Assisting Motor Skill Transfer for Dance Students Using Wearable Feedback

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ABSTRACT

Dance plays a crucial role in human well-being and expression. To learn dance, transferring motor knowledge across humans is relevant. Several technologies have been proposed to support such knowledge transfer from teacher to student. However, most of such systems applied a pragmatic approach focused on the feedback and the quality of the feedback system and not necessarily on the human mechanisms behind the dance learning process. In contrast, we inquire about the teacher-to-student motor knowledge transfer from the neural perspective to design motor learning wearable systems. We conducted interviews with dance students and teachers using vignettes based on motor learning theory as a discussion base. We derived insights about dance learning and identified a series of requirements for motor skill transfer-focused wearable devices. Based on our results, we present a prototype that reflects the minimum functional setup for effectively supporting motor learning.

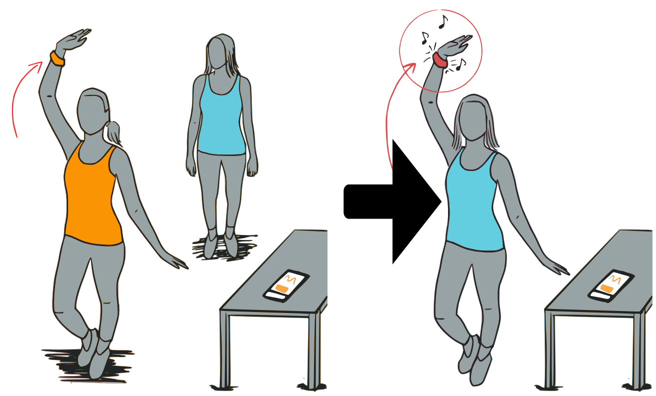

Figure 1: Wearable systems for motor skill learning (such as dance) must enable in-session and post-session practice to support motor skill consolidation at later stages of the learning process. Feedback should not distract the students from the primary task nor reduce body awareness.

CCS CONCEPTS

• **Human-centered computing** → *Ubiquitous computing*.

KEYWORDS

Wearable systems, Motor Learning, Dance teaching

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1 INTRODUCTION

Dancing is a common practice among humans [12]; group dancing and individual performances are part of the daily life of a significant part of the world population. People practice dance to exercise, for fun [3] and to increase their overall well-being [18]. Also, for many communities and individuals, dance is a key part of their identity [1] and a way to communicate [11]. In dance learning contexts, motor knowledge is often transferred in large groups, making it difficult for dance trainers to provide accurate feedback to dance students. In addition, personalized feedback, although the ideal, is expensive in human and economic resources and often not available [29].

On another note, interaction designers commonly overlook the long-term impact and the different stages of motor learning while focusing on system plausibility and feedback quality [19, 23]. Even if we understand the importance of the robustness and usability of the systems [20, 21, 28] the primary goal of such systems is supporting a motor and cognitive process on the user side that requires to be understood and considered during the design process. Dance teaching and motor skill acquisition have been extensively addressed from the system [4, 5], feedback [7, 27, 29] and interaction perspective. In contrast, we contribute a set of requirements to consider while designing wearable systems for dance teaching and motor skill transfer based on a neurobiological perspective of dance teaching and motor learning. Our contribution is four-fold:

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- We study neural theory to derivate design requirements and implications in the wearable feedback design context.
- We interview experts and trainees to gain knowledge about their experience in the motor acquisition process.
- We synthesize the different stages of motor learning and convert them into vignettes that the experts and trainees analyze and provide feedback about the best way to support them in every stage.
- We develop a series of central requirements when designing wearable devices for motor learning in dance.

2 REQUIREMENTS ANALYSIS

We aimed to design a system that supports motor learning in dance. To that end, we conducted a user-centered design process. As a first step, to build an understanding of the requirements of such a system, we conducted an in-depth literature analysis of existing motor learning theories. More precisely, we explored how the neurobiological theory behind motor learning can support wearable devices expected to support dance motor skill transfer. As a second step, we conducted semi-structured interviews with dance students and dance teachers. During the interviews, we discussed vignettes that were based on motor learning theory with the participants. This approach allowed us to blend the empirical knowledge from literature and practical knowledge from dance experts.

2.1 Motor Learning Theory

There is evidence that motor skills are developed in different cognitive stages [22]. Motor information transfers from short to long-term memory; the latter can be further divided into explicit and implicit memory [6]: Explicit memory is conscious while implicit memory is not, and it is therefore challenging to describe it in detail. In motor skill learning, individuals develop explicit memory in the early learning stages and consolidate the knowledge, moving it to long-term memory. Once learned, it becomes implicit memory and does not require continuous attention to be executed. Individuals retain motor skills over several years. Several models have been proposed to explain the neurobiological processes responsible for storing implicit memories and the contributions of different brain regions to motor skill learning and adaptation [8, 9, 13, 14, 17]. The stage of the learning process triggers different areas (or a combination of areas) of the brain [25]. For example, during the fast learning stage, the main contributions are given by the medial temporal lobe in the hippocampus. In the slow learning phase, this process is mediated by the cortical motor regions. Among the motor learning models explored, we pay special attention to Doyon's model [8], which is divided into five phases: (1) Fast (early) learning, (2) Slow (later) learning, (3) Consolidation, (4) Automatic phase of skilled behavior, and (5) Retention after long delays without practice

Significant improvements in motor behavior characterize the **fast (early) learning phase**. It is attention-demanding and produces a high cognitive workload when confronted with a task for the first time [23]. Fast learning is observable directly from the first session; researchers have found that the benefit of proper feedback is significant in the early learning phase [26]. Moreover, error correction is essential at this stage compared to later phases [17].

The slow (later) learning phase covers several sessions. During this time, the progress slows down, and the motor skill performance gets more stable and consistent. Motor learning itself is a time-dependent process. **Consolidation** is the intermediate process between practice sessions during which the explicit knowledge about a motor skill becomes more familiar and transfers to implicit memory. Moreover, evidence suggests that sleep has a main role in the motor memory consolidation [8, 16, 24]. Apart from that, the general interest, motivation, attentiveness, vigilance, and distraction influence how well a memory is stored [6, 15]. Motor consolidation is responsible for establishing the skill in the body's memory and lift it to the level of **automatic execution phase**. In this phase, executing the task does not require cognitive effort, and the motor skill has become automatic. The **retention phase** is finally achieved when a motor action is retrieved again after a time without practice, and such knowledge stays in memory for years.

2.2 Interviews

Learning a motor skill such as dancing usually involves (at least) two parties, the dance student and the dance teacher. These two parties have different perspectives regarding the dance learning process. We conducted semi-structured interviews (duration 45 minutes on average) to understand these different perspectives, thus gathering information from dance experts in the motor learning context. Due to the COVID-19 pandemic, the interviews were conducted via video conferencing software and audio-recorded after participant's informed consent. The interviews were conducted in the participant's native language, transcribed verbatim, and translated by a professional transcription and translation service. Based on the analysis of the expert interviews combined with the literature analysis, we established the requirements for a technology that supports knowledge transfer in the dance context.

Based on the four stages of motor learning by Doyon et al. [8], we developed a series of vignettes. The vignettes described an imaginary student going through the four stages of motor learning. We focused on the first four stages of motor learning as they depend on the active practice of a motor skill. We discussed every vignette in detail with each participant. This was followed by an open discussion about technology support for dancing. We adapted the interview protocols slightly to the needs of the respective user group (teachers, students). The vignettes and the interview protocols are provided in the supplementary material.

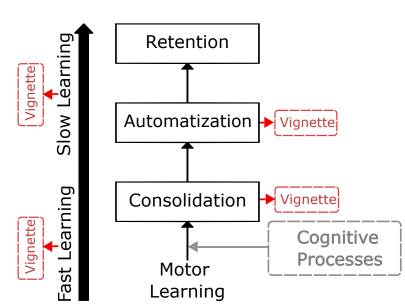

Figure 2: Motor learning process (adapted from [8]).

2.2.1 Participants. We interviewed 11 dance experts (2 male, 9 female). Five participants were dance teachers, aged 24–56 (referred to as $T[1-5]$). Six participants were dance students, aged 21–54 (referred to as $S[1-6]$). The participants practiced diverse dance styles, with six practicing a Ballroom dance (e.g. Tango, Jive, Waltz). The remaining five practicing a performing dance style (e.g. Ballet, Jazz dance, Modern dance, Belly dance). To provide meaningful insights, we required the level of the students to match at least phase 4 (automatic phase of skilled behavior). The participants were compensated with 10€ per hour.

2.2.2 Results. We applied an iterative analysis process combining open coding and thematic analysis in line with Blandford et al. [2]. As a first step, two authors coded 35% of the material (i.e. 2 student/2 teacher interviews). Through a set of iterative discussions, we established an initial coding tree used by one of the authors to code the remaining material. We then used thematic analysis to derive a more abstract understanding of the data.

We identified five themes in the interview data: *Teaching and learning style*, *Difficulties*, *Technique and health aspects*, *Feedback*, and *Vision* (for an overview see Table 1).

Based on our analysis of the interviews and the theoretical background, we derived four central design requirements.

The system should:

- be a lightweight, wearable system;
- offer personalized, implicit feedback for single dance figures;
- offer the possibility to combine the system with an explicit, audio-visual introduction to a dance figure, thus mirroring the structure of a classic dance lesson;
- integrate sonification elements.

The importance of having a **lightweight system** that does not hinder the variety of different dance moves was addressed by both dance students and dance teachers. The social context of many dance events further reinforces this need, as illustrated by the following statement of a dance student:

> On the one hand, sure, it's practical. On the other hand, it would probably be too much effort for me. Because either I have to carry something, I have to set something up, or attach something so that it works in a precise way. That would then probably be too much work for me. I'd have to take care of it. Most of the time I go dancing with friends, which is Friday nights where you go out together. If I want to use it actively then, I would have to make sure that I wear my sensors and at the same time have the program running, which measures it, and besides, make sure that I get the feedback. I don't think I would want that. (S1)

Another requirement that became apparent during our analysis was the need for **personalized, implicit feedback focusing on single dance figures**. However, relying on personalized feedback from technology without the involvement of dance teachers was still difficult to imagine for some dance students:

> What I would like from such a system is the possibility to get individual feedback from the teacher. This would imply that I have sensors somewhere on the corresponding parts of my body. [The data] arrives visually processed at my teacher so that they can give some kind of feedback in this regard, e.g. hands, feet, whatever you would need. I imagine a replication of the human body that is somewhere with my teacher and does what I do, and then they can explicitly say, "Hey, take your shoulders back a bit" or something like that. (S3)

Table 1: Overview of identified code groups from the interviews with explanations and examples.

Group	Short Description	Example
Teaching and learning style	Approaches that the participants use when they learn or teach a new movement	Showing the entire figure at the beginning
Difficulties	Common problems and classic mistakes when learning new dance movements	Complex dance moves
Technique and health aspects	Aspects that are considered relevant to learn the correct dance technique in a healthy way	Posture relevant
Feedback	How the feedback is transmitted and perceived	Explicit feedback after dance
Ideas for setup/ helpful tool	Approaches and technology the participants imagined for a dance learning assistant tool	Sensor positioning

Going beyond technology-mediated person-to-person feedback, many participants expressed interest in **implicit feedback**. For instance, one dance student reflected on feedback in the form of vibrations during dance practice:

> I can imagine the haptic feedback quite well. I think that would be the most intuitive for me now, I would say, or what I would like to have as a support, for example, that when I know, I have to move the right foot backward faster here, that I then get a slight vibration or something that [shows me the direction]. (S4)

Both dance teachers and dance students **envisioned recreating their dance classes** at home. However, while students mainly envisioned situations where the technology takes on the role of their dance instructor, dance teachers were more prone to retaining their expert role and using the technology to provide a new perspective:

> There could be an app that has two screen pages. One screen shows me what to do, and the other allows me to record myself. Then I can compare my recording one-to-one with the example. (T4)

Music and dance are deeply intertwined activities. In this respect, it is natural that **sonification** emerged as one of the key requirements. For instance, music can serve as an orientation point for training certain dance sequences:

> Picking out the parts of the music where you got it wrong and playing them several times so that you can practice them more often might also be a possibility. That you are told afterward, 'You didn't get that part quite right. That's how it would be correct. Now try it again', and then it's played back x number of times. (S3)

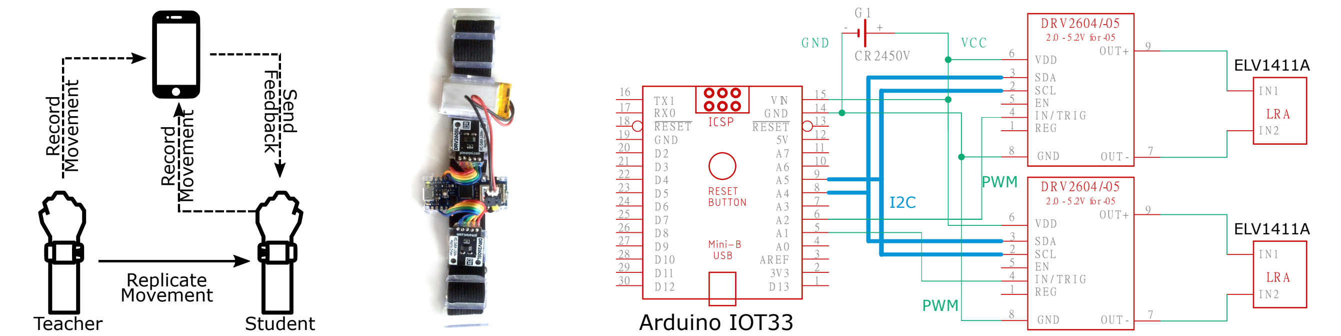

Figure 3: System architecture, prototype, and schematic.

On the other hand, the variation of certain musical elements could serve to gradually learn to dance in harmony with the music:

> That the beats become clearer. But I think that would be a way for someone to passively get used to dancing to the right beat, because I've noticed that the longer people dance, the less you have to count in, the more they have a sense of what's right and what's wrong. And of course, you could influence that in such a way that they don't even notice that they've made a mistake. (T1)

To reiterate, based on our literature analysis and the expert interviews (using theory-based vignettes), the design requirements called for a lightweight, wearable system that offers personalized, implicit feedback for single dance figures and integrates sonification elements. Furthermore, the system should offer the possibility to combine it with an explicit, audio-visual introduction to dance figures, thus mirroring the structure of classic dance lessons.

3 DESIGN

We developed a prototype inspired by the recommendations provided by the teachers and students and summarized in Section 2. The system (Figure 3) includes a mobile app and a set of wearable bands with vibrotactile feedback and Inertial Measuring Units. We focus on transferring knowledge through implicit feedback; avoiding explicit instructions as communicating dance movements can be challenging for both teacher and student. Our prototype addresses this point in two ways by (a) providing vibrotactile feedback in real-time when the student is replicating the movement and by (b) providing auditory feedback through sonification. We make this possible by recording the teacher's movements and later recording and calculating a correlation between the student's and teacher's movements. When the student follows the movement accurately, no feedback is provided. When the movement differs, the vibrotactile bands vibrate based on the correlation value, and the reverb of the song is altered accordingly. The user's goal is to keep the song playing and avoid the activation of the bands.

4 DISCUSSION AND IMPLICATIONS

The interviews showed that practice, feedback, and teaching the technical details of a movement are the most critical factors for improving dancing skills. Participants highlighted the role of feedback in early stages since it is harder to correct movements that already reached the automatic phase. The importance of repetitive practice is often stressed in the dance context. Therefore, the system should support continuous practice across motor learning stages. Also, approaches that prioritize implicit over explicit feedback can better support dance students. Furthermore, approaches such as sonification or real-time haptic feedback are well received by teachers and students [10]. In contrast, summaries or statistics after a session or the execution of a movement are less valued.

Besides, we observed a difference in attitudes towards non-dance-related training. These differences in attitudes were also reflected in the opinions about a technical setup. While T2, T3, and T5 value additional exercises to reduce the risk of injury and allow healthy dance training, for T1, it does not belong to the hobby field of dancing but competitive dancing. One explanation for this may be the different dance styles. The participants who practice a performing dance type often shared the same opinion that differed in part from participants who practiced a Ballroom dance style.

5 CONCLUSION

In this paper we applied neural theory to guide the design of a wearable systems for dance learning. We interviewed dance teachers and dance students to learn about their experience in the motor skill acquisition process. We used semi-structured interviews to ground neural theory in practical requirements, thereby considering learning stages beyond the first experience with a movement (fast-learning phase). We designed a prototype that considers the insights provided by teachers and students for dance learning. We found that dance students prefer implicit feedback to train a specific movement and explicit feedback for being instructed about the movement beforehand. Implicit feedback allows dance students to focus on a specific movement without being distracted. Designers of wearable systems in the context of motor learning should consider that learning a new motor skill involves more than a first exposition to the system. Our results emphasize the importance of considering the long-term usage of such systems. Hence, future work should evaluate the long term effect of systems with a similar structure to gain empirical validation of the architecture described.

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