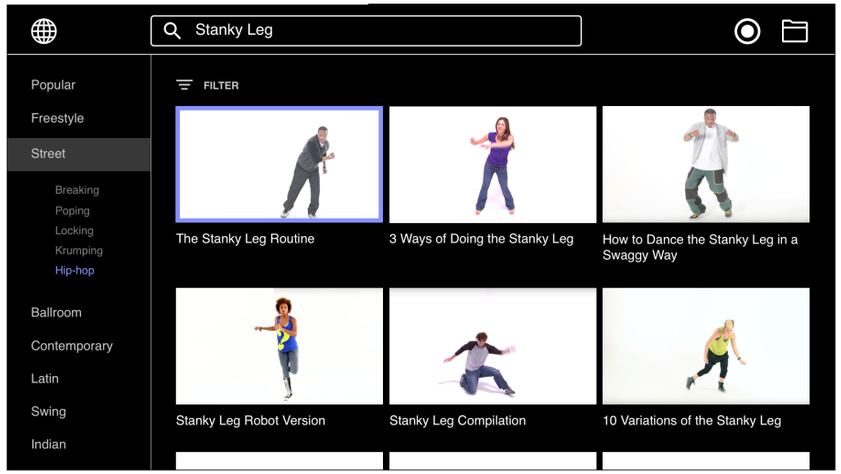




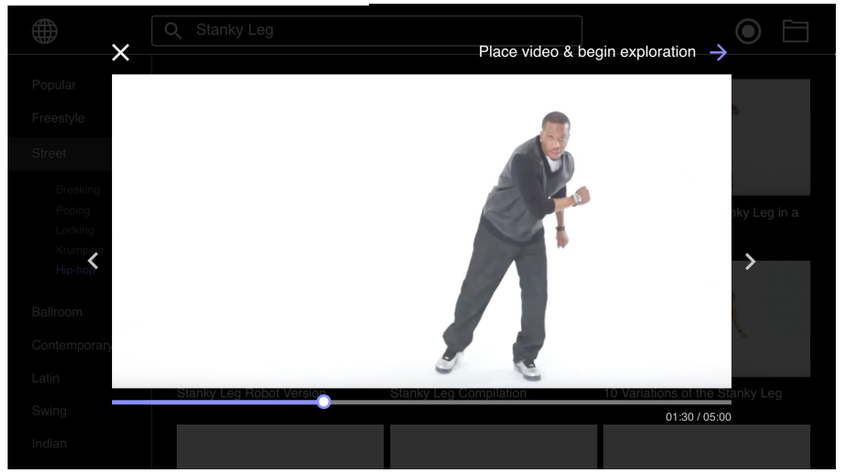
- *User Journey of the Browse Mode*

- *Selected Mid-fidelity Wireframes for the Browse Mode*

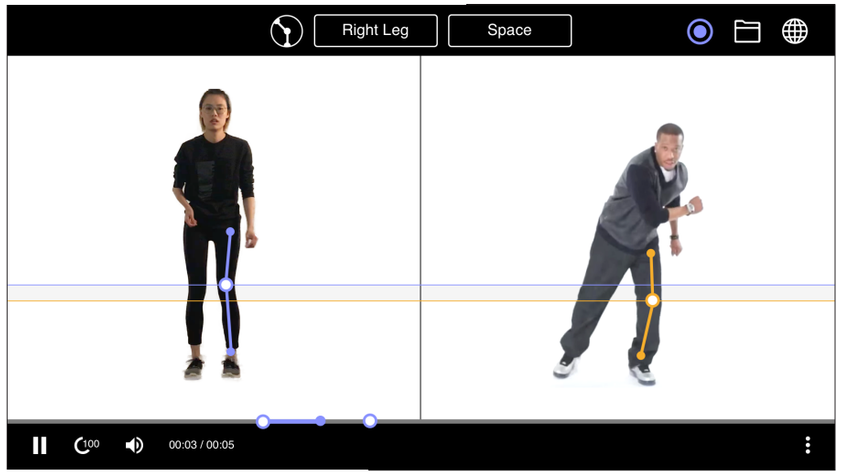
1. Search in World Style



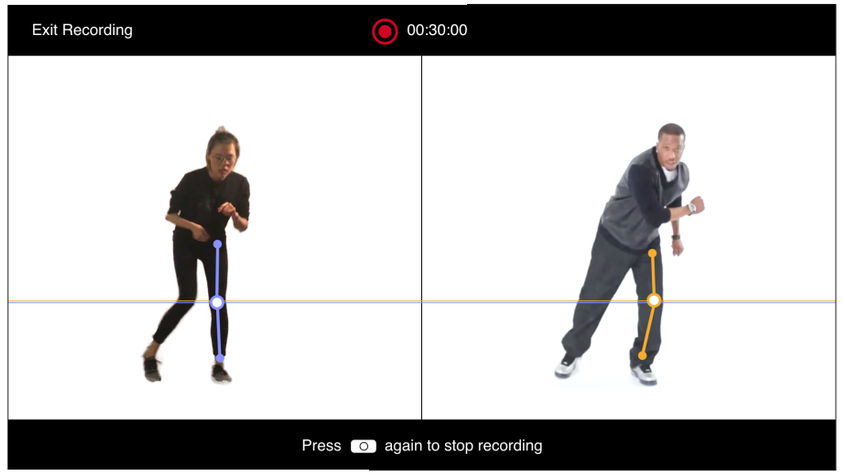
2. Select desired video



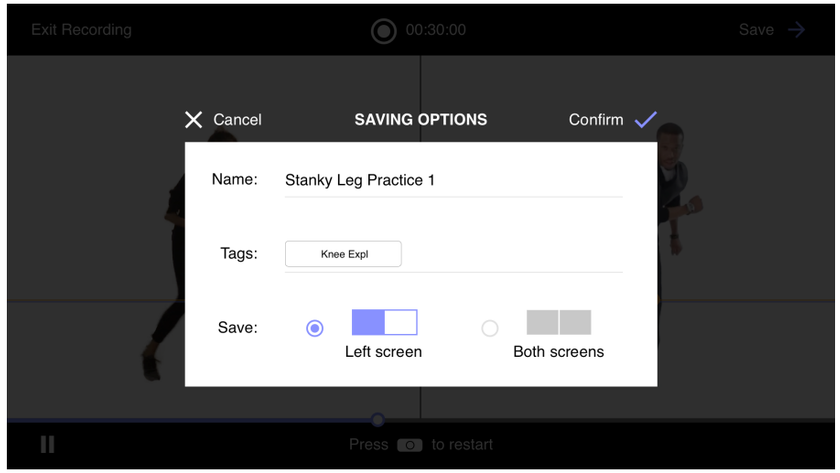
3. Follow video & see feedback



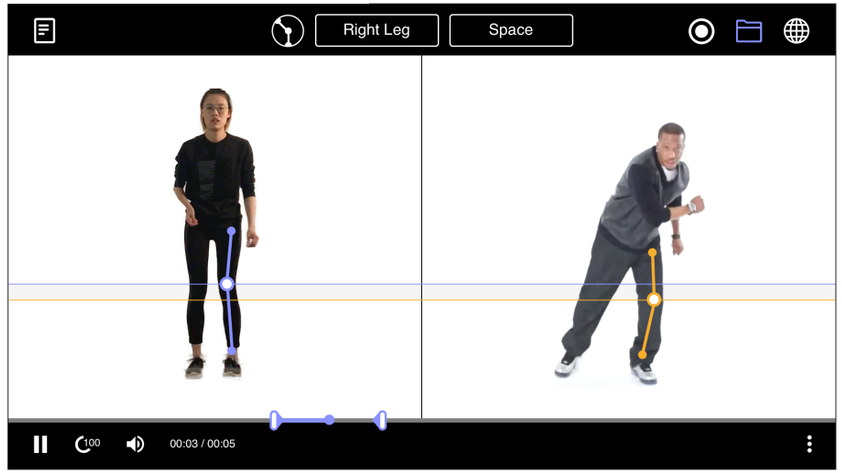
4. Record session



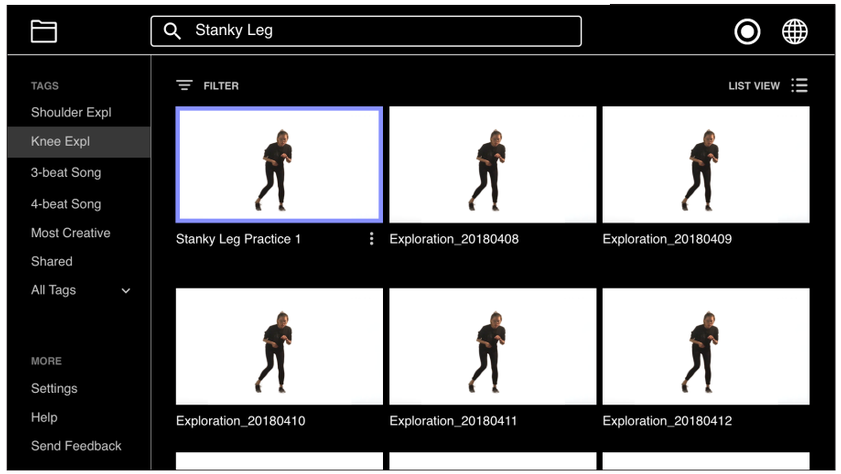
5. Save recording



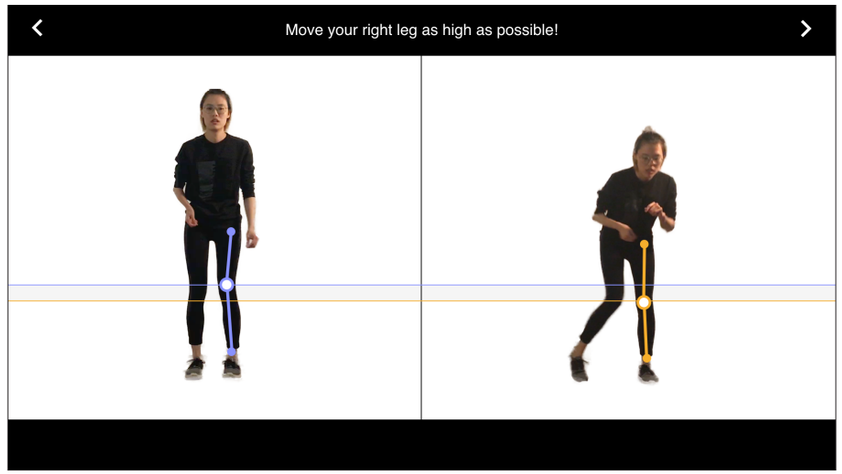
6. Go to My Library



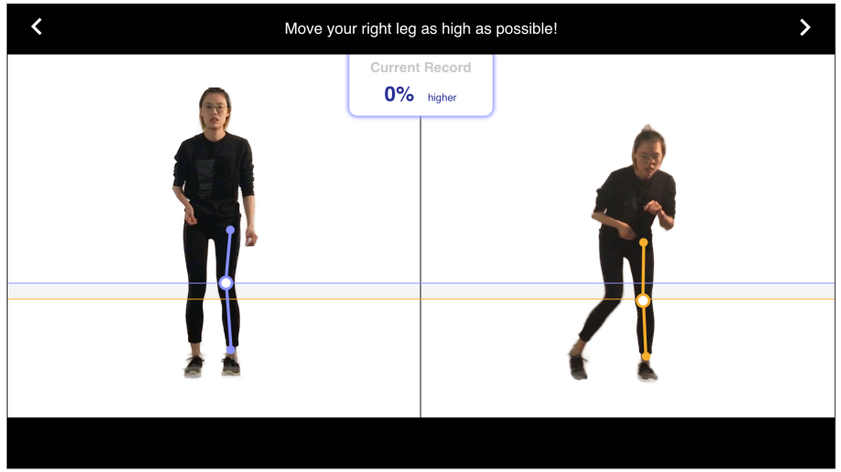
7. Select saved recording from My Library



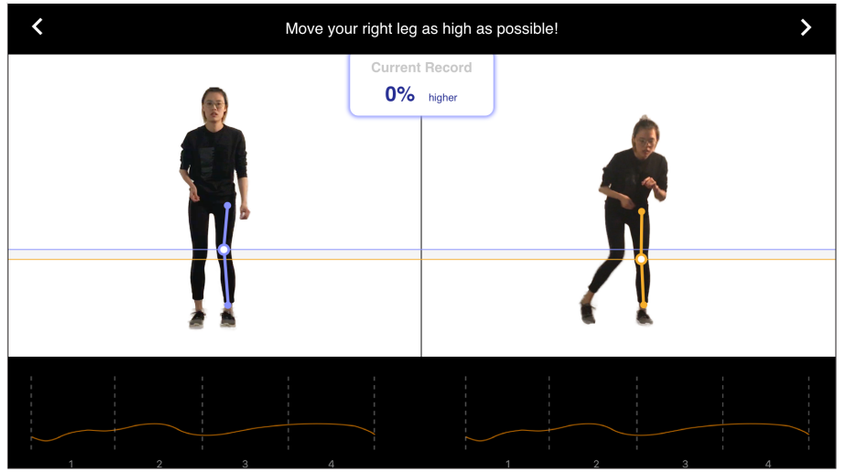
8. Swap video with selected recording & continue exploring



9. See current motion difference data



10. See motion difference data over time



User Testing & Design Iterations

I also designed and made a low-fidelity prototype for the armband controller. The idea of the armband is derived from the 3rd design principle that I synthesized previously. Dancers wish to see movement qualities in a continuous fashion and do not want their practices to be interrupted by the logistics of controlling videos. Thus I designed an armband that allows dancers to have the option of remotely controlling the application in addition to the conventional way of computer control. I tested the armband together with the mid-fidelity wireframes with potential users.

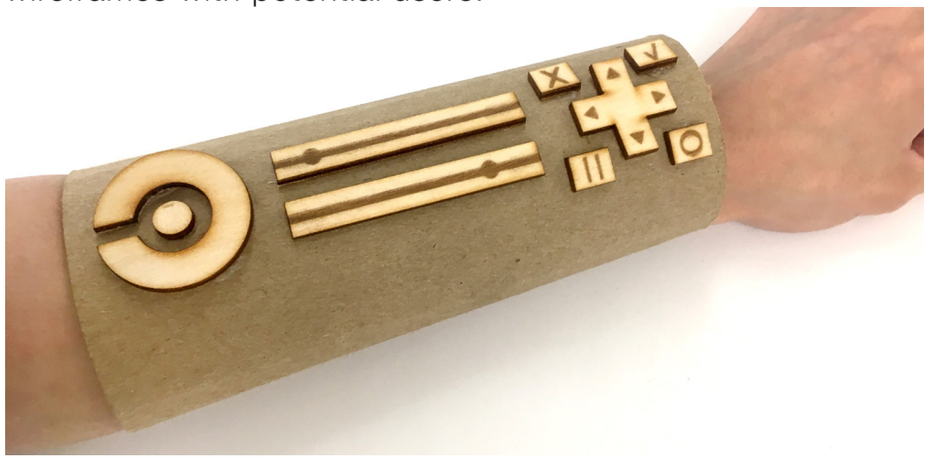


Figure 24: Armband Low-fidelity Prototype

Figure 25: User Testing

Problem 01 - Mental Model Mismatch

One of the biggest problems I found from user testing was that the function hierarchy in the current application design is not aligned with dancer's mental model.

First of all, dancers expect to see two exploration modes first, then select secondary functions.

However, in my start screen (Figure 26), I only provided the entry way for the Browse Mode (find movement quality), and put 2nd-level functions (record and my library) in juxtaposition with it.

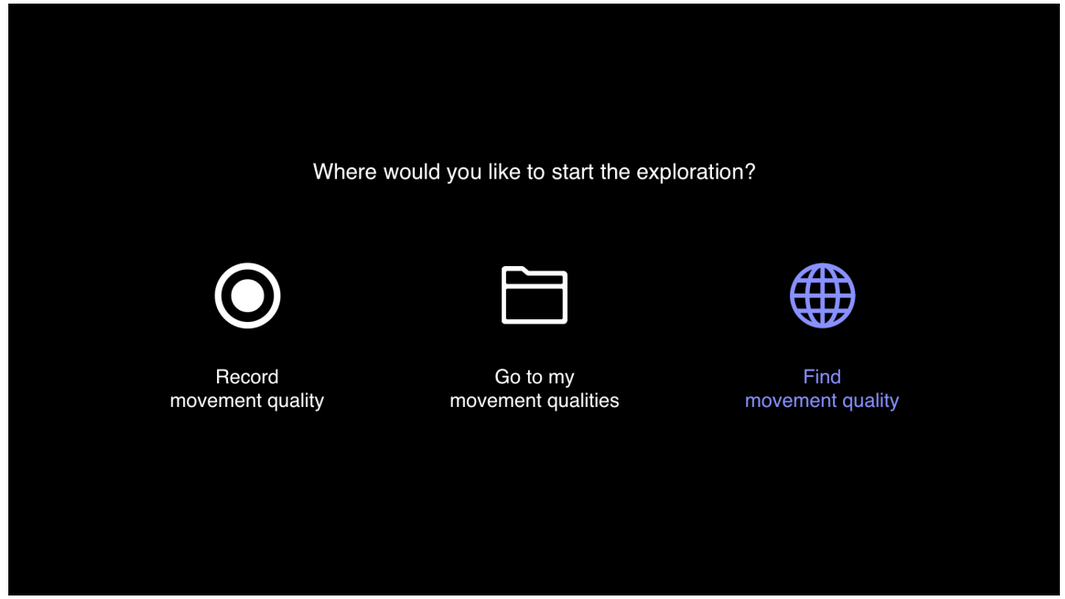


Figure 26: Start Screen

User Testing & Design Iterations

Secondly, dancers expect to easily distinguish between two modes and focus on one mode at a time because the goal for each mode is different. Under Create Mode, the video on the right is a recording of the dancer's self movement, because dancers want the dance to be as different as possible from this recording to discover new qualities. Under Browse Mode, what's on the right is an online video of another dancer. Dancers want to compare themselves in real-time with this video, and move their body to be as similar as possible to this desired new quality model.

However, my design (Figure 27) combined two modes into one interface, and provided features when they are not always relevant to the currently focused mode: when dancers are comparing themselves with another dancer in Browse Mode, they do not need to see the three pathways offered in Create Mode. Similarly, when they are comparing to themselves on the right, they do not need immediate access to World Style.

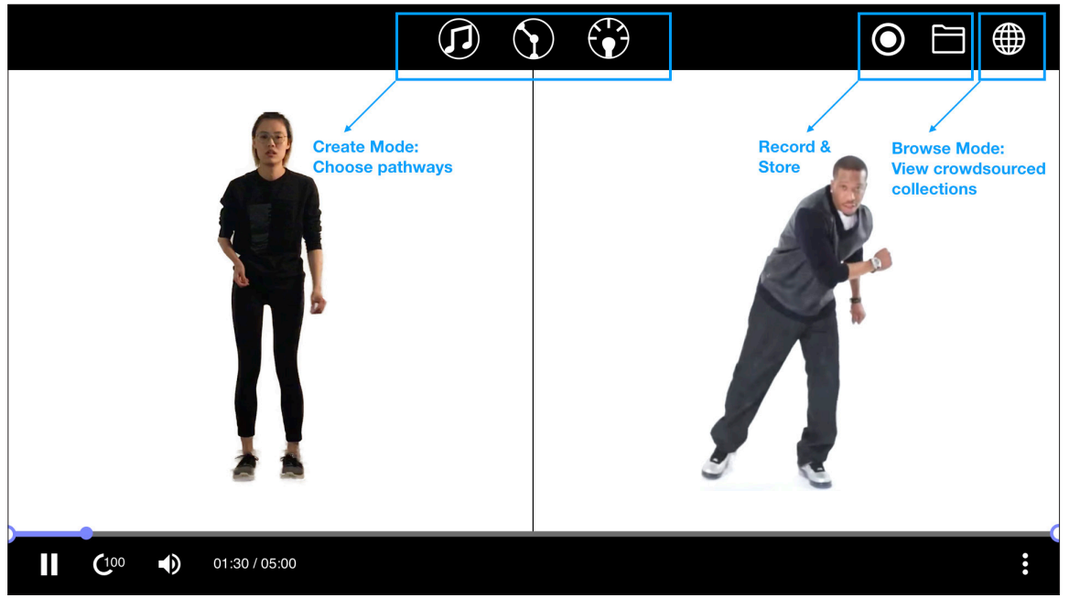


Figure 27: Main Menu

Problem 02 - Confusing Interaction

There were also areas where the proposed interaction design caused confusion among tested users. The first one occurred in the Saving Options step. When the dancer records a practice session, he can later (1) review this recording in My Library and see movement comparison, which requires saving both left and right screens into the recording; or (2) place this recording to the right to continue exploring in the Create Mode, which requires saving only himself in the left screen into the recording.

Considering the above scenarios, I came up with design on the right. However, the tested users couldn't figure out the implication of the choices. After explanation, they suggested to make saving both screens a default, and provide usage options later in My Library.

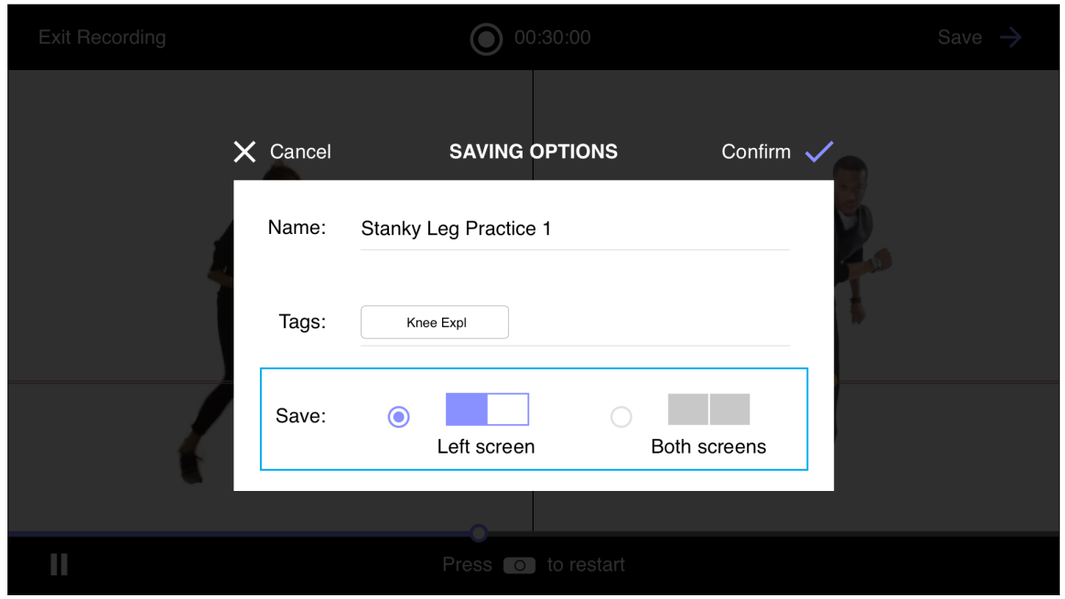


Figure 28: Saving Options

User Testing & Design Iterations

The second confusion happened when testing the interaction flow between the armband controller and the application.

When the tested users wanted to find the pause button to control the video, they expected it to be close to other control buttons. However, they found it next to navigation buttons, which was a surprise. In addition, they wanted to have hot keys on the armband to quickly access frequently used functions, so that they don't have to use the arrow buttons to navigate and access those functions. Also, when the tested users tried to bring up the main menu during exploration, they raised concerns of unable to bring up the menu from the computer end if the armband is out of battery (Figure 29).

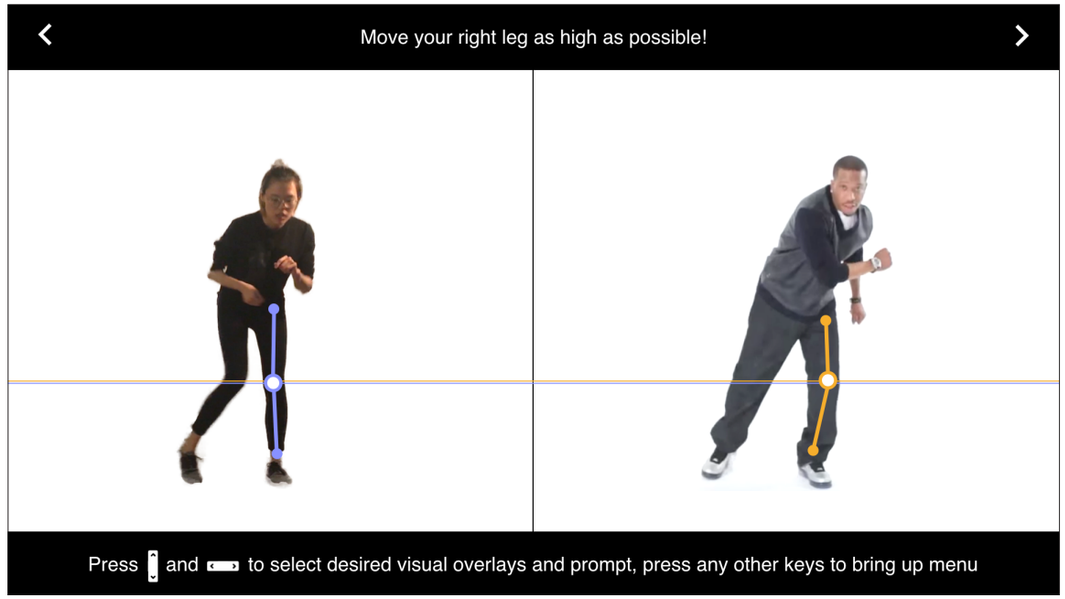


Figure 29: Exploration Interface

Taking all findings from the user testings into account, I reconsidered the user journey and iterated on the application and armband design. Here I will present a sample user experience of my iterated design following the highlighted routes in the new journey map (Figure 30).

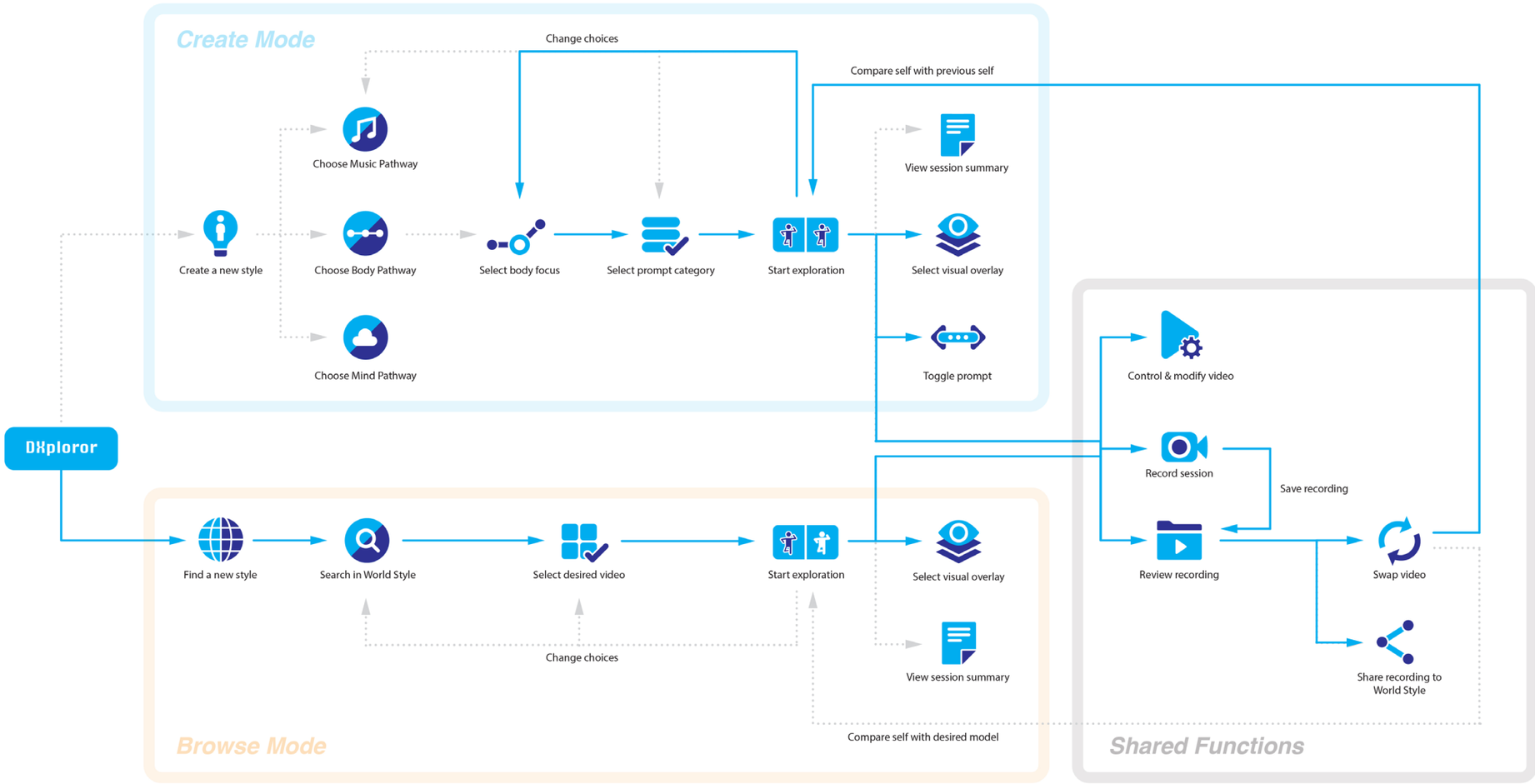
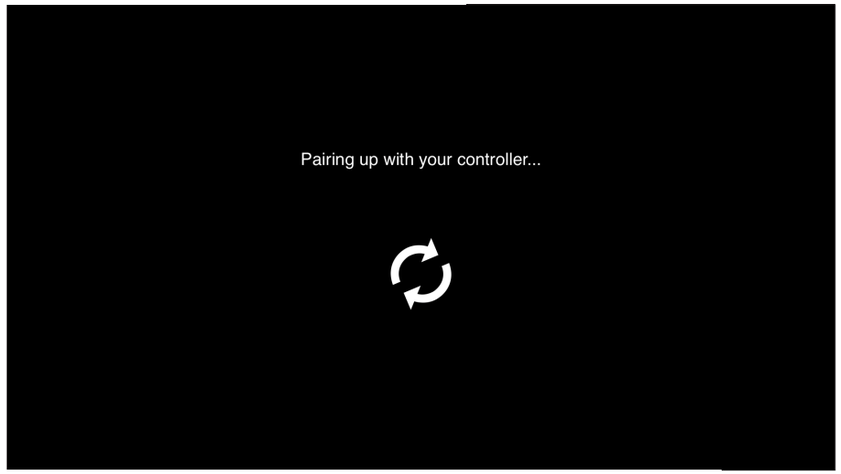


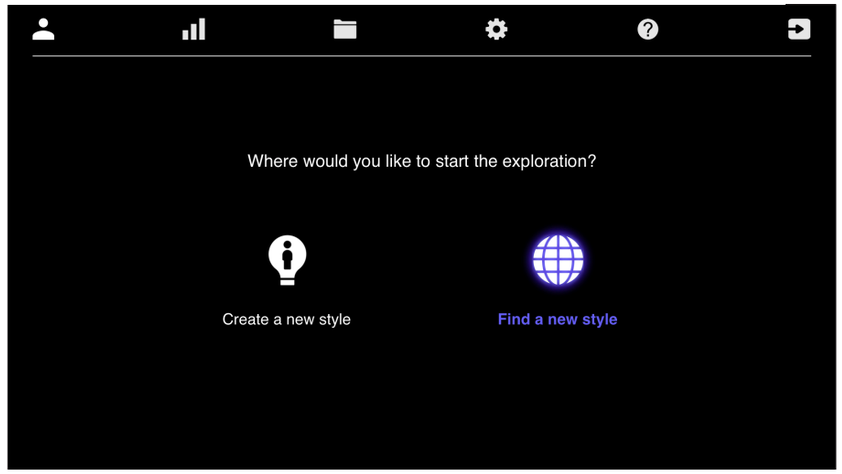
Figure 30: New Journey Map - Presented Sample User Experience Follows the Highlighted Routes in Map

User Testing & Design Iterations

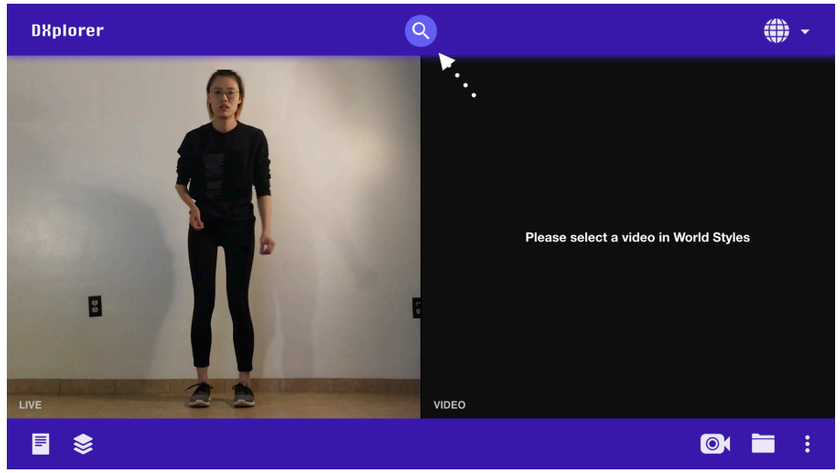
1. After pairing up with the armband...



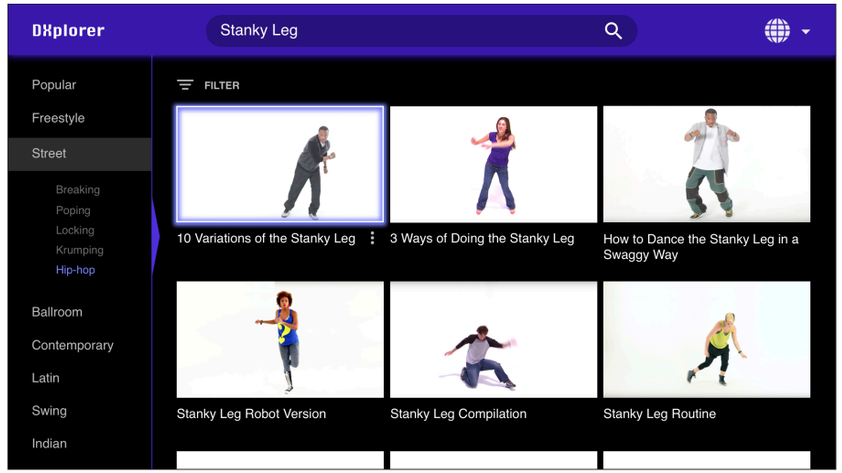
2. Dancer first chooses browse mode to start the exploration...



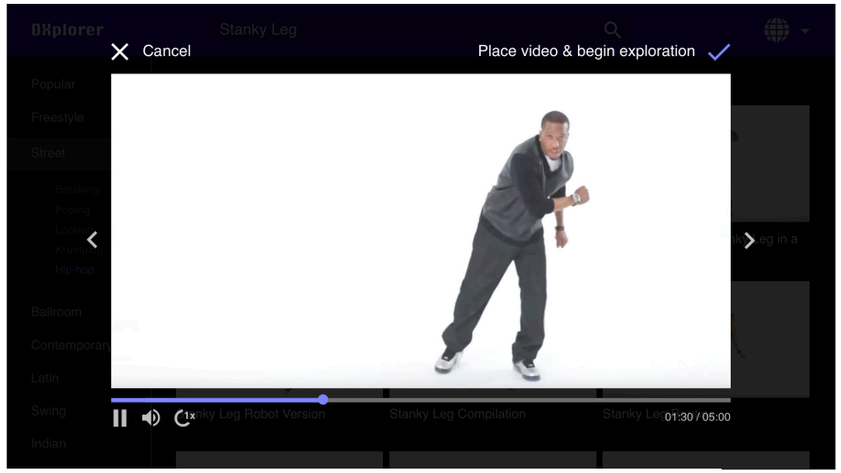
3. Dancer can search in world styles...



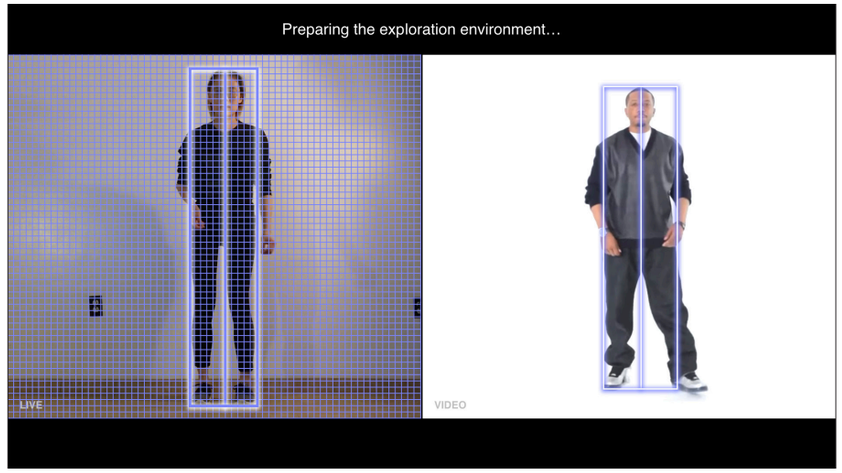
4. And browse various possible ways of dancing certain movements...



5. Once finds a desired style, dancer can place that video on the right...

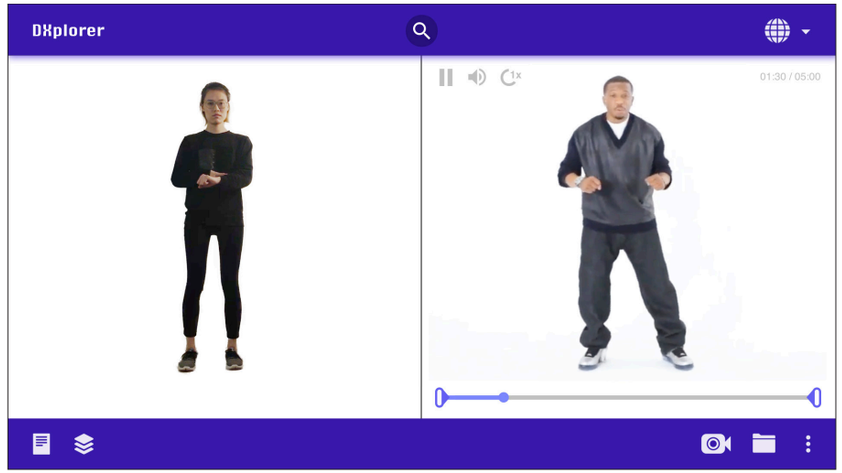


6. The system will scale the two bodies into similar proportions and...



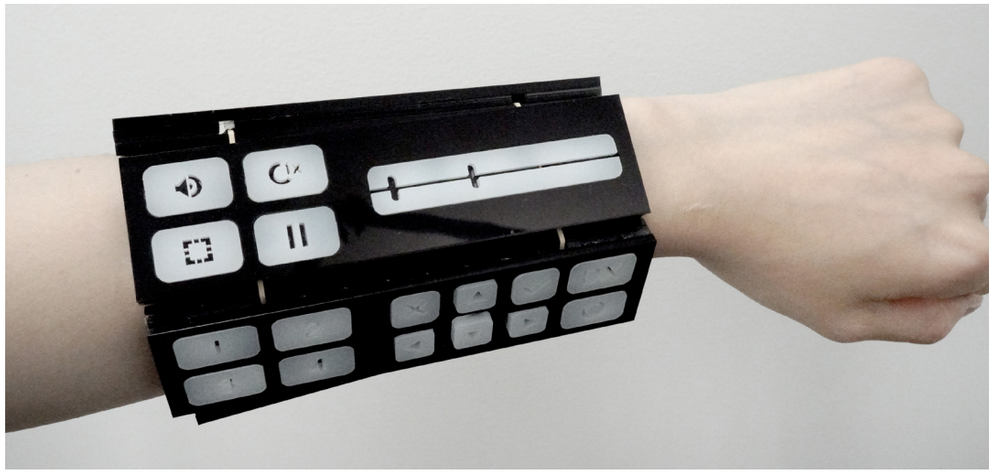
7. Masking the camera view with white background...

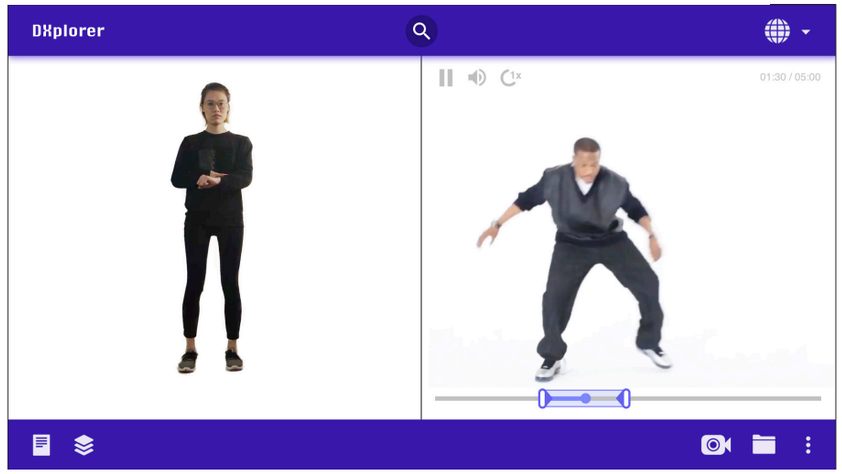
8. Dancer uses the armband to remotely bring up the menu...



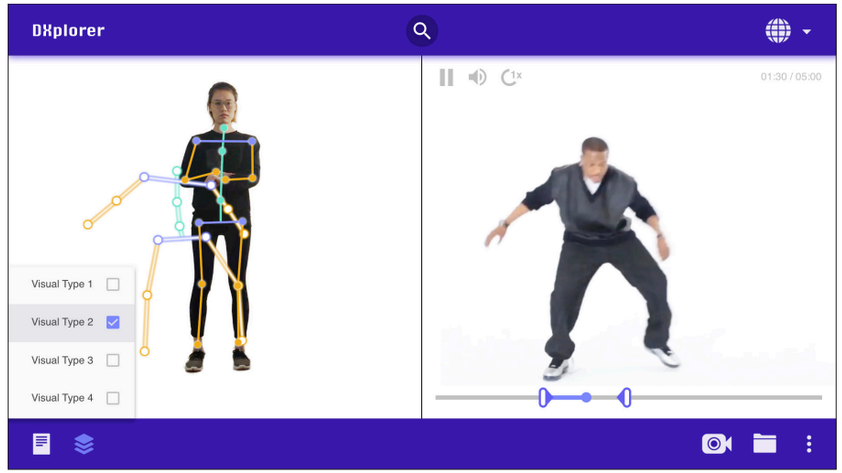
User Testing & Design Iterations

9. And control the video, such as clipping the video or changing the video play speed...

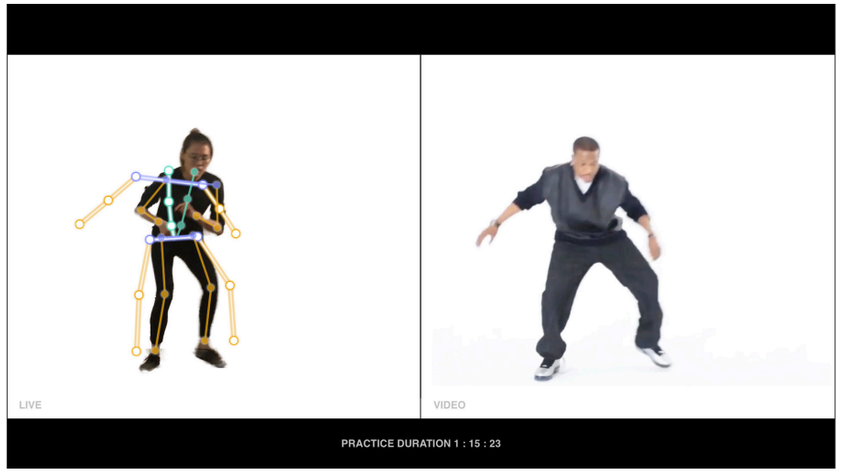




10. Dancer can select various types of visual overlays to help comparing motions, which can be quickly accessed by armband hot keys 1 to 4...

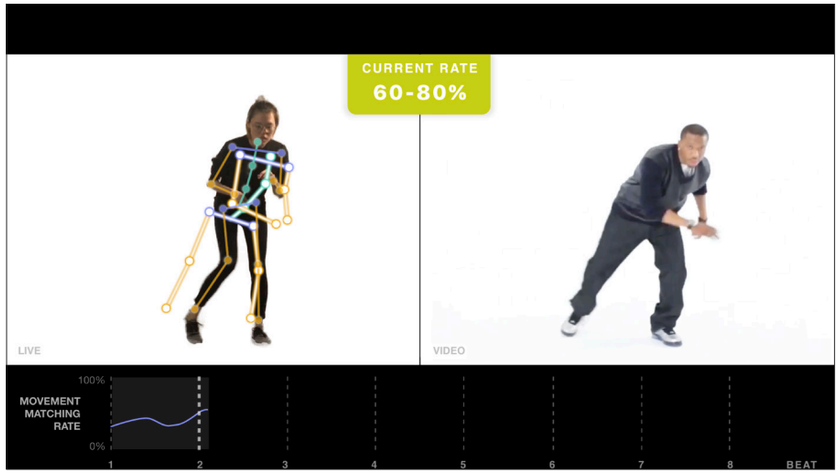


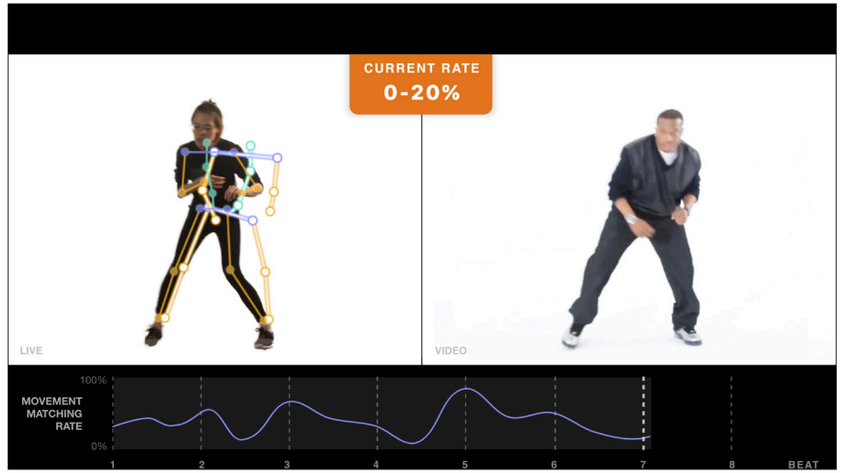
11. One type of overlay is showing both the body and the motion...



12. Another type is hiding the body and highlighting the motion...

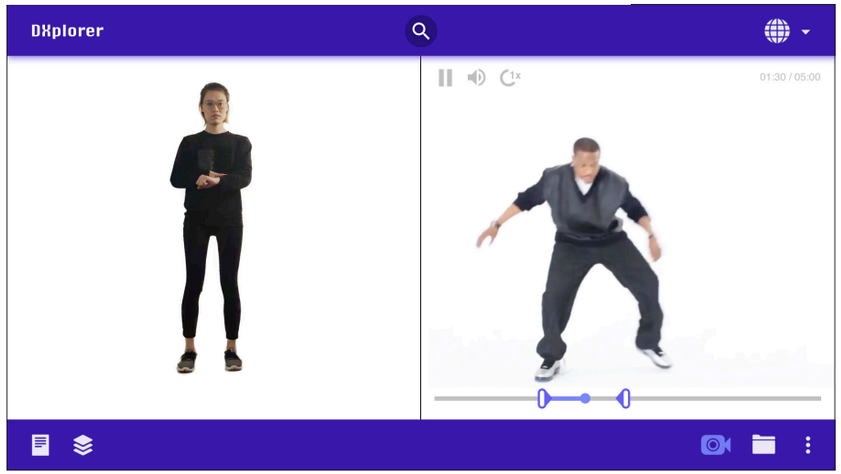
13. Another type is displaying the movement matching rate both in real-time at the top and over time at the bottom of the interface...

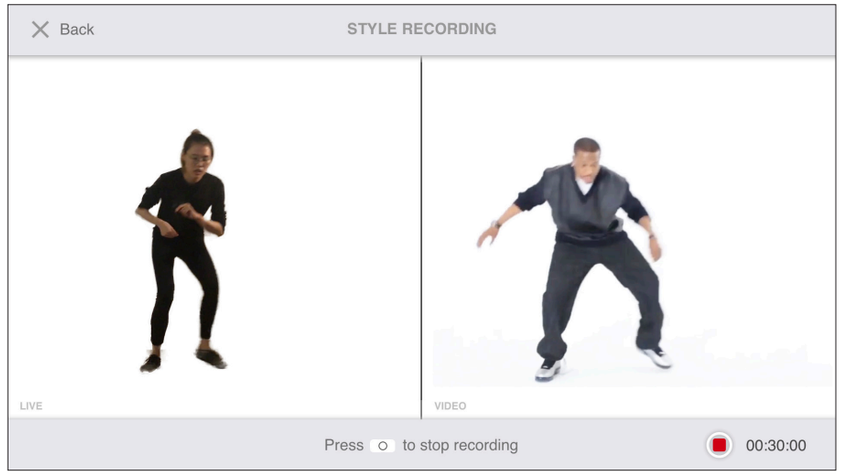




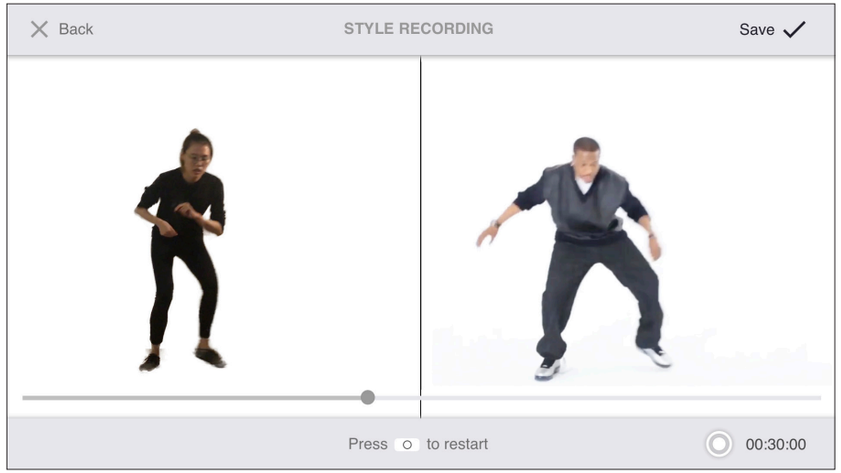
User Testing & Design Iterations

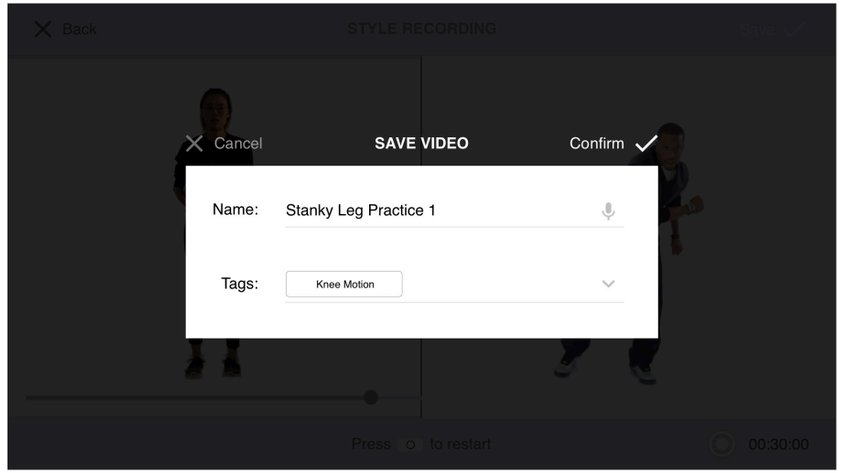
14. Dancer can record current practice session...



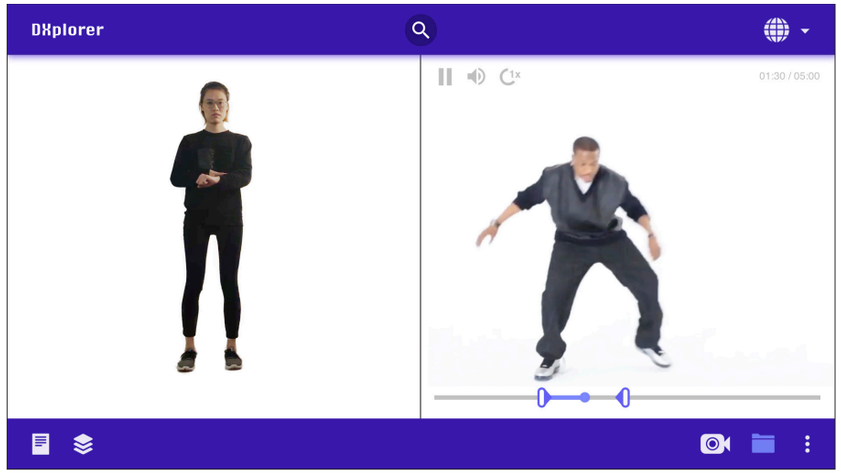


15. And save it...

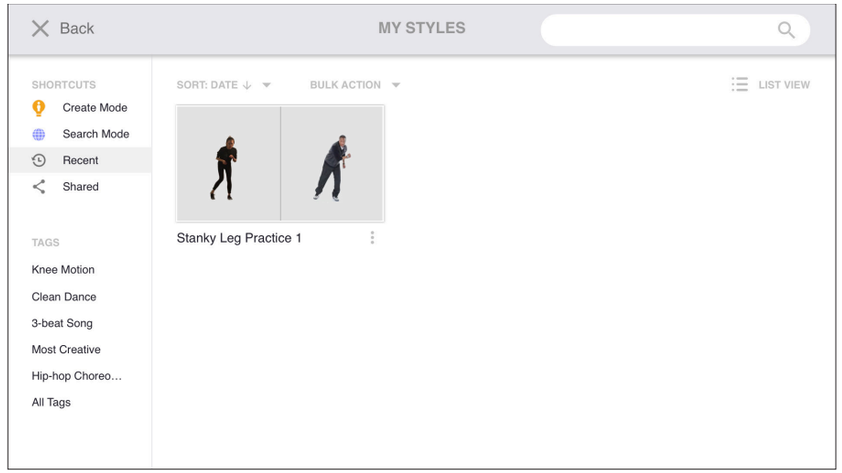




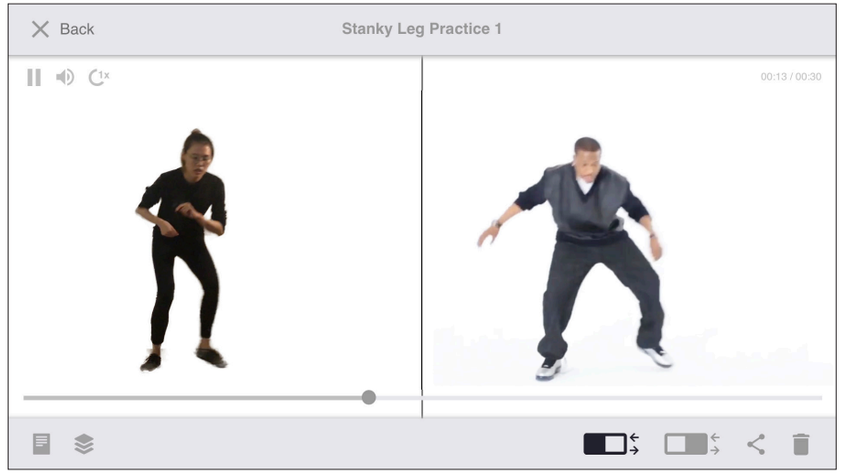
16. Into My Library. When accessing into My Library...



17. Dancer can see the video she just recorded...

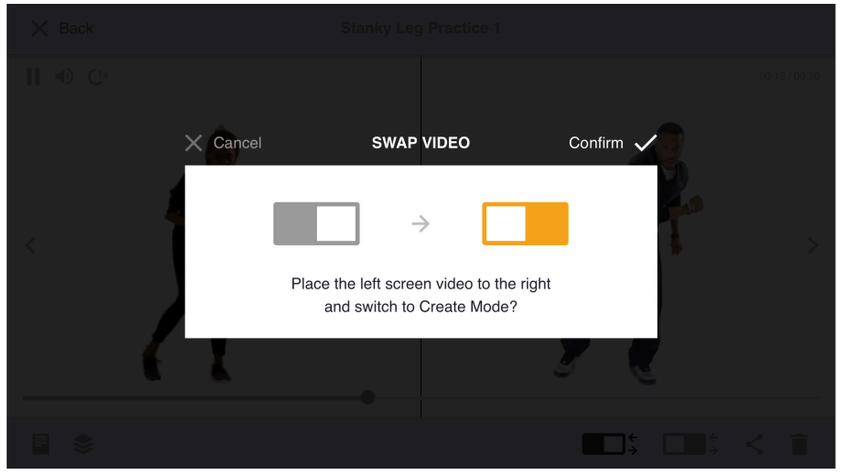


18. When the dancer reviews this recording, she thinks her movement quality is pretty close to the other dancer already, now she wants to continue discovering new styles by comparing with herself. So she select “Swap Left“ to swap the online video with the left screen of this recording...

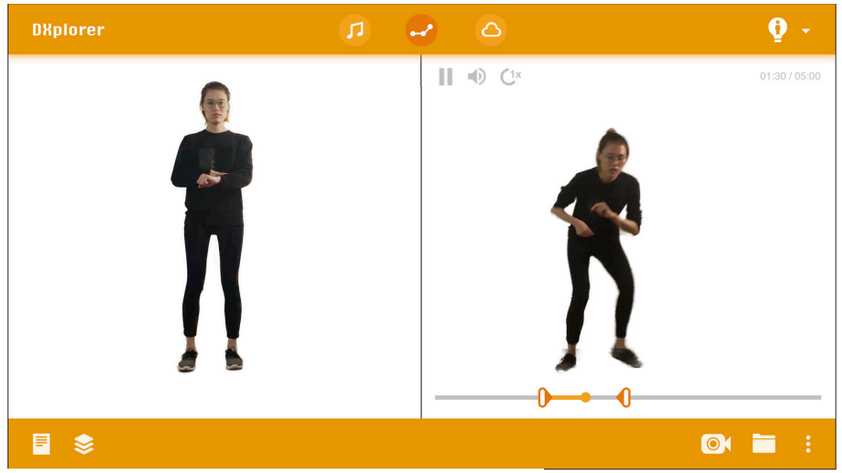


User Testing & Design Iterations

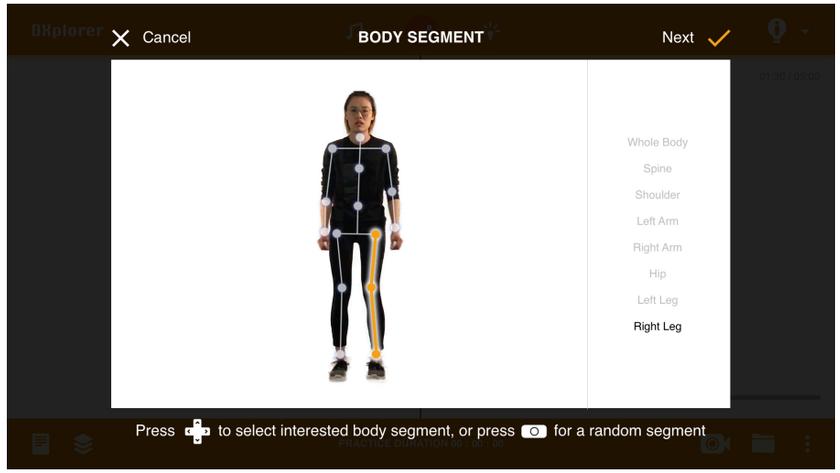
19. Once dancer confirms the action and enters the Create Mode...

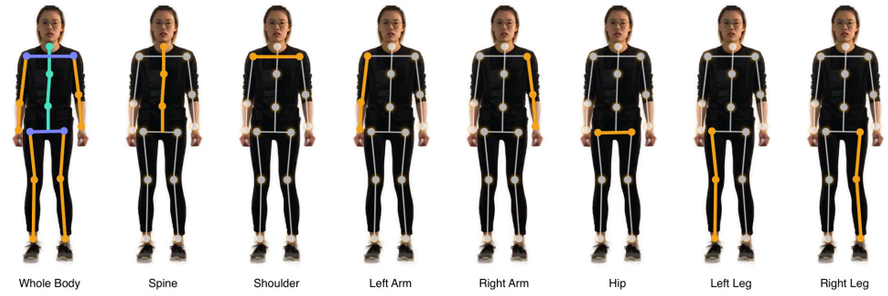


20. She wants to explore via the body pathway...

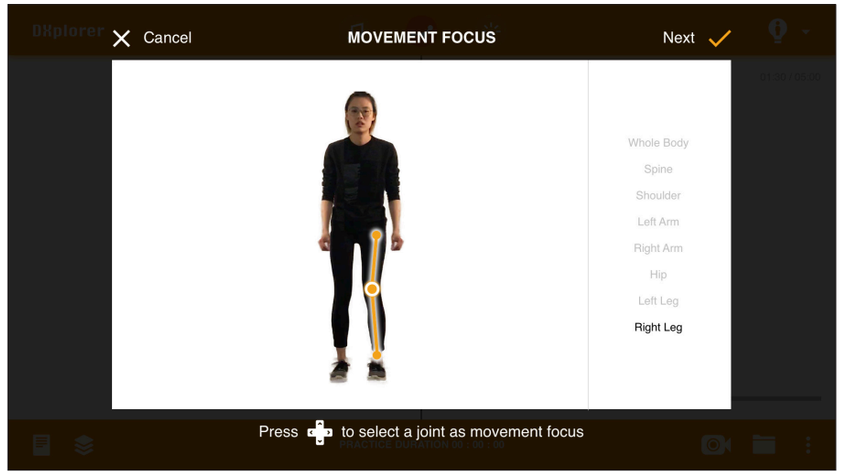


21. So she chooses the right leg as her interested body segment from 8 available segments...



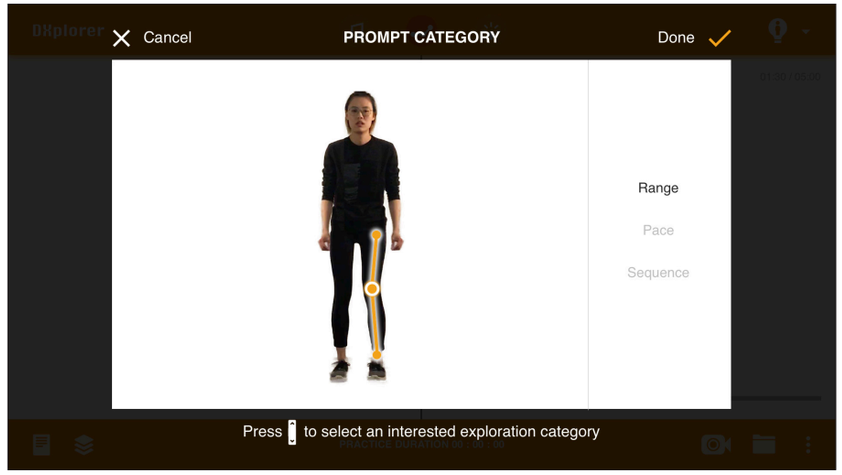


22. Dancer then choose the knee joint as her exploration focus. The choice made here will determine the motion tracking target for some of the visual overlay types...



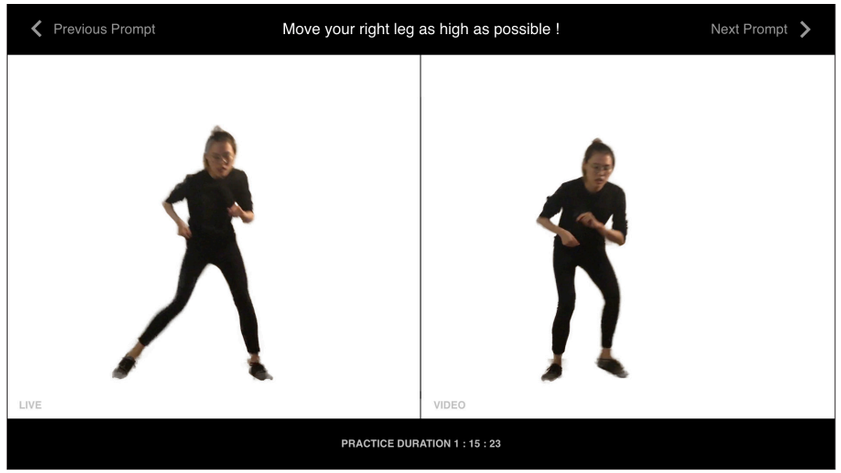
23. Dance then choose “Range” as her interested prompt category...

- “Range” prompts: prompts that inspire dancers to explore movement quality in the space dimension. Ex: “move leg as high as possible”.
- “Pace” prompts: prompts that inspire dancers in the time dimension. Ex: “move leg as quick as possible”.
- “Sequence” prompts: prompts that inspire dancers in the order dimension. Ex: “move right leg before left leg”.



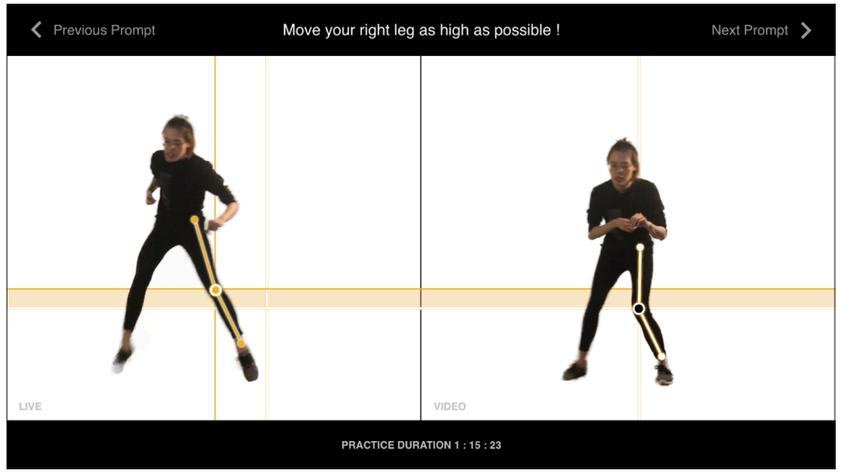
User Testing & Design Iterations

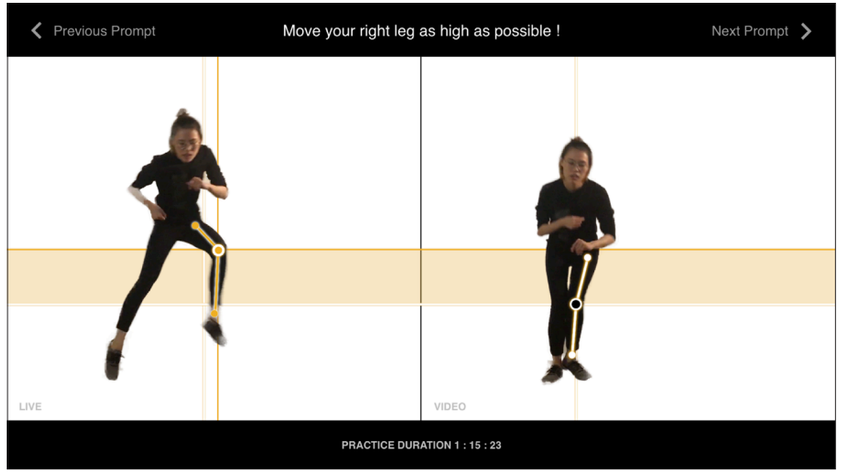
24. Now she begins exploration by following the top-shown prompt...

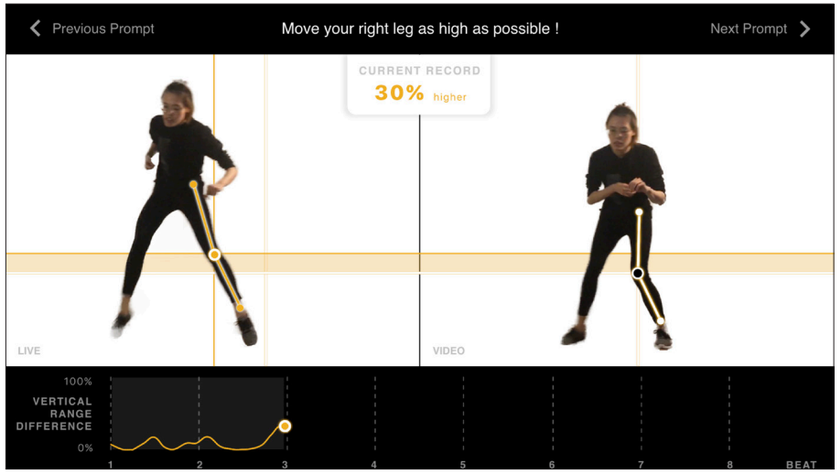


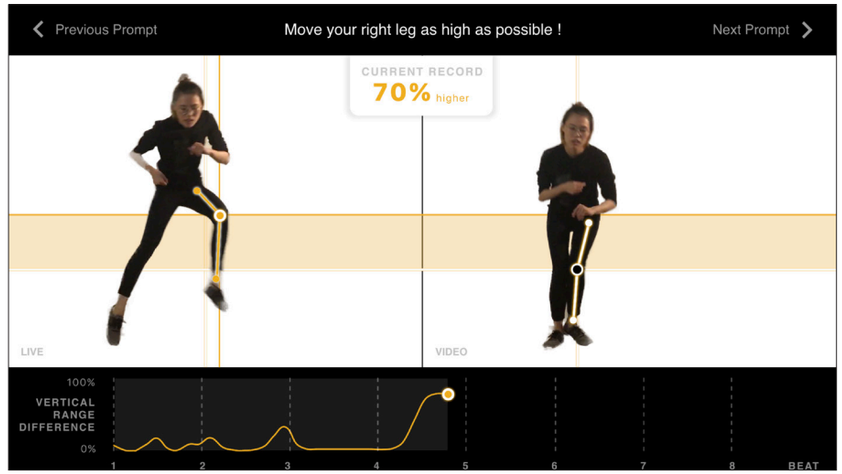
25. There is also a set of visual overlays for dancer to choose from...

26. But the goal of these visualizations is to encourage differences rather than the matching of the two styles...

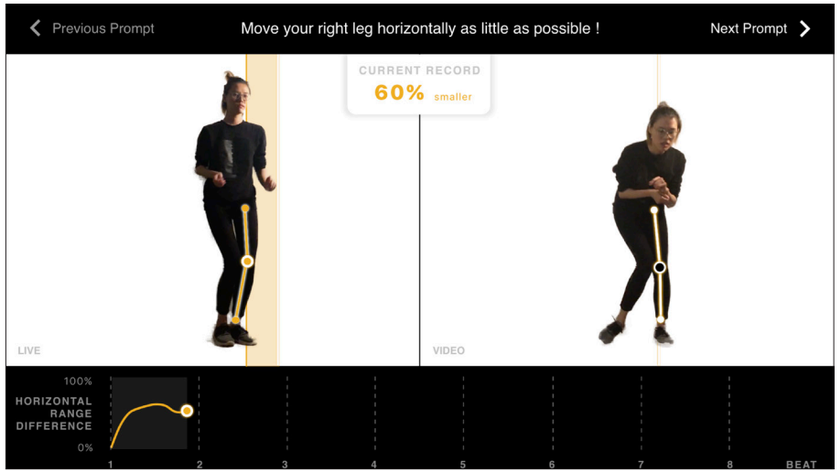


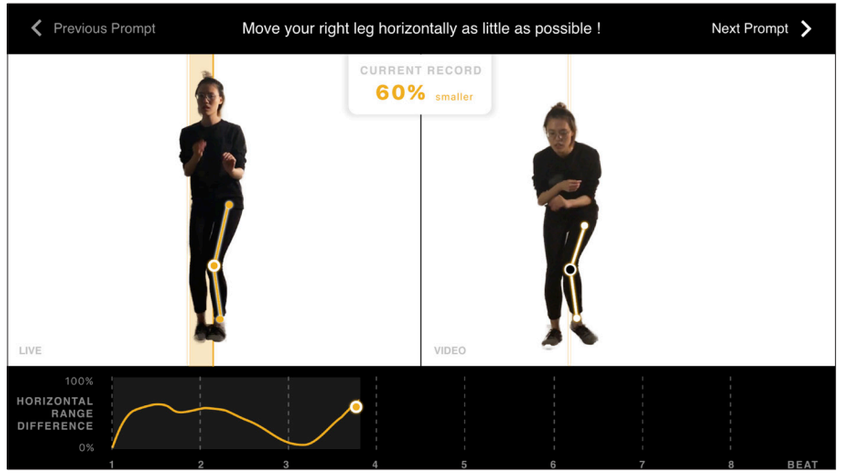






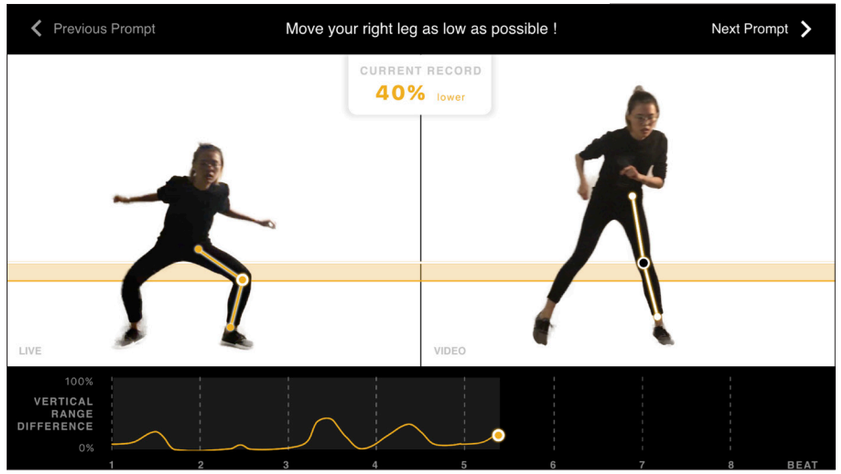
27. Dancer can follow a different prompt such as “move your leg as little as possible”, and change her movement into a different style...

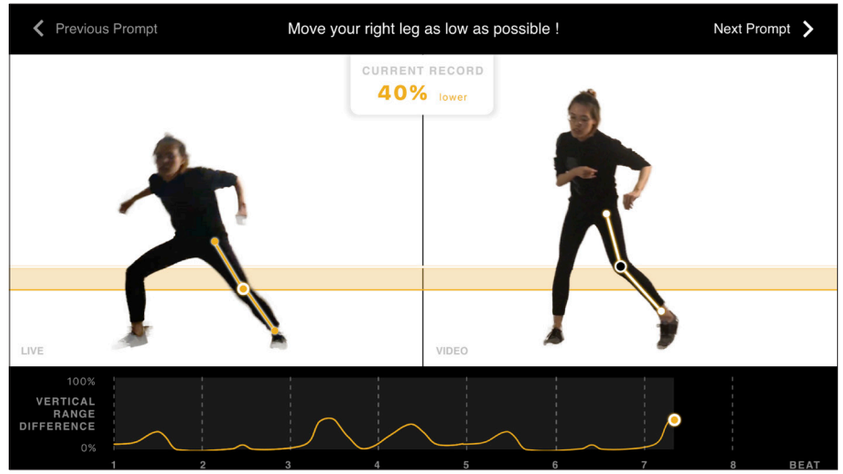




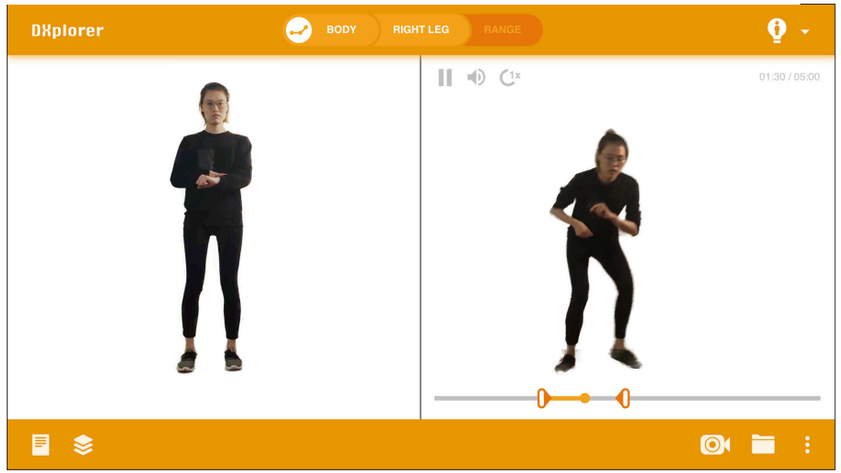
User Testing & Design Iterations

28. This is another prompt and the resulting styles...

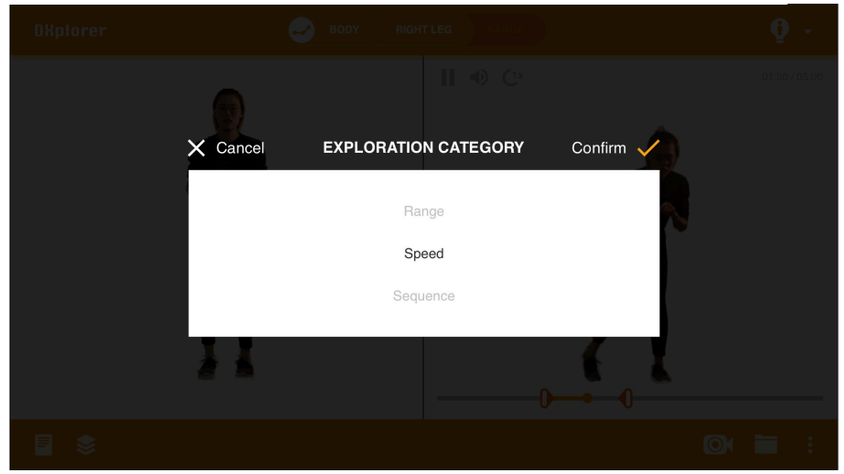




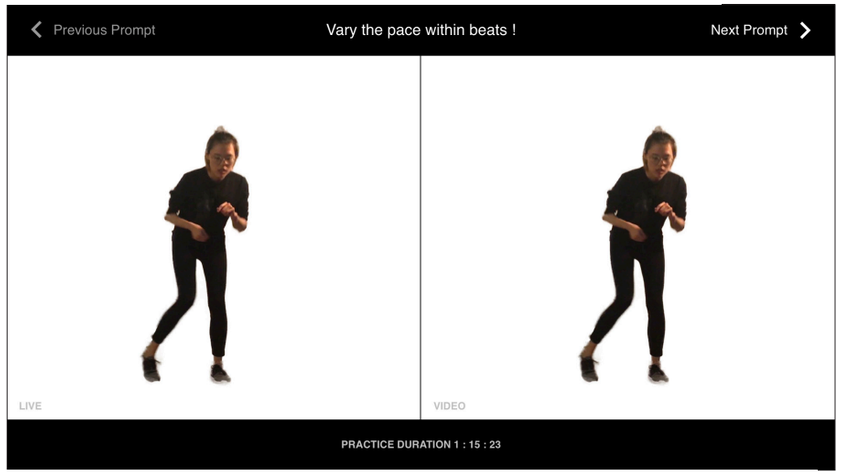
29. Dancer can change from the range prompt category...



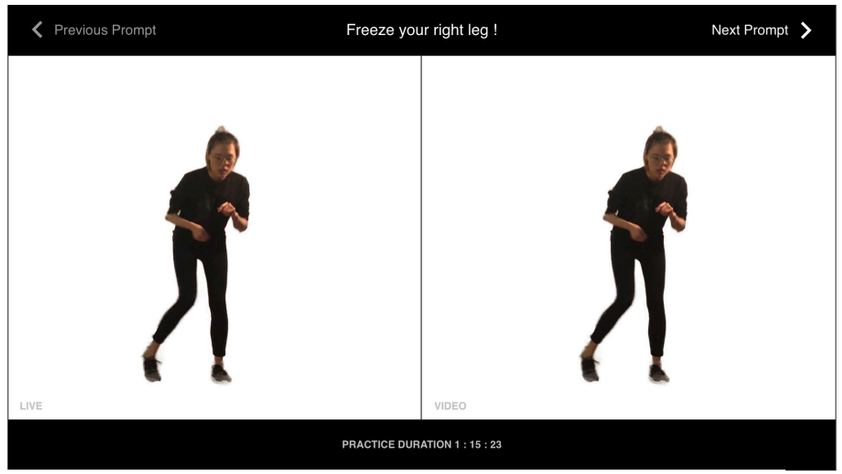
30. To the speed category...



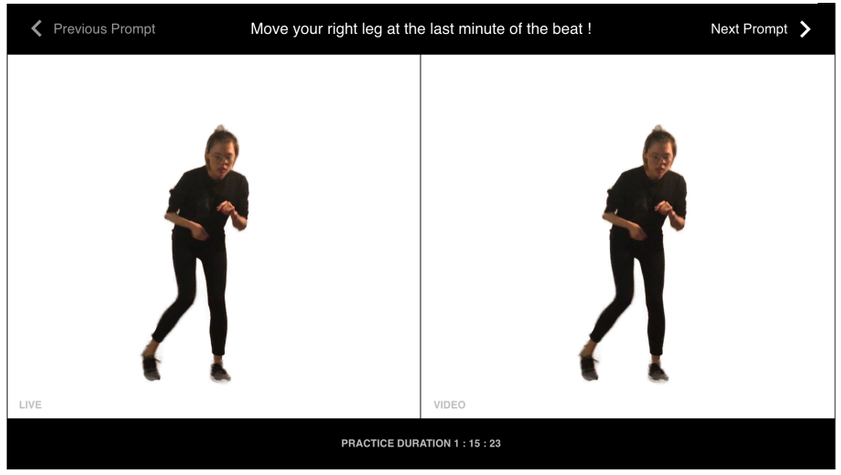
31. Then follow prompts such as “vary the pace”...



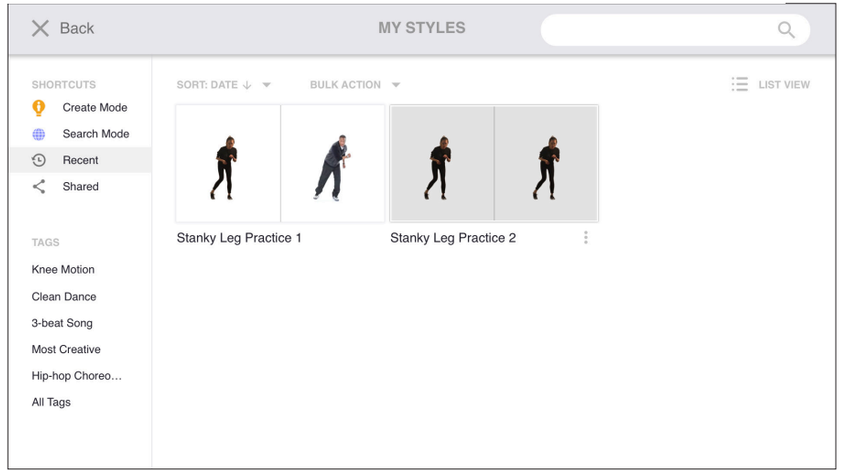
32. Or “freeze your leg”...



33. Or “move your leg at the last minute”...

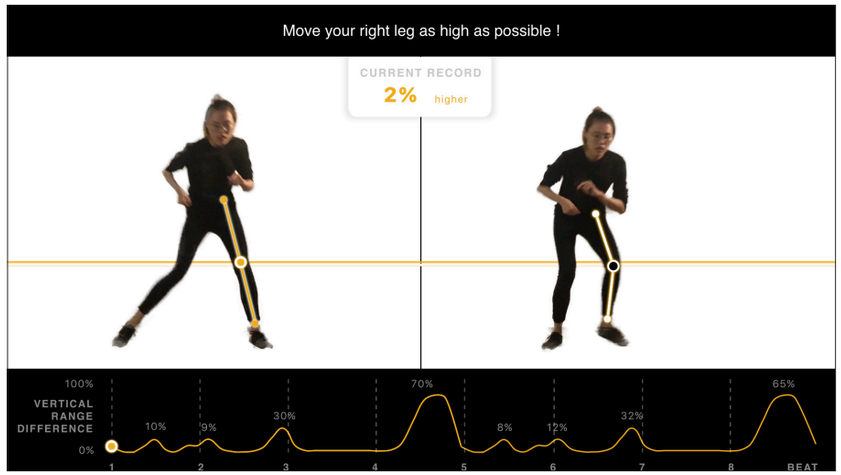


34. Dancer can record this session and review it in the library,...

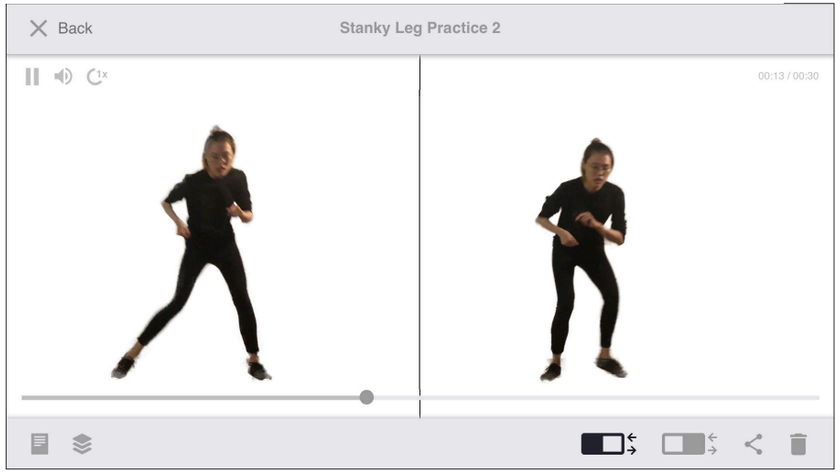


User Testing & Design Iterations

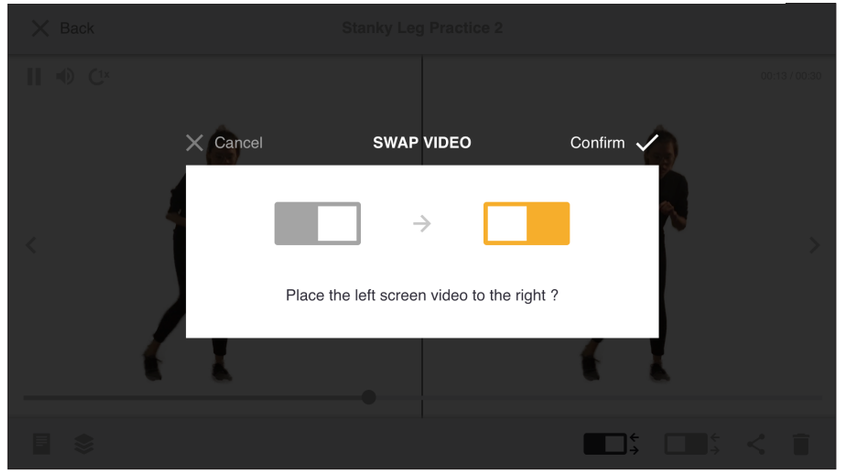
35. She can see the recorded motion data and further reflect on her exploration process. For example, if the record is not improving much, she might want to have additional physical training to increase body flexibility...



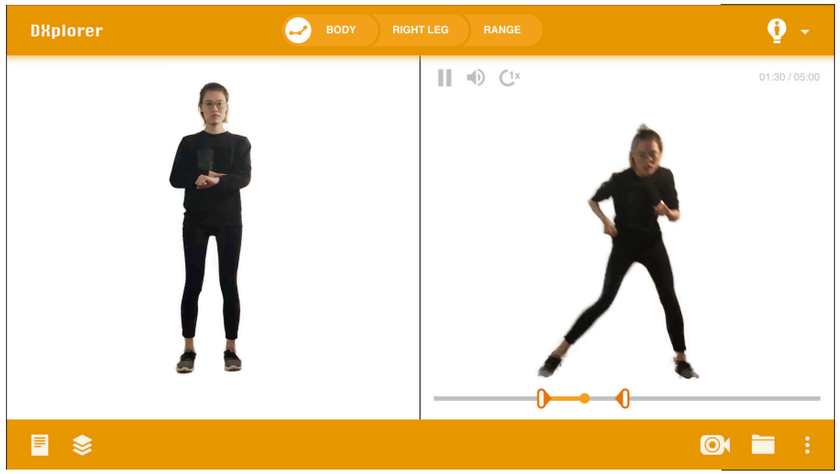
36. Dancer can also swap current video with this recording...



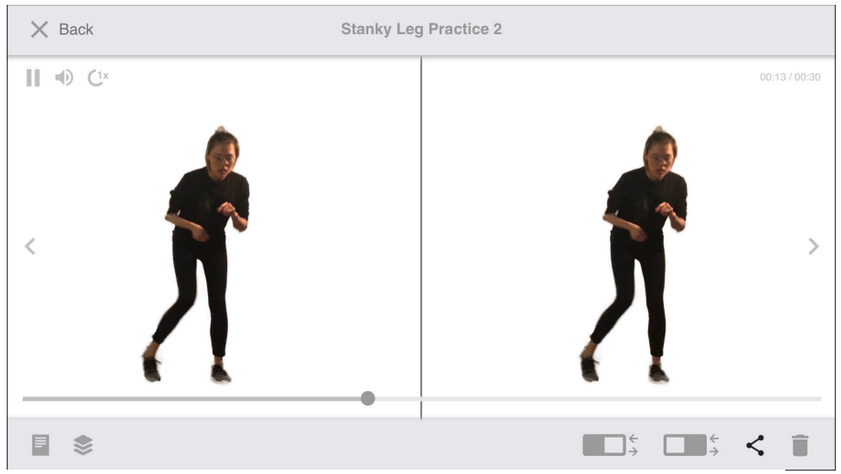
37. Confirms swapping...



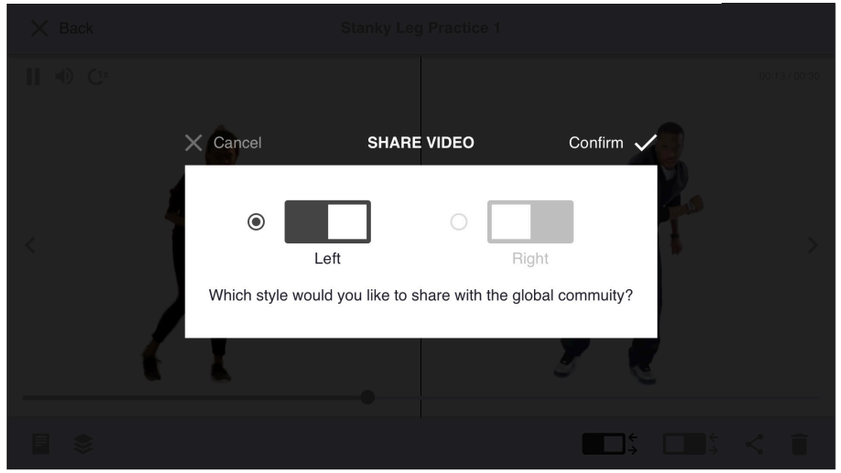
38. And start the next round of style exploration..



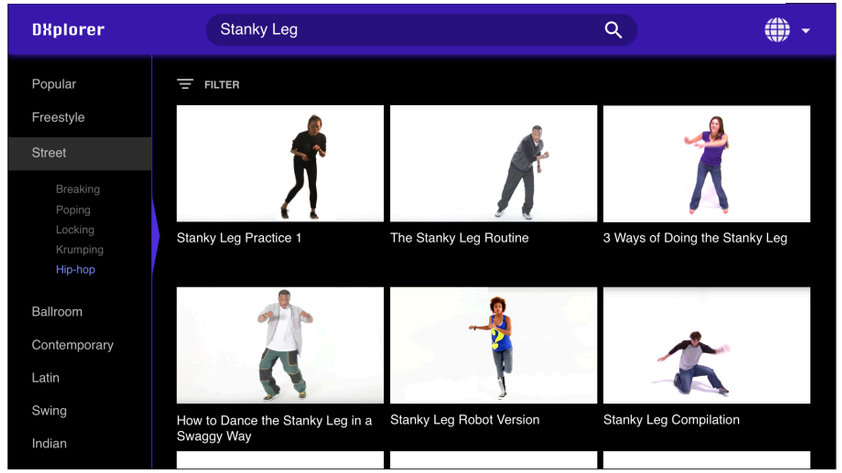
39. Dancer can also share the recording...



40. Choose which quality to share...



41. Then see the shared video in World Styles.



Development of Functional Prototype

To confirm the viability of the proposed tool using current or near-future technologies, I produced a functional prototype to realize the motion tracking and visual overlay display features integrated in the exploration process.

I found a Github library called OpenPose, which is a real-time human body keypoint detection system developed by CMU researchers. I modified the code and settings to adapt to my design. In combination with an open source software called “Custom Desktop Logo”, I was able to create the prototype shown on the left below, which simulates the 11th step in my sample user experience shown previously.

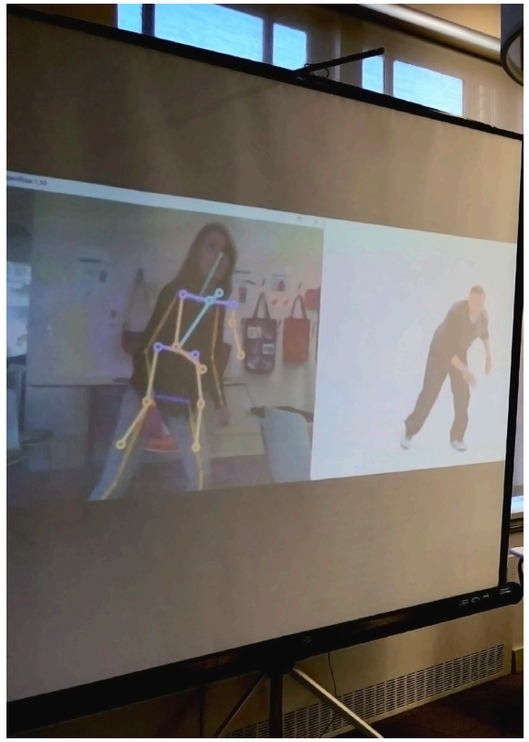


Figure 31: Functional Prototype

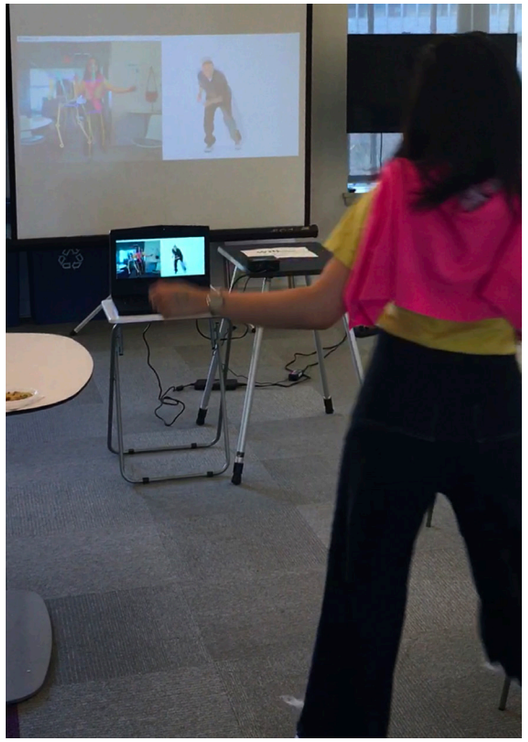


Figure 32: Prototype Setup

I conducted competitive analysis to confirm the originality of my proposed design, which comprised of comparison with current dance practice venues, as well as comparison with innovative motor learning products that use mixed reality technologies.

In summary, the proposed tool can help target dancers fulfill the following three needs all at once in a movement quality exploration process: discover various movement qualities, compare between two movement qualities in real-time and practice movement quality in a solo environment. And most of the product competitors cannot achieve in doing so.

Figure 33: Advantages of Proposed Tool

Competitive Analysis

Part I: Comparison with Current Dance Practice Venues

The chart shown below illustrates the advantages of the proposed tool (DExplorer) in detail: while in-person dance classes are good at providing real-time feedback, these feedback are momentary and lacked tools to keep track of; digital learning venues provide the right environment to practice movement quality, but they fail to provide real-time comparison between dancer's movement quality and the reference quality.

	MQ exploration	Live Feedback	Comparison Recording	Favorable Exploration Environment	Exploration Flexibility	Cost
1v1 Lesson	Low	✓	✗	✓	Medium	High
Group Studio	Medium	✓	✗	✗	Low	Medium
Dance Game	Low	✓	✓	✗	Medium	Medium
Youtube	Medium	✗	✗	✓	High	Low
DExplorer	High	✓	✓	✓	High	Medium

Figure 33: Comparison Chart

Part II: Comparison with Relevant Innovative Works

From literature review I learnt that the evolution of learning paradigm from traditional methods toward computer vision has eventually led people to adopt mixed reality (MR) as one of the promising directions for learning technology. Emergence of body tracking technologies such as Microsoft Kinect (motion tracking) or Athos Suit (muscle activity tracking) has shown great potential in integrating with MR to enhance dance learning experiences. From the competitive analysis I found that many MR tools have been developed to learn postures and for artistic/entertainment purposes, and few of them focus on finding and understanding movement qualities. The three works shown below are attempts that use MR to explore movement qualities:

- *MoComp*: a tool for comparative visualization between takes of motion capture data (Malmstrom, C. et al, 2016). Although this tool is helpful in showing details in movement differences, it cannot show those differences in real time. Dancers need to find additional tools to capture motion and stop dancing to review the data.

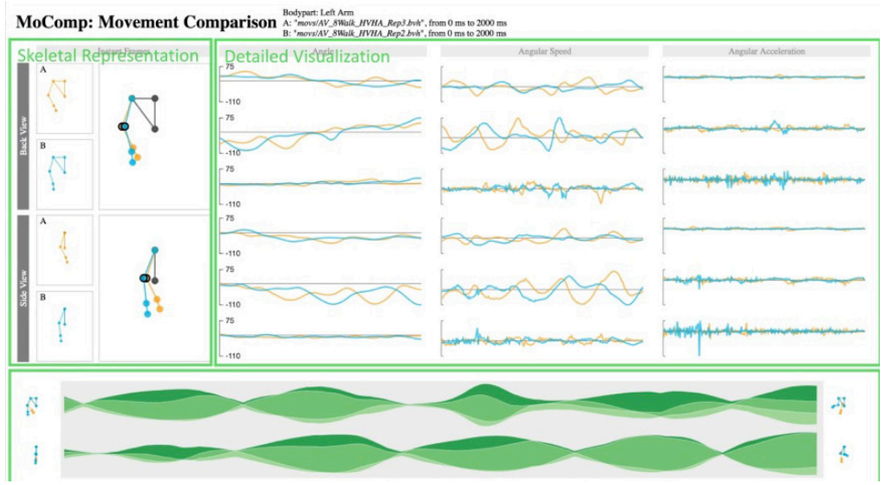


Figure 34: MoComp

Competitive Analysis

- *Real-time 3D simulation*: This system visualizes movement qualities in 3D shapes and motion trails in real-time (Tsampounaris, G. et al, 2016). Although the system inspires dancers to explore different ways of moving in a self-reflection approach, it does not provide additional motivation or goal (like guiding prompts) for dancers, who might be lost in the sea of fancy visualizations. Also, the system cannot show differences between current and previous movements, which makes it hard to reflect on dancer's practice.

- *Physio@Home*: The proposed design envisioned an augmented mirror that provides visual guidance on physiotherapy exercises (Tang, R. et al, 2015). Since the system is designed in a physical therapy context, it does not provide a variety of movement qualities but one correct way of moving.

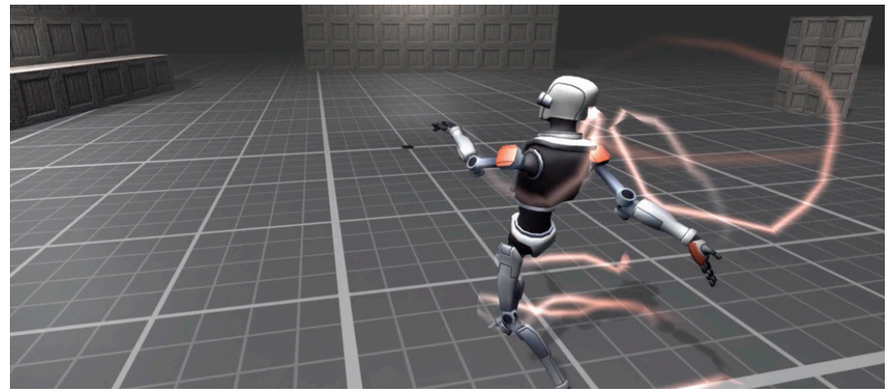


Figure 35: Real-time 3D Simulation

Figure 36: Physio@Home

FUTURE IMPLICATIONS

In this chapter, I first summarize my entire thesis, then discuss aspects in the proposed tool that I wish to further refine, which include further developing the user experience of the three inner pathways proposed in the system, improving the movement comparison functionality and experience, and designing the armband into a more powerful tool. I also point out aspects that I believe hold potential in aiding dance education and indicating future research opportunities in other learning fields, which include offering an self-discovery approach to find new movement quality, offering features to compare different movement qualities and record motion data to keep track of movement changes, and providing directions in investigating the relationship between music and body movement.

5

Thesis Summary

I started this project because dance performances fascinate me. I myself am not a good dancer, but I am always amazed by the complexity of the messages conveyed by dancers through their body movements. When I learned that there was a lack of effective tools that help experienced dancers find and understand movement qualities in solo learning environments, I was further motivated to investigate the topic.

The directions for tackling this problem are limitless, and I choose to approach it from the concept of bodily awareness. I thought that by providing tools that allow dancers to discover new movement qualities via enhancing awareness of body capabilities, and to easily connect the body, the music and the qualities of their movement via comparative feedbacks, dancers might be able to expand the expressive range of their bodies, and develop an ability to precisely control their body when they want to communicate certain messages.

The proposed design that I described in the previous chapter certainly has many areas that can be improved, which I will discuss in detail in the following page, but I believe that my thesis work has value in aiding dance education and indicating future research opportunities in other learning fields, which I will explain after discussing the limitations.

Points of Improvements

Based on research findings, I planned to offer three pathways in the Create Mode to explore new movement qualities: “Body”, “Mind” and “Music” (Figure 37). Due to time constraint, I was only able to detail out a portion of this larger system. I demonstrated how the “Body” pathway will work in my sample user experience via digital prototypes and a physical armband model, but only illustrated how the other two pathways might work in low-fidelity sketches (Figure 38).

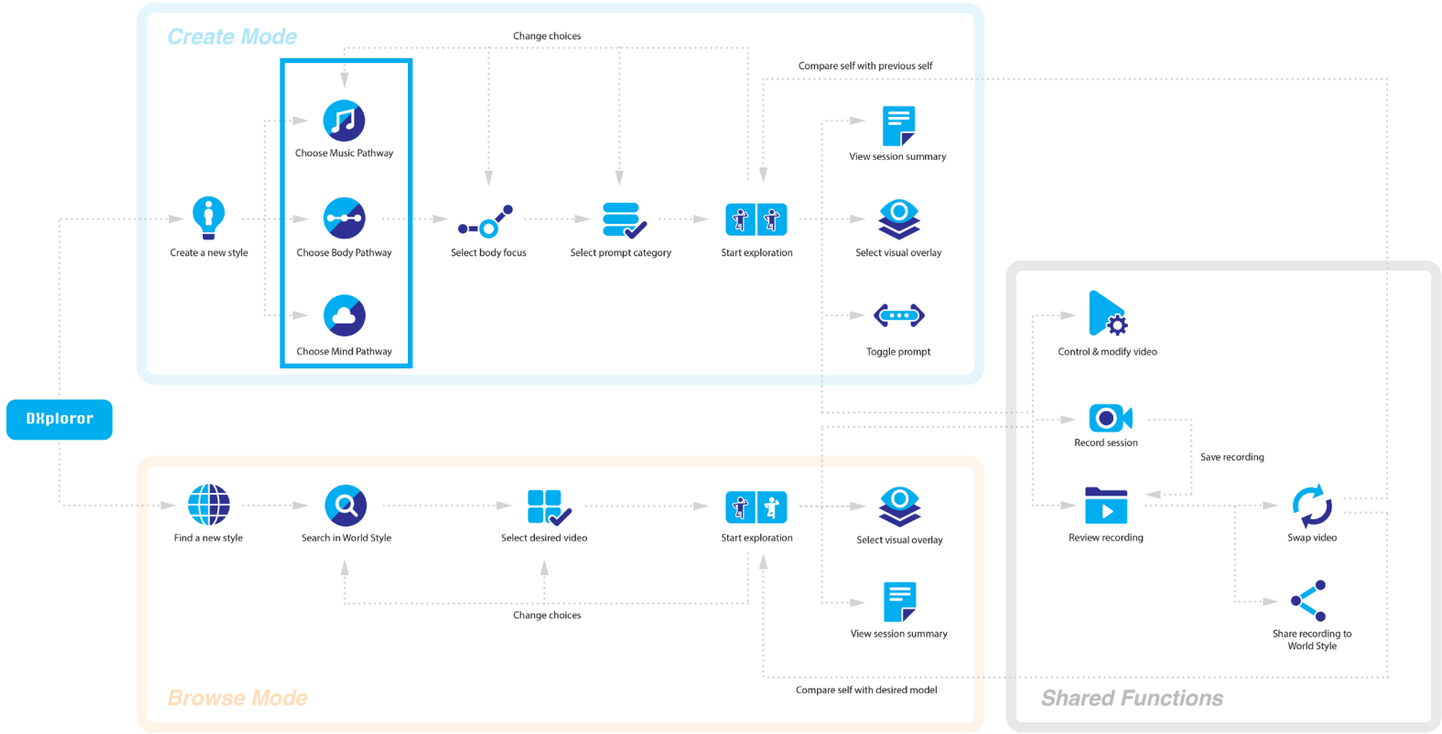


Figure 37: Final User Journey Map

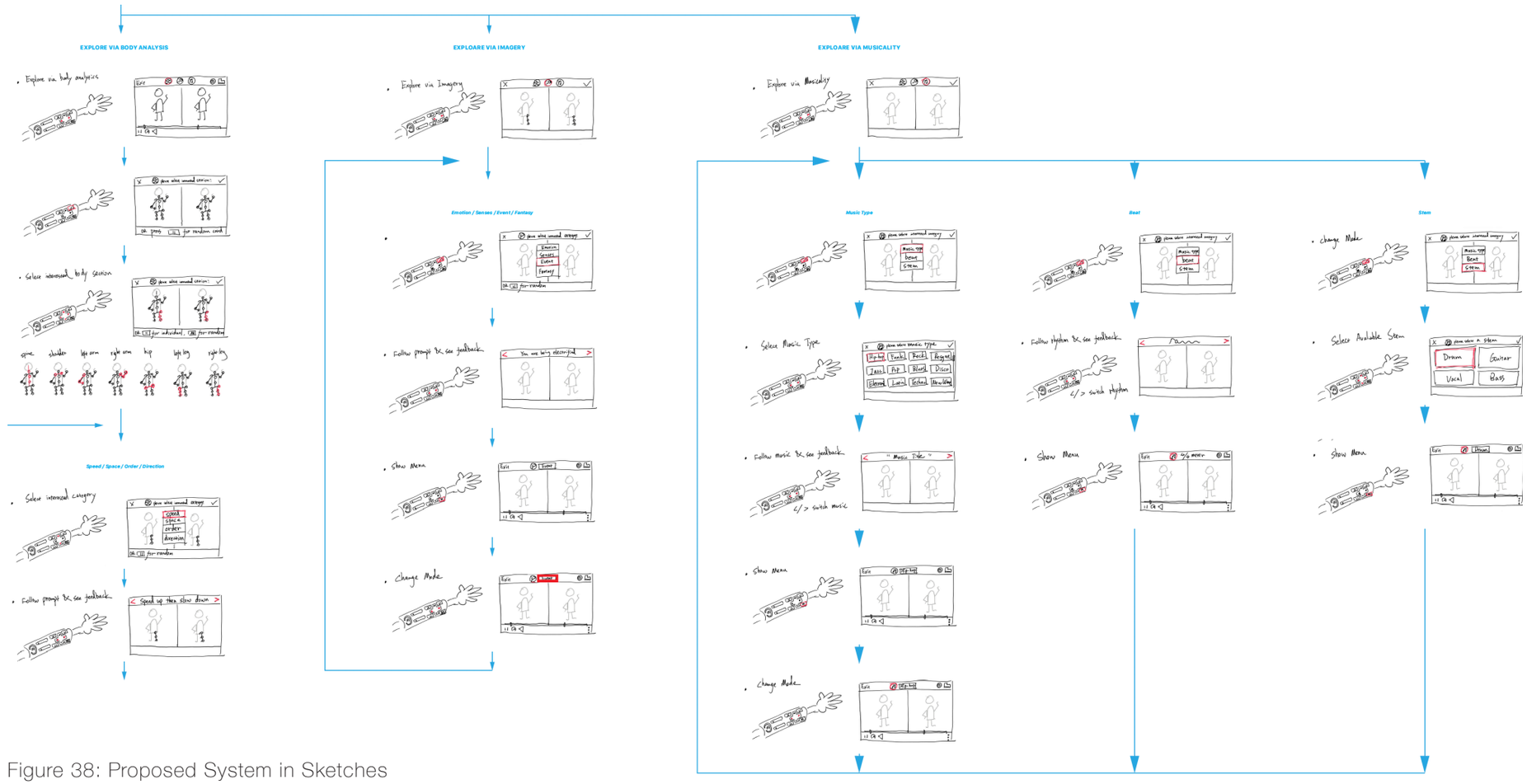


Figure 38: Proposed System in Sketches

Points of Improvements

In the “mind“ pathway, I proposed four exploration categories - “Emotion”, “Senses”, “Event” and “Fantasy” prompts:

- Emotion: prompts that evokes body’s emotional responses through mind. Ex: “dance in extreme sadness”.
- Senses: prompts that evokes body’s sensual experience through mind. Ex: “dance in a robotic way”.
- Event: prompts that connect dancers’ movement qualities with memories of a particular real-life experience. Ex: “dance as if you are being punched”.
- Fantasy: prompts that connect dancers’ movement qualities with memories of an imagined experience. Ex: “dance as if you are falling in love with the floor”.

In the “music“ pathway, I proposed three exploration categories - “Music Type”, “Beat”, and “Stem”:

- Music Type: dancers can pick a music genre, such as “Funk“ or “Classical”, and dance along with a random music work under that genre. Dancers can switch the genre and the music at any time to freely explore movement quality.
- Beat: after choosing this category, dancers will hear a random rhythm that is either in duple metre, triple metre, or compound metre, and try to dance along with it. Dancers can switch to a different rhythm at any time.
- “Stem: music stems are sound tracks of different instruments that constitute a music work. Since each stem has a different rhythm and timbre, dancers can select one of the available stems as inspiration of new movement qualities.

Points of Improvements

If I were to continue my research and design, I want to further design the details of these exploration categories and test my design with target dancers to test their effectiveness in discovering movement quality.

Another limitation of the proposed system is that the movement quality shown in the right screen video is only a partial one; dancers are largely constrained by whatever that is displayed in the 2D video. If the video only has a frontal camera view, the dancer will not know how the body moves from a side view. What's more, depending on where the dancer's computer is, the live camera view in the left screen might have a very different perspective compared to what's in the video. Thus their movement qualities are not comparable due to differences in variables. One consideration for improving the system is to capture movement quality in 3D, and as the dancer turns to a different angle in live view, the dancer in the video will be automatically rotated to the same angle accordingly. The system should also auto-detect dancer's environment and calibrate the video to the correct perspective.

Also, throughout my design process, I focused more on the application design than the armband controller. I see opportunities of developing the armband further into a more powerful tool in my proposed system. One possible approach is to use touch screens instead of physical buttons to expand the armband's functionalities. Another approach is to incorporate EMG sensors to track dancers' muscle activities and provide a visualization layer of body's inner force shift during movement in addition to other kinematic-based visual overlay layers.

Opportunities

The proposed design concept offered pathways to explore movement qualities in an inner-discovery fashion compared to the conventional way of externally imitating other dancers. This idea of self-exploration is in fact practiced often in other motor-learning fields, such as in martial arts: practitioners would imagine having enemies in front of them so that their combat movements can be more aggressive. Through my design, I hope this aspect will be more emphasized in dance education, and inform dancers of the importance of enhancing awareness of self body capabilities in dancing.

The proposed design offered features that can compare different movement qualities and record motion data to keep track of movement changes. This aspect will be especially helpful in physical therapy or sports training. Patients who are going through the rehabilitation process need tools to track their movement progress in order to self-reflect and communicate with physicians to receive the most suitable treatment. This need is also true for athletes. This might encourage other researchers to adapt my proposed design into these fields and develop new tools for use.

Although the “Music Pathway” in the Create Mode is not detailed in the proposed design, it offered directions in investigating the relationship between music and body movement. In fact, there is already a method established in this direction, which is called Eurhythmics. This means that the proposed design could be further developed and used as a tool in music education to awaken innate musicality through body movement.

REFERENCES

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- Alaoui, S. F., Caramiaux, B., Serrano, M., & Bevilacqua, F. (2012, June). Movement qualities as interaction modality. *In Proceedings of the Designing Interactive Systems Conference* (pp. 761-769). ACM.
- Alemi, O., Pasquier, P., & Shaw, C. (2014, June). Mova: Interactive movement analytics platform. *In Proceedings of the 2014 International Workshop on Movement and Computing* (p. 37). ACM.
- Bartenieff, I., & Lewis, D. (1980). *Body movement: Coping with the environment*. Psychology Press.
- Blom, L. A., & Chaplin, L. T. (1982). *The intimate act of choreography*. Pittsburgh, Pa: University of Pittsburgh Press
- Chenard, J. (2010). *The Michael Chekhov Technique: In The Classroom and On Stage* (Doctoral dissertation).
- Eades, P. (2014). *Handbook of human centric visualization*. W. Huang (Ed.). New York: Springer.
- Laban, R., & Ullmann, L. (2011). *Mastery of movement*. Dance Books.
- Loke, L., & Robertson, T. (2013). Moving and making strange. *ACM Transactions on Computer-Human Interaction, 20*(1), 1-25. doi:10.1145/2442106.2442113
- Payne, H. (2003). *Dance movement therapy: Theory and practice*. Routledge.

Literatures

- Proulx, M. J., Todorov, O. S., Taylor Aiken, A., & de Sousa, A. A. (2016). Where am I? Who am I? The Relation Between Spatial Cognition, Social Cognition and Individual Differences in the Built Environment. *Frontiers in Psychology*, 7, 64. http://doi.org/10.3389/fpsyg.2016.00064
- Retra, J. (2010). *Music is movement: a study into aspects of movement representation of musical activities among preschool children in a Dutch music education setting.*
- Shusterman, R. (2012). Thinking through the body: Essays in somaesthetics. Cambridge, UK: Cambridge University Press.
- Som, A. (2016). *Geometric Approaches for Modeling Movement Quality: Applications in Motor Control and Therapy* (Doctoral dissertation, Arizona State University).
- Xu, J.,Hu, Y., trans. (2015). Pan Gongkai: Dialogue with Richard Shusterman on Philosophy, Art, and Life. *Journal of Somaesthetics: Somaesthetics and Visual Art 1.1* (pp. 60-61).

Figures

Figure 1 & 2: Guest, A. H. (2014). L*abanotation: the system of analyzing and recording movement*. Routledge.

Figure 3: Official website of the Palace Museum, Beijing. http://www.dpm.org.cn/shtml/117/@/5484.html

Figure 4: van Schooten, K. S., Pijnappels, M., Rispens, S. M., Elders, P. J., Lips, P., Daffertshofer, A., ... & van Dieen, J. H. (2016). Daily-life gait quality as predictor of falls in older people: a 1-year prospective cohort study. *PLoS one, 11*(7), e0158623.

Figure 34: Malmstrom, C., Zhang, Y., Pasquier, P., Schiphorst, T., & Bartram, L. (2016, July). Mocomp: A tool for comparative visualization between takes of motion capture data. *In Proceedings of the 3rd International Symposium on Movement and Computing* (p. 11). ACM.

Figure 35: Tsampounaris, G., El Raheb, K., Katifori, V., & Ioannidis, Y. (2016, November). Exploring Visualizations in Real-time Motion Capture for Dance Education. *In Proceedings of the 20th Pan-Hellenic Conference on Informatics* (p. 76). ACM.

Figure 36: Tang, R., Yang, X. D., Bateman, S., Jorge, J., & Tang, A. (2015, April). Physio@ Home: Exploring visual guidance and feedback techniques for physiotherapy exercises. *In Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (pp. 4123-4132).ACM.

Stock Sources

- Open Source Software - Custom Desktop Logo: http://customdesktoplogo.wikidot.com/license
- Online Video - How to Do the Stanky Leg | Hip-Hop Dance: https://www.youtube.com/watch?v=RiSrd9i2PCw
- Open Source Library - OpenPose: https://github.com/CMU-Perceptual-Computing-Lab/openpose