Dance style transitions : from dancers' practice to movement-based technology

Elizabeth Walton

université PARIS-SACLAY

Dance Style Transitions : From Dancers' Practice to Movement-Based Technology

Transitions de Styles de Danse : de la Pratique des Danseurs à la Technologie Basée sur le Mouvement

Thèse de doctorat de l'université Paris-Saclay

École doctorale n°580 Sciences et technologies de l'information et de la communication (STIC)
Spécialité de doctorat : Informatique
Graduate School : Informatique et sciences du numérique
Référent : Faculté des sciences d'Orsay

Thèse préparée au Laboratoire interdisciplinaire des sciences du numérique (Université Paris-Saclay, CNRS), sous la direction de Wendy MACKAY, Directrice de Recherche

Thèse soutenue à Paris-Saclay, le 18 mars 2022, par

Elizabeth WALTON

Composition du jury

Caroline Appert Research Scientist, Université Paris Saclay	Présidente
Kristina Höök Professor, KTH Royal Institute of Technology	Rapporteur & Examinatrice
Sarah Whatley Professor, Coventry University	Rapporteur & Examinatrice
Danielle Lottridge Senior Lecturer, University of Auckland	Examinatrice
Mme. Wendy Mackay Directrice de Recherche, Inria Saclay, ex)situ	Directrice de thèse

THESE DE DOCTORAT
NNT : 2022UPASG027

Abstract

Researchers in Human-Computer Interaction (HCI) define movement either by its outward shape or its inner sensation, while movement experts, such as dancers, integrate both perspectives. With the continual development of accessible movement-tracking technology, some researchers seek to create recognizable movement gestures for both the system-at-hand and the user, from a third-person perspective. Simultaneously, researchers who consider the greater contextual, cultural, and experiential implications of this migration of technology into the home investigate the use of these new tools in uncovering and exploring new bodily sensation, from the first-person perspective. Professionally, dancers trained in a western tradition, such as ballet, inherently oscillate between: a) exploring novel movement possibilities and associated inner sensations, and b) understanding and incorporating input given by an outside view (choreographer, teacher, spectator, etc.). By understanding how they perceive and use internal and external signals, I believe that we will find opportunities for designing movement-based interaction which embraces these two important viewpoints of movement.

In my first study (Chapter 2), I concentrate on understanding how current user-centered methods for gesture- and movement-based interaction can be integrated, opening the possibility of dual perspective-supported methodologies and experiences. I create and give labels to related literature within *technology-driven design* and *experiential design* before extracting aspects from each, including the users, context, and the study goal, to facilitate comparison. I deliberate on possible cross-methodology integrations which alter the atmosphere and values surrounding the researcher and participant during studies.

Chapter 3 reviews the relevant literature that prepares the reader for the following chapters.

In my second study (Chapter 4), I investigate dancers' methods of questioning agreed-upon standards and relearning ingrained movements that open the body up for new sensations when approaching other types of movement. Specifically, I study dancers who move away from their childhood training in a highly codified form of dance, classical ballet, to find new movement pathways through similar poses and concepts. I identify dancer strategies for the three main activities during these dance style transitions and

discuss how to design to support changing rooted beliefs.

In my third study (Chapter 5), I focus on uncovering how to design feedback for movement exploration and comparing how dancers perceive and use this feedback in relation to that given by a choreographer or teacher in a real-life scenario. To do this, I introduce ImproviGrid: a button-based system with which a choreographer can give pre-saved information to a dancer in three different modalities: visual, non-verbal auditory, and verbal auditory. Through user studies, I find that the abstractness of the non-verbal, audio feedback allows for freedom in exploration, and leads to a greater variety of integration methods. I also show that dancers would use ImproviGrid in their personal practices, but that, depending on the dancer, the "controlling party" varies between the dancer, the system, or neither.

I conclude by reflecting on how to translate professional dancer practices, discussed in the previous two chapters, into methodologies to support everyday users in exploring new and interesting movement for gesture creation (Chapter 6). I consider the limitations of this work, the biases of choosing this particular population to study, and discuss directions for future research (Chapter 7).

Résumé

Les chercheurs en interaction homme-machine (IHM) définissent le mouvement soit par sa forme extérieure, soit par sa sensation intérieure, tandis que les experts du mouvement, comme les danseurs, intègrent les deux perspectives. Avec le développement de la technologie de suivi du mouvement, certains chercheurs cherchent à créer des gestes reconnaissables à la fois par le système et par l'utilisateur. Simultanément, les chercheurs qui considèrent les implications contextuelles, culturelles et expérientielles étudient l'utilisation de ces nouveaux outils pour découvrir et explorer de nouvelles sensations corporelles. Sur le plan professionnel, les danseurs oscillent de manière inhérente entre : a) l'exploration de nouvelles possibilités de mouvement et des sensations intérieures qui y sont associées, et b) la compréhension et l'incorporation des données fournies par un regard extérieur. En comprenant comment ils utilisent les signaux internes et externes, il est envisageable de trouver des opportunités pour concevoir une interaction basée sur le mouvement qui englobe ces deux points de vue importants.

La première étude (chapitre 2), se concentre sur la compréhension de la façon dont les méthodes actuelles centrées sur l'utilisateur pour l'interaction basée sur le geste et le mouvement peuvent être intégrées. Je crée et donne des titres à la littérature liée au sein de « technology-driven design » et « experiential design » avant d'extraire les aspects de chacun, y compris les utilisateurs, le contexte et l'objectif de l'étude, afin de faciliter la comparaison. Je délibère sur les intégrations possibles de méthodologies croisées qui modifient l'atmosphère et les valeurs entourant le chercheur et le participant pendant les études.

Le chapitre 3 passe en revue la littérature pertinente qui prépare le lecteur aux chapitres suivants.

La deuxième étude (chapitre 4), se concentre sur les méthodes utilisées par les danseurs pour remettre en question les conventions et réapprendre les mouvements ancrés qui ouvrent le corps à des nouvelles sensations lorsqu'ils abordent d'autres types de mouvements. Plus précisément, j'étudie les danseurs qui s'éloignent de leur formation d'enfance dans une forme de danse très codifiée, la danse classique, pour trouver de nouvelles voies de mouvement à travers des poses et des concepts similaires. J'identifie les stratégies des danseurs pour les trois activités principales pendant ces transitions de style de danse et je

discute de la manière de concevoir pour soutenir le changement des croyances enracinées.

La troisième étude (chapitre 5) se concentre sur la manière de concevoir le retour d'information pour l'exploration du mouvement. Pour ce faire, je présente ImproviGrid : un système à base de boutons avec lequel un chorégraphe peut donner des informations préenregistrées à un danseur selon trois modalités différentes : visuelle, auditive non-verbale et auditive verbale. Grâce à des études d'utilisateurs, je constate que l'abstraction du retour audio non verbal permet une liberté d'exploration et conduit à une plus grande variété de méthodes d'intégration. Je montre également que les danseurs utiliseraient ImproviGrid dans leurs pratiques personnelles, mais que, selon le danseur, la "partie contrôlante" varie entre le danseur, le système, ou aucun des deux.

Je conclus en réfléchissant à la manière de traduire les pratiques des danseurs professionnels, discutées dans les deux chapitres précédents, en méthodologies pour aider les utilisateurs quotidiens à explorer des mouvements nouveaux et intéressants pour la création de gestes (chapitre 6). Je considère les limites de ce travail, les biais liés au choix de cette population particulière à étudier, et je discute des orientations pour les recherches futures (chapitre 7).

Acknowledgments

During my thesis, I learned that there is rarely a research genius, but instead a full team needed to make research happen. I absolutely agree. This thesis work would not have been possible without the support of many different parties.

First of all, I would like to thank my thesis director Wendy Mackay. In a moment of weakness, she swept in and saved the day, getting my thesis back on track. Her ability to work with students, to listen to their ideas then pull from her massive, mental database of knowledge to give direction is incredible and heavily, positively influenced my work. When I struggled with my writing style, she was able to understand my ideas and main points in a paper, then organize and clean them up neatly, from which I learned greatly. Her willingness to share from her experiences showed her strength and determination, encouraging me to keep going when I was down. I would like to thank her for managing the team so well during the Covid-19 confinements, when fear and insecurity were high. I enjoyed not only our moments of work, but also dance chats about the latest New York City ballet article or upcoming season at the Paris Opera ballet. Wendy, thanks for all the work put into my thesis, especially during such an uncertain and fatiguing time.

I would also like to thank my jury members from my mi-parcours and my defense. Sarah Whatley and Caroline Appert, thank you for the insightful advice and encouragement that greatly impacted the second half of my PhD. Kia Höök and Sarah, thank you for taking the time and care with my manuscript and giving me such thoughtful and detailed feedback. Kia, Sarah, Caroline, and Danielle Lottridge, thank you for the support on such an intimidating day and for the interesting questions. Here's to the first all-female jury in computer science in Université Paris-Saclay history!

I also want to thank the Element project team. With their funding, they gave me the opportunity to pursue this very particular project, and I am very grateful. Thank you to my Element co-authors Baptiste Caramiaux, Sarah Fdili Alaoui, and Frédéric Bevilacqua on their contributions in my first publication. Thanks to everyone else for giving input on my work each month and throughout the process.

I also want to give some special shout outs to my lab mates from the ex)situ team. A big thank you to all the graduate students finishing up their PhDs when I arrived for giving advice and sharing their experiences. I want to say thank you especially to graduates like Carla Griggio, Philip Tchernavskij, and Janin Koch who, to this day, support and inspire me. Also to Benjamin Bressolette and Miguel Renom for our wonderful life talks as grumpy cats. I am a part of the Covid-19 era PhDs, which means that support and discussion had to be planned and done over the phone or computer. Big shout outs to Stacy Hsueh and Abby Liu for the weekly or bi-weekly calls while cooped up. I would not have made it through without you both. Lastly, a big thank you and bon courage to the younger generation of ex)situ, including Camille Gobert, Arthur Fages, Alexandre Battut, Wissal Sahel, and rest of the team. Here's to the other doctoral students who defended alongside me: Téo Sanchez, Viktor Gustafsson, Han Han, Miguel Renom,

and Alex Eiselmayer. We made it!

I would like to thank from the bottom of my heart all the participants from my 2 latter projects. Being a professional dancer or conservatory student, especially during a pandemic, when performances are cancelled and rehearsals limited to pods, is very difficult, and the enthusiasm to share and engage with my work was humbling. Thank you for trusting me with your stories and your movement over the last two years. I would like to give a special thanks to dance artist Liz Santoro for her involvement in my last project and her invaluable input throughout my thesis. For a choreographer with her own company and projects, time and space is hard to find, and I really appreciate that she made some for me.

I can not put into words how much I appreciate having my family during this difficult process. Mom, thank you for being there for daily support, encouragement, or ideas, and for keeping me close to the family, even from so far away. Dad, thank you for the behind-the-scenes support and being open to work with me on practical life problems even when I know you are not a true lover of Paris. Lily, we are both going through exciting and transformative parts of our lives, and even though this means we might not be in touch as much as we would like, I love and appreciate you beyond belief. Thank you for being an incredible sister. To the rest of my family, Wannie, Grandma Nancy, Aunt Jill, Uncle Tom, Kelly, Sammi, Uncle Lee, Lindsay, Kendall, and Charlotte: thank you for sending love and support, even when I had to work during vacations to make deadlines. A special shout-out to my belle famille, the Loridants, and my "French grandparents", Sylvaine and Pierre, for welcoming me in for summer vacations and relaxing weekend visits.

Quentin, thank you for everything.

Lastly, I want to thank all my dear friends who have made my experiences these last three years all the better. Maria, I am so thankful that a confinement dance workshop allowed us to meet, and I look forward to continual performance viewings and discussions over eggs or pizza! Vanessa, thank you for being a voice of reason in a time of stress, and for being a wonderful role model of a bada** researcher. Lucia, thank you for the moments of sharing intimate stories, research problems, and Spanish soap opera viewings! Meg, you are an incredible example of strength and determination, and I thank you for being the warm spirit that takes me back to Kentucky. I want to thank all of my amazing friends in Grenoble, including Emilie, Mathieu, the old BDS group, the runners, and the roommates who welcomed me and my furry plus one warmly into their home during the confinement. Thank you to all my dance friends from Kentucky, especially Theresa, Lilly, Georgia, and Katherine, who have been so available and interested in discussion about my thesis topic and dance life in general. A big thank you to Juliette, Gianna, Myriam, Hubert, and all the other dance artists that I've met during the last three years, who have impacted greatly my path and healing as a dance artist here. Pascale, thank you for not only being a teacher but also a friend. Limor, your time, insight, and support has been invaluable. I can not thank you all enough.

This thesis was funded by the Agence Nationale de la Recherche grant №ANR-18-CE33-0002 "ELEMENT".

Contents

List of Figures

List of Tables

1

Introduction

Suzanne Bødker defines the third wave of Human-Computer Interaction (HCI) by its broadening use context, from the workplace of the second wave into the home and everyday life (Bødker, 2006). Going beyond the public and collaborative to the private implies an inclusion of foundational aspects of life, such as experience and emotion. Within movement-based interaction design, we notice an increasing tension between utilising the developing technological capabilities to quantify movement and the third wave focus on the soma (Shusterman, 2008), sensation, and the felt experience. Devices like the Microsoft Kinect, the three-dimension accelerometer-based Wii, and advanced motion capture (MoCap) systems allow researchers to define movement using quantifiable information like displacement, speed, and acceleration for movement recognition and use. Conversely, as technology gets into the home, other researchers recognize the need to embrace more contextual, cultural, and expressive components of interaction. Therefore, we see an introduction of concepts which place the focus on the experience of the body and the person within, such a phenomenology and embodiment (Merleau-Ponty, 1996), somaesthetics (Shusterman, 2008), etc. Though Suzanne Bødker formalized the elements of the third wave of HCI in 2006, these two trending communities continue to work separately, keeping the gap between quantitative, third-person work and qualitative, first-person work in movement-based design [1] (see examples in Figure 1.1).

On the other hand, dance study and performance necessarily combines both points of view. Techniques, like classical ballet, include

[1] I employ the definitions for first-person and third-person perspectives by Merleau-Ponty, expanded upon in the HCI community by Svanæs (2013).

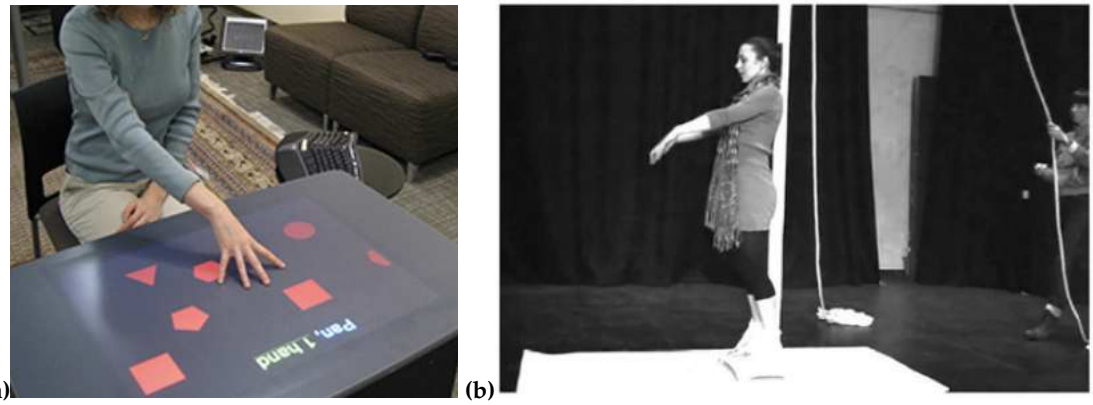


Figure 1.1. Wobbrock et al. (Wobbrock et al., 2009)'s gesture elicitation set-up (left) vs. Loke et al. (Loke et al., 2013)'s Interactive Art piece with integrated Feldenkrais method (right)

strict codification of poses and movements, named due to how they look from the outside (Franko, 2012). At the same time, no matter the technique and level of codification, dancers experience and understand movement through sensations, how a movement feels (Rivière et al., 2018). Dancers frequently transition between first and third person perspective to explore new movement and then reflect on how it happened to gain deeper understanding of the sensation and to continue their movement research [2]. In dance technique training, at least in western cultures, dance training often begins with techniques with highly codified movement vocabularies, like classical ballet and modern dance. [3] Western dance has expanded into different forms of contemporary dance which generally reject such highly codified work; however, depending on the style or creator, movement is codified in other ways, like through image-based vocabulary to describe the approach to moving[4] [5]. Performance as well, unless 100% improvised, includes some sort of defined structure or order so that dancers can recreate a piece evening after evening. Therefore, dance practice, even without technological involvement, includes a similar tension between quantification/codification and experience.

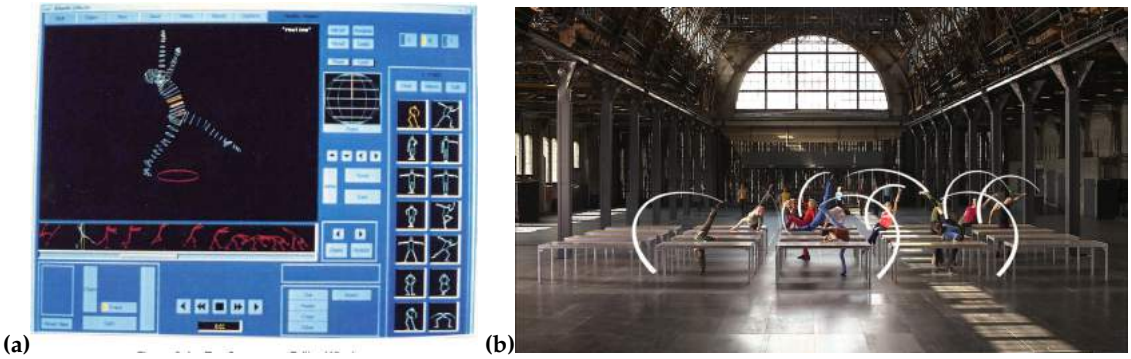
Within the HCI + dance community, Zhou et al. (2021) recently also brought to light this tension between these two trends: "In designing computational support for dance, the quantifying nature of algorithms collides with the felt bodily experience while attempting to concurrently recognise and cultivate expressive movement qualities.". Dance interactive learning systems often support mimicry or traditional ways of teaching in which the teacher "makes all the decisions and the learner follows these decisions" which requires "precision and accuracy of performance and the right/wrong paradigm is strongly applied" (Raheb et al., 2019). In these cases, the technological system inherently requires powerful movement capture and recognition capabilities. In choreography incorporating technology, historically,

[2] Höök et al. (2021) discuss this non-dualistic stance of experts in soma design.

[3] I focus on classical ballet, but other western techniques like jazz (Giordano, 1992), tap (Lewis, 2013), as well as eastern techniques, like Indian classical dance (Vatsyayan, 1974), are also highly codified.

[4] `https://rbdg.ca/en/rbdg-method/`

[5] Western dance rooted in the other major style at the time, Vaudeville theatre dance, also went through a transformation, into Broadway and film performance. This transition was greatly influenced by the difficulty of the career, the cultural context within the 1920's and 1930's, and technology development rather than codification rejection (Maslon and Kantor, 2008).



(a) **(b)**

Figure 1.2. Merce Cunningham's Lifeforms system (Schiphorst, 1993) (left) and William Forsythe's Synchronous Objects

through collaboration, researcher built systems that quantify the codification developed by the choreographer, like with Merce Cunningham's LifeForms system (Schiphorst et al., 1990) (see left image in Figure 1.2) and William Forsythe's piece *One Flat Thing Reproduced*, utilising the software *Synchronous Objects* (Palazzi et al., 2009) (see right image in Figure 1.2). More recently, some researchers created systems for supporting self-reflection as an approach to dance learning, through presenting the augmented dancer through a variety of visualizations (Raheb et al., 2018) or giving the dancer access to both the first and third person perspective of their movement (Yan et al., 2015). These example projects step away from teaching the dancer movement sequences, and instead support repetition and exploration for dance pieces or phrases already known. Though the system are quantitative in nature, the codification of the dance movements themselves is no longer included.

When Stanford researcher Rosanne Spector studied Merce Cunningham dancers using a MoCap system, the dancers explained the opportunity when quantifying artistic practice for deeper understanding of the relationship between dancer sensation and body mechanics[6]. With these dancer reactions, I see the opportunity to work with professional dancers and understand how to reconcile the quantitative and the qualitative, the measured and the sensed, the codified and the abstract in movement-based design, as they must do in their everyday career.

[6] https://news.stanford.edu/news/2005/march16/med-mercer-031605.html

In this thesis, I investigate dancers' relationships to how they feel and view movement, with the use of technology. My goal is to better design technological interaction so that both strengths of the body and the technologies combine to support novel movement creation and learning. I pose the following research questions:

- How do dancers balance the 'performed' and the 'experienced' dur-

ing activities of reflection and new movement exploration as their career develops?

- How do they use third-person-given information for movement exploration and novel movement creation?

- How do we re-imagine movement representations in technology that integrate 1st and 3rd person perspective, the interior and exterior view of the self?

1.1 Thesis Statement

As in dance work itself, dance support technology can be designed to be both quantitative and qualitative in nature, intertwining the codified and the experienced. However, to design in this manner remains a complicated question. I argue that through style transitions, we uncover a powerful method for hearing from dancers themselves about how they question codified and non-codified aspects of their training. Through structured observation with a feedback-focused prototype, we find out how to better support dancers with technology in self-exploration. Both present designers with user-centered methods for uncovering the real-world use of technology in a personal dance practice, and imply designing by a) combing the quantitative and the qualitative, and b) removing the highly influential context of the studio or stage to support the individual dancer.

1.2 Research Approach

I developed my thesis in the context of the French Agency of National Research (l'Agence nationale de la recherche) project ANR-18-CE33-0002 Element (Enabling Learnability in Movement Interaction)[7]. The Element project places importance away from intuitiveness and onto learnability in movement-based interaction. The team proposes developing learnable, embodied movement vocabularies, approachable even for novices, and adaptable systems that learn with the user as users improve in their motor skills.

[7] https://element-project.ircam.fr/

To support the multidisciplinarity of HCI research, I use methods that triangulate between observation, design, and theory, which draw from methods in design, engineering, and social sciences (Mackay and Fa-

yard, 1997). Using approaches of each kind is especially important when working with extreme users like professional artists. Though the presence of academic discussion on creativity dates to Ancient Greece (Rothenberg and Hausman, 1976), the one constant in artistic work is its continuous evolution. Even in contemporary work, which reflects on current, global issues such as the influence of technology on the human body [8], as society evolves, so does contemporary art. I believe it necessary to often re-enter the practices of art professionals and conduct research through multiple perspectives, creating conditions for technological intervention and discovery while continually returning to a theoretical basis. I examined current literature and opened up a design space through which I framed a deeper, narrower investigation through both the first and third person perspective. These works influenced prototype design, and initial evaluation, which I then related to current theory.

[8] https://steinhardt.nyu.edu/programs/art-education/art-education-definitions

Comparative Essay

I used a comparative approach to find similarities and differences between two divergent movement-based design methodological trends to find opportunities from resolving present tensions. Other researchers previously presented comparative essays as an approach for finding how two research methodologies or concepts might benefit from integration of the other. Examples include: the comparison of International development and HCI to discuss the future of "information and communication technologies for development," or ICT4D (Toyama, 2010); HCI and software engineering to aid with the future lessons on developing interactive systems (Fernandez and Young, 2005); and Usability and Actability to clarify purpose and use for each (Cronholm, 2001). In my work, I compared the methodological trends which I define as *technology-driven design* and *experiential design* so that I can clearly delineate the differences and bring to light their impact on the research atmosphere and researcher-participant relationship of studies within each category. I use these results to discuss the opportunities available to overcome drawbacks of each trend by integrating practices from the other trend, in order to alter the research context which hinders results.

Semi-Structured, Story Interviews

I conducted semi-structured interviews to better understand the first-person experience of a dance style transition from ballet to another style of dance. More specifically, these were story interviews (Mackay, 2019) which employed a version of the critical incident technique (Flana-

gan, 1954), looking specifically at how expert dancers approach learning movement in a new style. We asked dancers about recent moments when they needed to learn a movement or a concept in their new style, and focused on methods used to approach the movement, with specific interest on impact of their previous ballet training and the role of the teacher/choreographer. As this transition process is mostly absent of technological intervention, we interviewed the dancers with the goal of finding design opportunities for supporting their current transition activities and strategies, as well as using the transition as a case study to better understand of the real-world, professional practice and question the design of current dance learning support systems.

Technology Probe

To question how to design improvisation co-collaborators, I created *ImproviGrid*, a prototype used as a technology probe, and explored how dancers received its feedback in a real-world, Covid-19 setting. A technology probe, like other probes, is used to uncover the unknown, but specifically combines "the social science goal of collecting information about the use and the users of the technology in a realworld setting, the engineering goal of field-testing the technology, and the design goal of inspiring users and designers to think of new kinds of technology to support their needs and desires." (Hutchinson et al., 2003) ImproviGrid ties pre-selected input to individual buttons on a MIDI Grid controller, in order for the user to give feedback in multiple modalities (visual, audio, and verbal) to a dancer during improvisation or choreography. I designed the probe to support a Wizard-of-Oz (Connell et al., 2013; Weiss et al., 2010) study, during which the probe is manipulated by a professional choreographer or teacher. During the study, one choreographer controlled the system while I observed the dancers in improvisation to see how the input from the system inspired new movement ideas or constrained their movement and how the two parties communicated with other through technology mediation. The results presented us with how dancers process and use input they are given, and how they and the choreographer view the role of the system.

Structured Observation

To study how dancers understand and use given open feedback from a system, I employed the structured observation methodology (Garcia et al., 2014; Koch et al., 2020; Liu et al., 2021). Structured observation integrates "elements of a controlled experiment" into observation in a real-world setting with ecologically valid activities in order to identify

new phenomena out of "messy, creative behavoir", while remaining in the context of informing design. We drew from an already existent activity, improvisation with external direction for choreographic creation, but with a focus on the dancer and their individual experience. This dancer focus is especially relevant as personal practice at the home soared during the pandemic. Just as Garcia et al. (2014) used structured observation to better untangle the creative processes of expert composers, I used structured observation to clarify the movement exploration process of dancers and the relationship they have with given input from a real person in comparison with that of a technological system. Additionally, by designing equivalent tasks and using a within-subjects design, structured observation presents researchers with similarities and differences in participant behaviour. In my case, I utilised feedback modality (visual, audio, verbal) to facilitate comparison among participants.

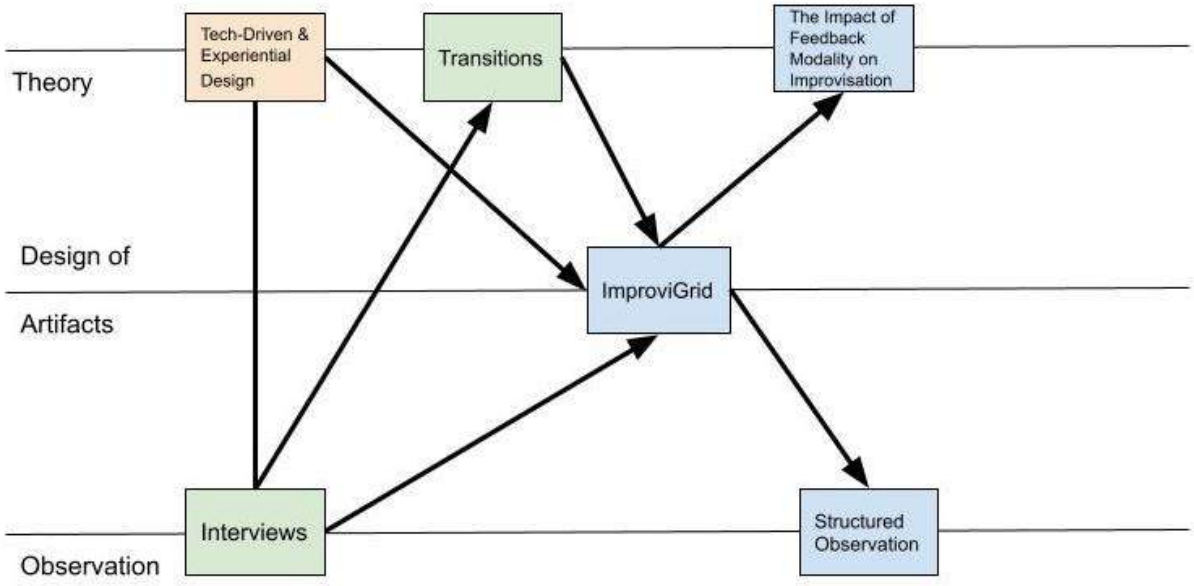


Figure 1.3. Mackay and Fayard's HCI method triangulation, among theoretical, the design of artifacts, and observational work

1.3 Researcher Positionality

I myself am not only an HCI researcher, but also a dance artist who completed a dance style transition. My background directly influenced my research interests during this thesis. I prioritized certain perspec-

tives and methods because of my work with movement. I present more information about my dance self, discuss how it framed my work, and overview the resulting strengths and weaknesses of this thesis endeavor.

Here is an overview of my dance experience: As a child, I started my dance studies in multiple styles, including tap and jazz dance, before concentrating on classical ballet. I trained in ballet from ages 10 to 18. As I got older, I realized that my body was not made for the classical ballet training. I began to broaden my horizons into contemporary ballet and modern dance while continuing my studies in classical technique. At 17, I had a major injury, resulting in surgery and multiple rounds of physical therapy. I took time to heal and began experimenting with techniques like the Gaga movement language [9] during university (where I studied computer science). I then re-approached contemporary dance during my doctoral degree. As I was interviewing dancers and designing ImproviGrid, I found myself knee deep in my own transition, exploring contemporary, modern, yoga, and Feldenkrais methods as well as participating in multiple workshops with contemporary choreographers at facilities like the Atelier de Paris [10] and PARTS school for contemporary dance [11] in Belgium.

[9] https://batsheva.co.il/en/gaga

[10] https://www.atelierdeparis.org/masterclass/

[11] https://www.parts.be/

I found this transition process personally motivated and generally unsupported. I moved away from the childhood schooling in a institution where teachers relate to our training experience, understand our goals, and know how to get us there. I began a more "freelance" training, taking classes structured around a technique or style and rarely taking the dancers' previous experiences into consideration . I hypothesized that I was not alone in feeling so detached. I was hungry to make this process and the approaches to transition successfully concrete for myself and for other dancers. I also saw the potential of this concretization for translating and sharing with computer scientists to better inform future support tools. My need to support this transition process for myself, then for other dancers and designers, motivated this thesis from the very start.

This motivation influenced my chosen user population: successfully style transitioned professional dancers. I looked for dancers who worked or studied (at a competitive institution) in their second style because of their extensive experience approaching the transition on a daily basis and finding techniques or tools that helped with their re-learning. These dancers continuously questioned topics like their previous ballet training and, even when they performed styles like tango and folk

dance, had experience, knowledge, and influence from somatic and other habit-breaking techniques. To me, these potential users held untapped knowledge to which I could relate and understand, and would be interested in delving into their transition and potential tools to support it.

I also chose to use qualitative methodologies that focused on uncovering the first-person experience of the dancers. With my background, I knew that professional dancers related to movement as more than "a change of position" [12]. They did not need technique training support, to be told from the outside whether things were right or wrong. I knew that they received this feedback in class or rehearsal or from seeing themselves in the mirror or on video. I was interested in building for their needs, for my needs. Therefore, I chose to focus on their first-person perspective to understand their experiences. (Additionally, previous research by Höök et al. (2018) presents the need to embrace the first-person perspective in body-based design.) I used qualitative methods like semi-structured interviews and structured observation to capture the nuances in each dancer's personal experience. My position and motivation as a dance artist and researcher also influenced my methodological decisions, focusing on qualitatively uncovering the first-person felt experience of these professional dancers.

[12] https://dictionary.cambridge.org/dictionary/english/movement

These choices culminate into "super powers" that bettered the impact of my results. Frich et al. (2019) mentioned the difficulty in recruiting expert creatives, which could correlate with the trend within HCI to create simple CSTs for novice users. Though Frich et al. do not discuss why this difficulty arises, I hypothesize that time, money, energy, intellectual property fear, and researcher potential treatment/ lack of knowledge about practices of the professional artists all have an impact on their willingness to participate in studies. Dancers can be specifically difficult to study since dancers and choreographers tend to avoid anything that could possibly disturb their kinesthetic experience (Raheb et al., 2019). As someone from that community, however, I was able to recruit participants through my personal network, including colleagues of past ballet classmates and other workshop participants and dancers from their networks. Especially when it is prohibited to compensate these artists for their time at my research institution, a personal network of professional dancers for recruitment is priceless. Additionally, my shared training with the dancers "enabled a mutual understanding of language and lived dancing experience, which helped bring out certain issues in the interview-discussions" (Ehrenberg, 2015). Instead of explaining vocabulary words or movements themselves, dancers were able and willing to delve into the more sen-

sitive parts of the style transition, like dying childhood dreams and non-human, disturbing sensations. Because of my training, I was able to put myself in their shoes, invoking my second-person perspective, to understand their first-person experiences, in order to understand how to design technology based on their needs. Lastly, my thesis director, who also danced and experienced a transition from ballet to jazz dance, and myself performed analysis in a very specific context brimming with intimate discussion, nuancing our subjective understanding of the results. I argue that my work with future users, including myself, offers results, designs, and future implications inaccessible with more distanced research team.

Concurrently, my experience develops inherent weaknesses. Novack (Feld, 1992) and Ehrenberg (2015) describe the cultures of classical ballet, improvisation, and contemporary dance that influence (un)noticeable behaviors and assumptions in how dancers act and move. Because I transitioned from studying classical ballet to contemporary dance, my research questions, decisions, and data analysis was influenced by my cultural bias gained from being a part of both cultures. My results and analysis could therefore be hard to expand upon for all style transitions in dance, athletics, or rehabilitation, even though similarities and potential significance exist. I therefore do not try to hide the weakness that my training generates in my research, especially in the generalizability of the work.

Additionally, I believe that as a movement-based interaction designer, it is necessary to train in some form of movement- or body-based activity, to gain awareness and understanding of both. I agree with Hummels et al. (2007) in the necessity to "educate the senses" for movement-based designers. Wulff (2020) agrees, that in order to study ballet: "You have to do it (ballet) in order to understand it." I follow their lead by structuring my research so it can be supported by my training in dance and somatic practices. Additionally, as Vandenberghe and Slegers (2016) (among others) discuss, user-focused methodologies in HCI often have a pitfall trying to "do good for others." I find designing for myself more ethically sound. I therefore believe the influence of my experience and motivation align with the approaches of others in the HCI field.

I position myself not only for my reader to better understand and interpret my work, but also to highlight my zone of research in order for other research opportunities to appear in the white space.

1.4 Contributions

This thesis includes *theoretical*, *empirical*, and *technological* contributions (see 1.3):

Theoretical Contributions:

- The movement-based design approach trends which I define as:
  - *technology-driven design*: which focuses on improving gesture and movement recognition and formulation for the system and user; and
  - *experiential design*: which includes embodied design, focusing on supporting the user in developing body awareness and exploring sensations
- Design opportunities when integrating the first-person perspective into technology-driven design and when integrating a structure for detached, comparable movement capture into experiential design
- The definition of a *Dance Style Transition* and the use of transitions as a method for critically questioning an activity and the tools that exist to support it
- The *Movement Substrate* approach to: hold different dance movement representations; define the relationships among them; support communication through the observer point of view, but definition through the mover and the machine points of view
- The activity of *definition making*, during which dancers develop vocabulary terms for movements, understanding and choosing descriptive language to capture and transmit this understanding
- The demand to expand co-creative agent output modality beyond visuals in order to best integrate them into expert improvisation and choreography making

Empirical Contributions: I present the key findings from my two empirical studies completed during this thesis:

- Professional dancers who have undergone a *dance style transition* developed strategies for overcoming habits, learning movements in the

new style, and supporting a sustainable style transition, in which external guidance plays differing roles

- In order to become an expert in a new style, dancers are obliged to changed their previously ingrained mentalities toward their view of the body, the teacher, the performance, their vocabulary, and any other issues surrounding dance training and performance.

- Dancers prefer to freely explore their movements with the audio cues, though some dancers favored the structured exploration with the verbal cues

- Dancers find the visual feedback more constraining that verbal or audio feedback; however, many discussed the utility of constraint for creativity, especially for non-verbal audio feedback.

- Dancers relate to the verbal and audio cues the most similarly to real-life experiences with inspiration support tools, the latter similar to interaction with a choreographer.

Technological Contributions:

ImproviGrid is a prototype in which we store pieces of information in buttons as feedback for dancers during improvisation or choreography. I represent the information of each button as either a short video clip, a short audio clip, or a verbal phrase spoken using the 'say' command on OS X. This prototype not only uncovers how to design for future deep learning-based improvisation co-creators, but is useful for choreographers and teachers in transmitting information to their dancers in new and creative manners.

1.5 Thesis Overview

Chapter 2 presents "the view from 100,000 feet " of the movement-based interaction literature, so to speak. I define technology-driven and experiential design, and employ these definitions to describe the current state of the movement-based design methodologies. Through comparison of different aspects of the curated works presented, I discuss potential future approaches which blur the line between qualitative and quantitative work.

Chapter 3 zooms closer into the tension between the first-person sen-

sation and the third-person codification within dance. I dive into three specific themes in the related literature: western dance history, HCI dance learning systems, and HCI choreography support systems.

Chapter 4 describes a study focused on the dance style transitions of dancers, in which they approach learning a new style of dance after having become experts in another (here, in classical ballet). Dancers currently use minimal technology during this process; therefore, I describe implications for designing movement-based technologies to support the activities involved in this transition, and discuss how our findings imagine novel design approaches for storing, defining, and interacting with dance data and to balance control between dancer and system.

Chapter 5 details an exploration into movement exploration and questioning of expert dancers through the deployment of the technology probe, ImproviGrid. The chapter begins with motivation and description of the probe itself. Then, it depicts the study and related results in which I used the probe to study dancer use of feedback during improvisation.

Chapter 6 reflects on the greater implications when designing movement-based interaction for non-expert movers. I discuss potential approaches for integrating movement exploration and habit breaking into gesture design, and the challenges in adapting dancer approaches for beginner users.

Chapter 7 concludes with an overview of the contributions of this thesis work, as well as discussing opportunities for future research.

2

Movement-based Design: The Tension between Technology-Driven and Experiential Approaches

This chapter compares and contrasts the movement quantifiers and movement qualifiers communities in order to uncover patterns to spark design opportunities for movement-based interaction.

My team and I published this chapter at the 32nd International Francophone Conference of Human-Computer Interaction (IHM). This work, entitled ***Reconciling Technology-Driven and Experiential Approaches for Movement-Based Design*** *(Walton et al., 2021) was completed with Baptiste Caramiaux, Sarah Fdili Alaoui, Frédéric Bevilacqua, and my thesis director Wendy Mackay.*

2.1 Introduction

Computing continues to move away from the desktop and workplace context, having a more and more ubiquitous presence. Ever since the mobile phone entered the market in the 1980's[1], mobile computing has grown, to the point that in 2011, the number of mobile phones overtook that of landlines in the United Kingdom[2]. In 2010, Steve Ballmer noted the transition from mouse-and-keyboard-based technologies to more "natural" interfaces based on "touch, speech, gestures, handwriting, and vision"[3]. That same year, Microsoft released the Kinect which

[1] https://www.tigermobiles.com/evolution/

[2] https://www.telegraph.co.uk/technology/mobile-phones/8581624/Mobile-phone-calls-overtake-landline-calls-for-first-time.html

[3] https://www.huffpost.com/entry/ces-2010-a-transforming-t_b_416598

allowed for movement-based interaction within the home. A year later, Fitbit released an impressive update for its wearable activity tracker[4]. Additionally, the following fives years saw more advancement in body tracking devices with the Apple Watch[5] and movement tracking and generation with discoveries in deep learning[6]. Even though these technologies existed and had been studied previously within a lab setting, the user ability to purchase and bring home these technologies posed an opportunity and need for researchers, especially within Human-Computer Interaction (HCI), to develop and improve interaction.

[4] https://www.wareable.com/fitbit/story-of-fitbit-7936

[5] https://www.wareable.com/smartwatches/apple-watch-review

[6] https://adeshpande3.github.io/The-9-Deep-Learning-Papers-You-Need-To-Know-About.html

At the same time, others like Bødker (2006) observed the implications of the ubiquity of technology: the continuously blurring line between the workplace and the home, the broadening use context and applications, and the inclusion of other aspects of life such as culture and experience. Within body- and movement-based interaction, researchers like Höök and Mentis integrated and designed for the experiential body as it is defined in philosophies like phenomenology: "It (the body) is... the condition and context through which one is in the world" (Mentis et al., 2014). Some like Loke and Robertson trained in and integrated movement studies or body-based practices like the Feldenkrais method (Loke et al., 2013), estrangement (Wilde et al., 2017), and making strange (Loke and Robertson, 2013) into their research. From repercussions of available body-based technologies, these communities of researchers approached interaction design outside of the task-filled workplace, placing importance on the experiential body and its movement within the greater social context.

We hypothesize that comparing these coincident yet dissimilar trends in HCI research will bring to light potential opportunities. Therefore, we define two terms for discussing works which hail from one of the trending approaches or the other: *technology-driven design* and *experiential design*. In *technology-driven design*, the overarching goal is to improve interaction with a specific piece of technology which exists in a specific context. In this case, researchers develop potential scenarios in which the technology could exist or if it is already on the market, draw from and test within the existing contexts for improvement. On the other hand, we define *experiential design* as encapsulating works which have the goal of exploring and integrating into design elements related to how the conscious body experiences, reacts to, and perceives the world around. In this case, researchers study how the body understands, feels, and senses the movement it is creating. If technology is explicitly present, it is present as a tool for design or used for uncovering and understanding nuances in movement.

To facilitate comparison, we define and employ the term *aspects* of interest of a design approach: the combination of design features and user study methodology that specifies the goals and choices of users, as well as the context and procedures. With this term, we present the following questions which framed our work: What aspects differ between these two approaches? What aspects of the approaches are similar? How does each approach and its aspects impact the results? How could we beneficially re-imagine the approaches to view design opportunity with novel outcomes?

We present a comparative essay of our two defined approaches in order to create and resolve a tension through their divergent nature. Therefore, we intend to compare these approaches in order to re-imagine alternative design practices rather than structure the literature around these two approaches. To do so, we further clarify technology-driven design and experiential design through some of the existing literature, mapping publications to their associated design approach. We follow by analyzing the set of works through their aspects. Then, we finish by discussing potential ways of re-imagining the two design approaches when partially integrated into each other.

2.2 Technology-Driven Design

We define technology-driven design to include works whose goal of improving movement- and gesture-based interaction entails developing the best gesture for each command. For the system, this means a high likelihood of recognition. For the user, this means interacting using a gesture set that is easily discoverable, learnable, and memorable. Under this definition, we include works which either help a (non-technical) interaction designer or end user explore, create and/or learn a gesture set in the 2D or 3D space during early stage, mid stage, or prototyping phases. More specific goals include offering clearer communication between the system and user and understanding user behavior in gesture creation. For clarity's sake, we define a gesture as any movement generated by the user to control an interactive system. Since we categorize the following works in technology-driven design, we plan to see studies surrounding specific technologies examined within specific constructed or existing scenarios.

We include references based on their publication date and breadth across the approaches we defined, as well as across the different chosen aspects of each approach. Publication dates range the mid-2000s to the

mid-2010s, concurrent with the aforementioned trends, when many ubiquitous-computing technologies hit the market and Bødker (2006)'s Third Wave paper appeared. Chosen references also present aspects that permit interesting comparison and cover contrasting goals, limitations, and contributions (methodological vs. technological). We refine the group of references by selecting those with either the greatest impact (measured via citations) or that offered insightful critiques of those papers. For example, we include Wobbrock et al. (2009)'s most cited work on user-defined gestures for tabletop surfaces which is the first implemented gesture elicitation study ever run (Villarreal-Narvaez et al., 2020). We also include work by Donovan and Brereton (2004) which we label as technology-driven design but which happens early enough in the design phase to not study a completed system. Additionally, we do not filter references based on a particular type of movement or gesture, but focus on having a range in methodology. We note that we do not intend to do an exhaustive review of the literature, but rather choose references based on these fairly tight criteria.

Testing a Developed Prototype

Here, we present a few examples of prototyped systems designed for supporting the user in gesture design. These systems can, for example, reveal the available, unused space to the user midgesture or present tracking and system recognition information to the user for reflection. We break this section down into two parts: support for designers in gesture design and support for end-user gesture creation and execution through dynamic guides.

Supporting the Designer Design for the User Ashbrook and Starner (2010) proposed MAGIC, a system for gesture recognition, visualization, and comparison, to help users successfully design gestures with the system point of view; however, they found difficulty in presenting and visualizing information comprehensibly. MAGIC, or Multiple Action Gesture Interface Creation tool, offered support for: gesture creation and tracking by recording accelerometer and displacement data; gesture testing for recognizability against similar gestures meant to "trick" the system; and false positive checks against everyday movements found in the included Everyday Gesture Library database. MAGIC visualized data of gestures, test samples, gesture occurrences, etc., in tables and graphs or videos. For testing, the authors asked users (experienced UI designers) to create gestures with high levels of goodness (high levels of system recognizability) and low levels of gesture overlap with everyday movements. The team found that users took advantage of video playback to remember previously de-

signed gestures and to discern which gestural features caused system misidentification, but barely took advantage of other data. Also, Ashbrook and Starner received mixed reviews related to feedback comprehensibility and resulting emotional responses (e.g. frustration from not understanding).

Kim and Nam (2013) developed the EventHurdle, a software tool to help designers rapidly and iteratively prototype sensor-recognized gestures. EventHurdle, a system which recognizes and automatically codes movements, presented user-defined gestures on a 2D interaction workspace, allowed for gesture definition with visual markup language, and automatically generated related code snippets for quick prototyping. When placed in the hands of design students then professional designers, EventHurdle supported users in designing then testing gestures in recognition test mode as well as staying in the flow of design. Still, designers wished for the tool to include more radical idea exploration.

In these studies, researchers developed and tested systems meant to help gesture interaction designers against common design obstacles including difficult iterative visualization and retrospection, false positive testing, and time-consuming interaction prototyping (especially when not technically trained). Researchers therefore approached improving gesture-based interaction by simplifying, presenting, and in some cases, making interactive, system recognition information. Designers could then develop gestures around this information. In the next section, we describe projects in which researchers took a different approach: assisting and understanding end users (without interaction design experience) in gesture creation and/or completion.

Let's See the End User's Approach: Dynamic Guides Bau and Mackay (2008) designed a dynamic guide called Octopocus that combined forms of feedforward and feedback to support users in learning and remembering mobile phone screen gestures. To clarify, dynamic guides present users with "continuously updated information" during gesture execution. In this implementation, the system presented the user with possible paths that correspond to recognized gestures. As the user continued the gesture, the less likely paths became thinner and thinner until they disappeared. When tested against a standard Help menu then a Hierarchical menu, users outperformed with Octopocus, resulting in better user learning, execution (thus easier system recognition), and remembering.

Delamare et al. (2016) implemented OctoPocus3D meant to aid users

with mid-air gesture execution. Similarly to the OctoPocus system for a mobile device, Delamare et al. presented potential gesture paths as pipes in a 3D space with diminishing radii. During testing, the user viewed the path visualization and their Kinect-tracked gesture on a desktop screen in front of them. When comparing OctoPocus3D with other feedback and feedforward mechanisms from the literature, Delemare et al. found an initial but not continued increase in the system recognition rate and a lack of influence of visualization scene stability on recognition rate.

Lastly, Malloch et al. (2017) compared feedforward dynamic guides, called fieldward and pathward, for supporting user creation of memorable, machine-recognizable touchscreen gestures. Pathward, whose implementation draws inspiration from Octopocus (Bau and Mackay, 2008), revealed the negative space and proposed next steps for a gesture in the form of line or arc segments. In the fieldward guide, Malloch et al. depicted the screen space as a heat map, blue representing the negative space and red representing a gestural next step that would form an existing gesture. The team found that most users placed importance on memorability, creating gestures they could remember then adding a "tail" for system recognizability reasons. The fieldward guide best encouraged this approach, resulting in longer gestures that users did not seem to mind.

In these works, research teams took the approach of improving gesture learning, correct execution, and memorability through system support for the (untrained) end user. Again, the teams presented "simplified" system gesture recognition information and, in this case, transformed it to guide the end user in gesture execution. Additionally, not only did teams focus on the success of the system in aiding the user but also inspected user strategy for insights into human behavior.

Demonstrating a Methodology

The second type of research that we categorize as technology-driven design encapsulates works which present methods for supporting users in creating gesture commands without system recognition. These include methods for utilizing reinforcement to encourage exploration of a user-sensor movement space and for uncovering and presenting a taxonomy of gesture vocabularies from future end users. We also divide this section into two parts: methods for movement and gesture exploration and forms of gesture elicitation.

Early Stage Exploration Williamson and Murray-Smith (2012) devel-

oped a systematic technique for mapping out the range of possible movements for any sensor placed anywhere on the body. They employed reinforcement through audio feedback for user exploration of movement novelty within a joint user-sensor space. The authors broke gestures up into micromovements, and defined a codebook of distinct motions (composed of micromovements) in order to track the novelty of each movement. For reinforcement, the team chose to use audio decay based on the originality of the movement performed, ranging from pleasing to not so pleasing. Williamson and Murray-Smith tested their methodology with untrained users wearing an inertial sensor mounted on the elbow or wrist, finding similarly sized user-sensor spaces for both.

Donovan and Brereton (2004) developed the Meaning in Movement game to explore actions and gesture in early-stage design in order to better understand and design an appropriate future system for particularly skilled users in structured contexts. Dental professionals are examples of users with pre-developed, expert-level fine manual skills who, due to health codes, work in a fairly extreme setting. To approach examining relevant gestures, the researchers developed Meaning in Movement: a game led by a facilitator in which users develop gestures from three user-proposed words related to their work. Though initially the researchers hoped for as minimal facilitator involvement as possible, the approach and directions given proved too general for the task. Therefore, the facilitator aided in leading the discussion to understand the three words, proposed acting out scenarios in the effort to transform words and sentiments into movements, and reminded users of the goal and requirements of the game. After, the team better understood the presence of the facilitator, who in the future, would participate at the same level as the users. Note: We chose to include this work for comparison since we label it as technology-driven design (due to the influence of the gesture command system final goal), even though it tackled such early design that a specific technological system was not yet involved.

In these works, researchers proposed methods for early-stage gesture exploration with potential end users. Through word-inspired games and reinforcement, ends users expressed their work experience through gesture or twisted their wrist to hear pleasing sounds. For the researchers, these methodologies helped with uncovering possible movements either for the joint user-sensor system or within specific scenarios motivated by future system development. In the next section, we present gesture elicitation studies, during which users define gestures for potential systems themselves.

Gesture Elicitation Wobbrock et al. (2009) studied how users invent tabletop gestures. The group experimented with the guessability study method (Wobbrock et al., 2005) "that presents the effects of gestures to participants and elicits the causes meant to invoke them." During the study, the system presented the effects of 27 commands, and asked the user to create both one- and two-hand gestures for each while thinking-aloud. The researchers found that the gesture database created by members of the team only covered around 60% of the user-defined gestures. Additionally, the authors found influence of the desktop paradigm, presented for example by the fact that 72% of the user-defined gestures were mouse-like, as if a user's single-touch movement translated to a mouse click. Lastly, around 43% of the gestures were labelled as physical gestures, those that employed or assumed the presence of physics-based concepts from the real world. Lastly, they created a taxonomy of user-defined surface gestures and related agreement scores. Tsandilas (2018) offered a detailed critique of the above gesture elicitation methodology and called into question the entire methodology, which does not account for agreement that occurs by chance.

Ruiz et al. (2011) made use of the same guessability method to discover user-defined motion gestures with mobile devices. Ruiz et al. studied motion gestures which occur when users translate or rotate the mobile device. Ruiz et al. asked users to design then perform 19 action- or navigation-based tasks in which either the user acted on the phone as a whole or a specific application. The gestures proposed encompassed multiple themes, two of which we note. First, many of the gestures resembled those executed when using today's mobile devices. For example, a large majority of participants (17/20) picked up and placed the phone on the ear to complete the 'Answer Call' command. Secondly, the authors found that some gestures reflected interaction with old-school technology like an old telephone and an Etch-a-Sketch.

Connell et al. (2013) used the Wizard-of-Oz approach within the guessability study method to explore full-body gesture elicitation with children. We explore three of the five major themes that emerged from the videos and subsequent transcriptions gathered. Firstly, the authors found a relationship between previous technology use, gestures defined, and overall gesture consensus. Secondly, the authors found potential support for individual preference and age impact on the gestures developed. Lastly, their results showed the possible impact of contextual cues on gestures performed as well.

In each case, researchers implemented a guessability method to draw

System	*Target Users*	*Study Context*	*Design Phase*	*Focus of Movement*
Magic	Designers	CS Lab	Mid-stage	Mid-Air Acceleration
EventHurdle	Designers	CS Classroom	Mid-stage	x-y Displacement & Mid-Air Visual Shapes
OctoPocus 2D	End Users	CS Lab	Prototyping	x-y Displacement & Mid-Air Visual Shapes
Octopocus 3D	End Users	CS Lab	Prototyping	x-y-z Displacement
Fieldward and Pathward	End Users	CS Lab	Prototyping	x-y Displacement
Rewarding the Original	End Users	CS Lab	Early	Mid-Air Acceleration & Rotation
Meaning in Movement	End Users	in-situ	Early	Visual Shapes
Gesture for Surface Computing	End Users	CS Lab	Early/Mid-stage	x-y Displacement
Motion Gestures for Mobile Interaction	End Users	CS Lab	Early/Mid-stage	Mid-Air Acceleration
Elicitation, Child-defined Gestures	End Users	in-situ	Early/Mid-stage	Visual Shapes

Table 2.1. Examples of Technology-Driven Design Research (CS: computer science)

out gestures from adult and child users. Although they identified gestures by visually inspecting the video, rather than via system recognition, the technology defined and structured potential gestural inputs. Existing technological interactions also heavily influenced which gestures were identified. Overall, this approach aimed to unveil user behavior with existing technological devices, with the goal of improving design for gesture-based interaction.

Summary

Table 2.1 presents ten examples of technology-driven design research, including the target users, study context, intended design phase, e.g., when the support system or the methodology is used, and the focus of the movement, e.g., measure of movement the sensor captures, like position, speed, or visual shape. Bold examples are tested prototypes while non-bold examples are developed methodologies.

Table 2.2 identifies the overall goals of each study in Table 2.1. These studies target end users who work outside of computer science or design, and often take place in computer science (CS) laboratories, rather than real-world environments. These systems focus on two different phases of the design process: some support early-phase design, such as user-sensor motion space exploration; whereas others support users

System	*Goal*
Magic	Address 1) "Designers are not generally domain experts in gesture" 2) "Testing gestures in everyday life can be very difficult"
EventHurdle	Address: "Relating users' input from gesture-based sensor values requires a great deal of effort on the designer's part and disturbs their reflective and creative thinking"
OctoPocus 2D	"Helping users to learn, execute and remember new gesture sets"
Octopocus 3D	Address: Users not knowing "(1) What commands are available and (2) how to trigger them"
Fieldward and Pathward	"Help developers design novel gesture vocabularies support users as they design custom gestures for mobile applications"
Rewarding the Original	"General technique for establishing a set of motions suitable for use with sensor systems, by drawing performable and measurable motions directly from users"
Meaning in Movement	"Designing future interactive systems which are more appropriate to the types of skillful actions and richly structured environments"
Gesture for Surface Computing	"Help designers create better gesture sets informed by user behavior"
Motion Gestures for Mobile Interaction	For the designers: "Allow the creation of a more natural set of user gestures" For smartphone creators: "Guidance in the design of sensors"
Elicitation, Child-defined Gestures	"Explores the applicability of using the elicitation study methodology to examine child-defined gestures for whole-body interaction"

Table 2.2. Technology-Driven Design Example Goals

and designers in mid- or late-phase design activities, such as when creating gestures, iterating ideas or testing the design.

We highlight three relationships between pairs of aspects:

Focus of Movement and Technology: Movement possibilities by the user may be constrained by the system, the device on which it is implemented, and the type of gesture being captured. For example, since Fieldward and Pathward are implemented on a mobile device, user-invented gestures remained x-y line segments possible on a fifteen cm by seven cm flat surface. The technology also defined the body part in motion. For example, in *Rewarding the Original*, users explored movement with their wrists and arms while keeping their legs still while wearing the inertial sensor on their wrist or elbow. Lastly, the learned industry standards related to a specific piece of technology, like what Wobbrock et al. (Wobbrock et al., 2009) termed the "desktop paradigm", influenced the users in defining gestures as seen through the high percentage of interaction imitation.

Target Users and Goal: We also find a difference between the study participants and the study audience. As noted, (untrained) end users were the participants in most of the studies. The research goals, on the other hand, generally focused on aiding designers in developing

improved interaction and more "intuitive" gestures.

Study Context and Goal: Finally, we note the interaction between the in-the-lab study contexts and the solution-driven study goals. Most researchers working with technology-driven design completed studies in a CS lab or classroom setting. Teams completed studies outside of a lab setting for specific target user groups including dental professionals and children. The study goals addressed explicit problems like the difficulty of "testing gestures in everyday life" or proposed clear solutions like a "general technique for establishing a set of motions suitable for use with sensor systems".

Through analysis, we first called attention to aspects of works we've labeled as technology-driven design, like a inclination toward CS lab study contexts and in the approaches taken (through observing interaction with a designed a prototype or applying a described methodology) for different design phases. After, we called attention to some cross-aspect observations including the link between the technology used and the focus of movement, the target users and the greater audience and goal of the paper, and the study context and goal of the study. These observations will be further discussed in relation to the experiential design analysis in the Discussion section. Additionally, we stress that our conclusions relate to the scope of this paper, as tendencies among the chosen aspects of chosen references which we use to describe technology-driven design, and not the literature as a whole.

We defined technology-driven design through example works which focus on improving gesture-based interaction through systems for supporting designer and user gesture creation/learning or through methodologies for early gesture exploration or elicitation. These works represented successful approaches for designing and testing gesture command interactions shaped by the constraints of a specific system and its purpose in a specific context. Limitations of this approach included a remaining difficulty in human-computer communication and finding novelty in gesture creation when interacting with known technologies.

2.3 Experiential Design

We define experiential design to include works with approaches that start from the conscious body and its related perception and sensation during movement and interaction. Instead of using movement and gesture as recognizable command inputs, we include works which

use technology as materiel for exploring inner sensation, to investigate movement perception and understanding among different populations, or as a resource for interaction and play, reflection, and discussion in embodied design. Our definition also encompasses works which focus on developing methodologies for interaction design with and for the felt experience of the conscious body, for which corresponding technology can then be developed.

We note that we chose these references in a similar fashion to those which populate technology-drive design: based on publication date and overall breadth of the defined design approach. As stated, these works date from the mid-2000s to the mid-2010s and either have a great impact or put main methodologies into question.

Testing a Developed System

We classify works which contribute technological prototypes and related study results as one part of experiential design. In these examples, system designers study the interaction in an artistic context such as an interactive dance performance or exhibition, which facilitates movement exploration and contemplation. Additionally, due to the artistic nature of the setup, users range in level of exposure and curiosity to similar movement-based works, a majority being those with a base interest in the body and its sensations. Design of these systems could involve integration of existing tools or methodologies from body-based practices.

For example, Loke et al. (2013) presented their system which successfully used "movement, touch, balance and proprioception as input modalities" and focused on somatic bodywork framed by the Feldenkrais methodology. The team of researchers, artists, designers, and Feldenkrais practitioners staged an event entitled the *Sensorium Gymnasium* which consisted of six experimental art pieces aimed "to translate the subtle and profound experiences of our own somatic experiments into aesthetic experiences for others." One of the pieces, Surging Verticality, consisted of a Wii fit, audio Feldenkrais recordings with headphones, and a stretchy large piece of fabric attached to the participant's heels. The pressure sensors in the Wii fit received information about the applied force from the user which, using Max/MSP[7], was translated into generated sound. Surging Verticality presented each visitor with the opportunity to probe into her sense of balance, weight change, and the notion of her own body. From analyzed audience comments, Loke et al. described audience member questioning, acquired awareness, and imagination related to balance and engagement plus the ability to ex-

[7] https://cycling74.com/products/max

periment in the open studio atmosphere and through the Feldenkrais somatic method. Additionally, they noted that not all audience members responded positively as some felt more anxious and unbalanced during the experience. However, overall, the experience allowed for audience reflection.

Another example, entitled *Seeing Movement Qualities* (Mentis and Johansson, 2013), investigated everyday user ability to visualize, understand, and also perform movement qualities through an interactive dance performance. Mentis and Johansson created an artistic installation in which users controlled professional dancer performance and music played through movements performed in front of a Microsoft Kinect. Mentis and Johansson along with a Laban Movement Analysis (LMA) expert defined Kinect-detectable movement classes which corresponded with LMA's Effort qualities of Weight, Time, Space, and Flow[8]. The team recorded with the Kinect and video camera all user interactions as well as conducted post-event interviews, and compared qualities labeled for each 15 second interaction by the LMA expert, the system, and the users themselves. Mentis and Johansson found a difference in movement quality recognition, visualization, and classification between the LMA expert and the users (only 66% agreement). Additionally, they found that in such an open context (researchers did not give any system or performance explanation), the majority of users took other strategies outside of movement qualities when approaching the system, if they felt comfortable approaching at all. Lastly, Mentis and Johansson described the two scenarios in which they thought interaction through movement qualities would be useful: for user control of the system with explicit explanation (like *A Light Touch* by Alaoui et al. (Alaoui et al., 2012)) or to support user self-reflection.

[8] http://www.laban-analyses.org/laban_analysis_reviews/laban_analysis_notation/overview/summary.htm

In these works, researchers developed systems either to offer users the opportunity to explore nuances in their movement or to examine user and expert understanding of movement qualities. The researchers approached movement-based interaction through studying the potential for technological tools to uncover new movement sensation or understanding. The technology acted as an artifact for exploration and questioning for both the users and researchers.

Presenting a Methodology

Within experiential design, we also include works which present movement-based interaction designers with different methodologies. These methodologies can encompass one or multiple phases in the design process, changing shape based on the objective of the phase. We also include

works which offer movement-based interaction designers with general strategies or guiding principles to be added to the designer's tool belt.

Comprehensive Methodology

Loke and Robertson (2013) emphasized the first-person, felt experience within human-centered design when developing *Moving and Making Strange*. Artists use the method of making strange for creation, performance, and design to uncover movement possibilities by "unsettling or disrupting habitual perceptions and taken-for-granted conceptions of the moving body" (Loke and Robertson, 2008). Loke and Robertson combined making strange with results from multiple ethnographic studies focused on the act of falling and the choreographic practices of dance makers to generate Moving and Making Strange. The researchers proposed a "toolkit" for working with three main perspectives (the mover or the first-person perspective, the observer, and the machine) and perspective-corresponding movement-based activities to support the exploration and testing of design concepts. Loke and Robertson stated that there was a need for a "methodological shift in perspectives for designers such that one of their fundamental activities is cultivating the bodily awareness of the forms, processes, and qualities of movement being considered for design." (Loke and Robertson, 2007).

Márquez Segura et al. (2016) worked to "translate the abstract theory of embodied interaction into design practice..." which culminated into the methodology *embodied sketching*. The authors defined embodied sketching as "a characterization of design practices... that foregrounds the somaesthetic experience for the exploration of, and design for particularly interesting physical experiences." Through embodied sketching, the researchers intended to place importance on ideation instead of evaluation, incorporate the felt experience earlier than usual when completing movement-based design, and incite creativity through play. They introduced multiple implementations of embodied sketching through the following scenarios: 1) bodystorming (Schleicher et al., 2010), a method during which designers use enactment for situated prototyping; 2) participatory embodied sketching, in which potential users manipulate an existing prototype and facilitators and surprisingly the users themselves adjust the socio-spatial configuration in order to encourage interaction creation; and 3) designer sensitization, in order for a designer to question and reflect on the first-person perspective and felt experience of a design. In the end, the researchers uncovered the strength in applying different implementations of embodied sketching for different moments, stakeholders, and

degrees of establishment of the prototype or idea(s) within the design process.

In these works, researchers presented comprehensive methodologies to include the first-person perspective, felt experience and the somaesthetic experience in a variety of design activities. These teams therefore approached movement-based design through the development of methodologies as guidance for others designers. In the next section, we present works in which either through compiling design examples or speaking with experts in the field (including expert self-reflection), researchers delivered findings as tools for movement-based interaction.

Tool Belt of Strategies and Guiding Principles

Some teams utilized Research through Design (Zimmerman et al., 2007), presenting design exemplars and lessons learned for other designers. For example, in *Move to get Moved*, Hummels et al. (2007) presented their exploration of the notion 'interaction creates meaning' through interactive systems or methodologies like the Design Movement Approach and the Choreography of Interaction (in which "design is focused on creating activities and movements"). These projects and the resulting lessons learned culminated into 7 guiding principles for movement-based interaction including the richness over the tangibility in interaction and the need to design through moving and interaction.

Another examples is Höök et al. (2018)'s work unpacking and explaining the strong first-person perspective through: soma-based design exemplars; methodologies like disrupting the habitual and autobiographical design; and theoretical underpinnings like Merleau-Ponty (1996)'s phenomenology of the body and definition of the first-person perspective, Dewey (2005)'s aesthetic experience, and Shusterman (2008)'s somaesthetics. With this philosophical framing, Höök et al. engaged in a conference workshop, interacting with some participants' design exemplars, and discussing approaches for attending to the designer's bodily self while working with design materials. The patterns recognized from the spectrum of exemplars, which is presented to readers as an annotated portfolio (Gaver and Bowers, 2012), and the selection of author-employed, soma-based design methodologies, aligned with the importance of first-person perspective attendance and awareness development.

Others employed empirical methods like autoethnography and inter-

view analysis to uncover design implications. Höök (2010) dug deeper into designing for the felt experience of the body through her autoethnographic study of horseback riding. Seven themes emerged including: the delicacy of signals sent between two independent agents; the continuous transition between viewing the body externally and the sensations experienced internally, and how understanding that relationship can lead to improved expression of experienced moments; and the importance of rhythm and balance as aesthetic experiences. She transformed these themes into clearly applicable design implications such as the need to incorporate rhythm into aesthetic experience design and the emphasis on silent, sensitive signals that lead to a partnership of mutual understanding.

Through interviews with prominent researchers in embodied design, Alaoui et al. (2015b) uncovered methodologies and challenges of movement (self)observation, an irreplaceable tool for deciphering and translating felt experiences for easier adoption. The authors brought to light and formulated the following techniques: attunement (as preparation for observation), attention (to own experience or to patterns among others and their surroundings), and kinesthetic empathy (in order to feel with other body/ies). They reported on the frustrations of fluctuating between the "inner embodied state" and the "outer design mode" and expressing felt experiences in textual language not only for self-understanding but also while communicating with other stakeholders.

Researchers discussed, reflected on, and interacted with each other and their projects in order to uncover overarching themes and concrete tools for movement-based interaction design. As in the previous section, these researchers approached improving movement-based design with guidance for other designers and researchers. However, in this case, the tools came in the form of guiding principles for the design tool belt.

Summary

Table 2.3 presents eight examples of experiential design research, including the target users, study context, intended design phase, and focus of movement. Bold examples are tested prototypes while non-bold examples are developed methodologies.

Table 2.4 identifies the overall goals of each study in Table 2.3. As before, we see a relationship between the approach, e.g., testing a developed system or presenting a new methodology, and the target user

System	*Target Users*	*Study Context*	*Design Phase*	*Focus of Movement*
Re-sensitising the Body	End Users	Artistic Exhibition	Prototyping	Nuance of Movement & Sensation
Seeing Movement Qualities	End Users	Interactive Performance	Prototyping	LMA's Effort qualities
Moving & Making Strange	Designers	Immersive Space	Structuring Exploratory Activities	Felt Experience
Embodied Sketching	Both	in-situ	Structuring Exploratory Activities	Felt Experience
Move to get Moved	Designers	Diverse	Structuring Exploratory Activities	Interaction Perception
Embracing First-Person Perspective	Designers	Workshop	Throughout	Felt Experience
Transferring Qualities	Designers	in-situ	Throughout	Felt Experience
Strategies for Embodied Design	Designers	Workshop	Throughout	Felt Experience

Table 2.3. Examples of Experiential Design Research

group, i.e. end users or designers. These studies involve diverse settings, with a special emphasis on artistic contexts. Here, the foci of movement often encapsulates subtle aspects of movement, such as sensation and perception, which as seen, technology-driven design tends not to address.

We highlight three relationships between pairs of aspects:

Focus of Movement and Technology: We see a link between a study's focus of movement and the presence of the technology. The only example in which researchers included clear movement definition was "Seeing Movement Qualities," in which researchers studied end user understanding through system interaction. Otherwise, the focus of movement included elements of movement not specifically apparent to an outside observer or directly recognizable by a system like the felt experience and sensation perception. In these studies as well, if hardware or software technologies were present, researchers used them as "design resources" (Márquez Segura et al., 2016). Additionally, the possible movement and body parts used were boundless. We concur the aspects and diversity of types of movement explored relate to the technology's presence and use during a study.

Target Users and Goal: Additionally, we notice the personal inclusion that the goals subtly describe even when the target users are end users. To start, the goals include terms such as "the central role of the body" and "bodily experiences," exhibiting a encompassment of all possible users since as humans, we each have a body through which we ex-

System	*Goal*
Re-sensitising the Body	"To translate the subtle and profound experiences of our own somatic experiments into aesthetic experiences for others"
Seeing Movement Qualities	"To situate the perception of movement qualities – both in terms of perceiving one's own movement qualities as well as perceiving the qualities in another's movements"
Moving & Making Strange	"An approach to movement-based interaction design that recognizes the central role of the body and movement in lived cognition"
Embodied Sketching	"A way of practicing design that involves understanding and designing for bodily experiences early in the design process"
Move to get Moved	"Illustrate... which kind of methods, tools, knowledge and skills can help designers become and act as experts in movement-based interaction"
Embracing First-Person Perspective	"Unpack one of the design sensitivities unique drawing performable and measurable motions to our practice: a strong first person perspective"
Transferring Qualities	"To shed some light on... What are the possible bodily experiences we may aim to design for, and how can we characterise them?"
Strategies for Embodied Design	"Investigate the value and challenges of observing movement experience in embodied design"

Table 2.4. Experiential Design Example Goals

perience the world. Additionally, in studies for end users, the goals represent either translating experiences for others to feel or studying a concept like movement perception but within the plural context: the user, expert, and researcher movement perception of themselves and others. In studies for designers, the inclusion is also present in supporting other designers to become "expert in movement-based interaction" or in questioning "bodily experiences we may aim to design for."

Study Context and Goal: Lastly, we note a tendency between the contexts (outside of the lab) and exploratory goals. Study contexts were either artistic, interactive, or realistic (in-situ). The goals invoked ideas of questioning through "investigat(ing) the value and challenges" and "shed(ding) light on... possible bodily experiences".

During analysis, we brought attention to aspects of our labeled experiential design works including the increased presence of subtle aspects of movement representing the foci of movement and the link between the approaches taken (through studying interaction with a technological probe or developing a methodology) and the target users. Additionally, we again pointed out cross-aspect observations including the correlation between the focus of movement and the technology use, the target users and the audience of the goal, and the study goals and contexts. These observations will be further examined in relation to technology-driven design in the following section. Again, we stress

System	*Target Users*	*Study Context*	*Focus of Movement*	*Goal*
TDD Prototypes	Both	CS Lab	x-y-(z) Tracked Changes	Support users & designers in gesture design or learning
TDD Methods	End Users	CS Lab/in-situ	x-y-(z) (Non)Tracked Changes	Explore (all) possible mov'ts & uncover user gesture behavior
ED Prototypes	End Users	Exhibition	Sensation & Qualities	Translate or understand mov't sensation & qualities
ED Methods	Designers	in-situ & Workshops	Felt Experience	Support design for the experiential body

Table 2.5. Overview of Analysis: (TDD: Technology-Driven Design, ED: Experiential Design)

that our conclusions relate to the scope of this paper, as we consider tendencies among the chosen aspects of chosen references to describe experiential design, not the literature as a whole.

We defined experiential design through selected works which place priority on listening, perceiving, and communicating the felt experience of the conscious body in order to a) design systems for supporting or uncovering nuances in movement exploration or understanding; or b) integrate the felt experience into movement-based interaction design. These works successfully translated sensual experiences into technology-infused exhibitions and design guidelines. Limitations included continued difficulty in a) communicating and sharing felt experiences and b) system and method approachability for non-experienced, hesitant users.

2.4 Discussion

Study aspects, such as users and context, encourage research projects to develop certain atmospheres, values, and relationships between the user and the researcher. For example, our analysis of technology-driven design identified that: a) the positioning of technology constrains the possible movement so that it can be detectable, therefore, influencing the focus of movement for a study; b) in technology-driven design, though the audience of a work is system designers and researchers, the target users tend to be non-technical end users and interaction designers; and c) the positioning of the technology leads to studies conducted in computer science research lab settings.

These examples suggest that we create study scenarios in which researchers remain distant and observe untrained users as they develop the movements that they would like, given the constraints implicitly produced by the device and its positioning. We thus find outcomes with respect to gesture vocabularies to be unsurprising and heavily influenced by industry norms.

Similarly, from our experiential design analysis with its different positioning of technology and the related a) exploratory context with b) researchers and potential users, and c) an unstructured openness toward movement, we uncover difficulties in system approachability due to a lack of structure and in recognizing and translating perceived sensations into a shareable format.

We therefore would like to re-imagine the relationships and values within the two design approaches defined above by altering analyzed aspects and discussing potential outcomes.

Integrating the First and Second Person Perspective into Technology-Driven Design

As previously stated, technology-driven design results in a researcher role of outside observer, tracker, and analyzer of the set of users, meaning she takes the third-person perspective. On the other hand, experiential design incorporates more first- and second-person perspectives as researchers and users alike can observe and communicate perceived sensations. We could imagine integrating first- and second-person perspective into technology-driven design by including a movement exploration phase during gesture design or elicitation with a subsequent discussion of user inner sensations.

What impact would this integration have on a technology-driven design study? We hypothesize that the researcher would then take a more personal approach to observing the user, incorporating techniques such as attunement, attention, and kinaesthetic empathy. The researcher would also explore the user performed movements herself. The roles of user and researcher would then approach each other, meaning the study would have less of a performance-feel and act more as an exploration with play. We speculate then that designed gestures would expand past industrial standards. We imagine gesture innovation and discovery of more innate user behavior when placing importance on activities supporting the first- and second-person perspective in technology-driven design.

Integrating Structure for Movement Capturing into Experiential Design

As previously mentioned, in experiential design, the felt experience has a central role. The technology is positioned to support the user in this process as a design resource or material through which the user can experience novel sensations within an exploratory context such as

a workshop or immersive space developed by or with the researcher. However, what if we want to capture and analyze movement from a workshop?

As seen in technology-driven design, we imagine the potential constraint if we explicitly include tracking technology like mobile phones or wearable sensor. A first-person perspective post-session with a Body Sheets (Tennent et al., 2020) is another option for capturing movement data from a workshop. However, the nuance in personal reflection of sensation would hinder the possibilities of creating a sort of standardized translation for capturing. Therefore, we could imagine an outside viewer, like a video camera or an expert annotator, translating the movement from a session into a standardized language. We note that for LMA, for example, Bernardet et al. (2019) found that inter-rater reliability ranged from weak to acceptable. However, a single LMA expert transcribing could give standardized interpretation and translation of movement from a movement exploration session that could be used to capture the movement. Finally, the inclusion of an outside expert viewer could change the trusting atmosphere and the user-researcher relationship of the experiential design study.

Methodological Impact and Limitations

We highlight the limitations of our design re-approaches since the overall movement- and gesture-based interaction context played a large role in their development. We defined both technology-driven design and experiential design in relation to a split within movement- and gesture-based design, displayed through events like the commercial explication of "Natural User Interfaces" and the integration and expanded discussion of somatic practices and phenomenology into HCI. As Bødker (2006) noted, with more ubiquity in technology comes a broadening of contexts; therefore, we paid high attention to the context and environment within each defined approach. We do realize, however, that research on movement- and gesture-based interaction with more ubiquitous technologies has been around for much longer. We therefore chose references that situated within our selected time range and which either presented or questioned the status quo being developed, especially methodologically. Because of our interest in understanding the implications of these trending yet divergent approaches, we specifically looked at contextual aspects of a system within the study ecosystem, e.g. greater goal of the authors, target users, study context, etc. These chosen aspects led to a discussion therefore related to resulting study atmosphere, values, and relationships. We could imagine very different design re-approaches if, for example, we chose

to highlight the variety of definitions for gesture within the related timeline and context or if we followed the evolution of gestures in relation to developing technology. However, by framing this comparison through divergent trends which arise from reactions to particular movement technology development, we extract opportunity from opposition, contributing relevant, re-imagined design approaches and therefore participating in the advancement of movement-based interaction design.

2.5 Conclusion

Inspired by research trends beginning in the early 2000s, we define and compare two approaches to gesture- and movement-based interaction design: *technology-driven design*, which focuses on improving command-based interaction with a specific technology in a specific context, and *experiential design*, which focuses on integrating and uncovering the felt experience in interaction. We illustrate our definitions by categorizing selected related works, and analyzing each based on specific aspects of the study, including: study context, design phase, and focus of the movement. We present relationships between pairs of aspects, such as the link between the target users and the overall study goal, and compare them. We also discuss the atmosphere, values, and user-researcher relationships that result from configuring different elements from each design approach. We conclude with insights for re-imagining these approaches when elements of each are integrated into the other approach and the resulting impacts on study outcomes.

3

Background

This chapter presents related literature, highlighting the tension between movement codification and sensation. I begin by discussing how western dance styles like classical ballet, modern, and contemporary dance developed, and the balance between the first and third-person perspective for the dancer. I include a review of dance learning systems and choreography support tools in HCI, commenting on influences to include quantitative or qualitative representations of movement.

3.1 The Evolution of Codification in Ballet-influenced Dance Techniques

La danse, c'est une énergie, pas une suite de positions et de figures. C'est un mouvement que l'on sent à l'intérieur et qui se voit de l'extérieur.
-Wayne Byars[1]

[1] Dance is an energy, not a series of positions and figures. It is a movement that you feel inside and that you can see on the outside.

Classical ballet is a highly codified style of dance that finds its roots in Italian and then French courts (due to the marriage of Henri II and Florentine Cartherine de Medici) during the 15th and 16th centuries. Over time, the simple and elegant social dance performed as a part of artistocratic banquets and masquerades transformed into an art form of "intense and exact classicism" studied since the founding of the Royal Academy of Dance in Paris in the 17th century. Since then, classical ballet spread and developed stylistic differences mainly in countries including England, the United States, Russia, Denmark, Italy, and

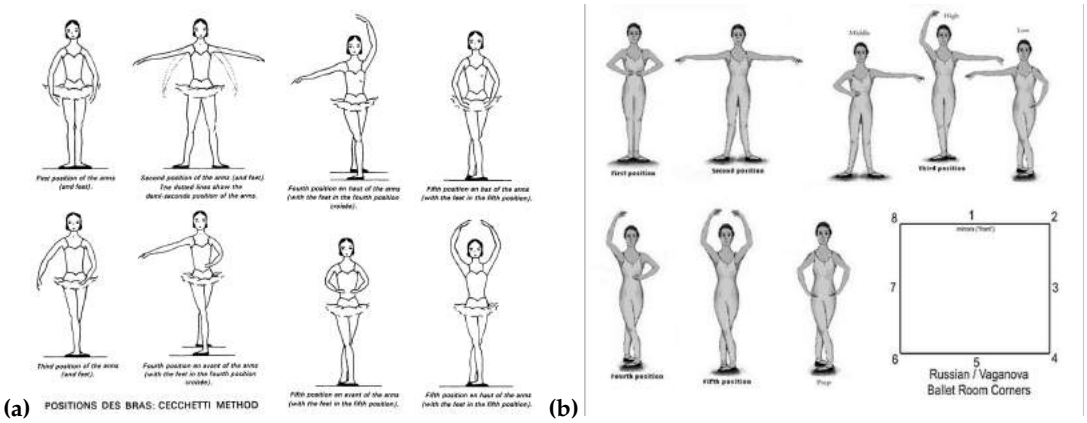


Figure 3.1. The Basic Body Positions in the Cecchetti method (left) and the Vaganova method (right), which are very similar, yet have distinct differences in the 1st and 4th positions specifically.

France (Franko, 2012). Though the exact positioning of the hands or strictness of the technique differ across countries, the basic vocabulary of positions and steps remains similar if not the same. As an example, notice the overall similarities between the basic arm and feet positions in the Cecchetti method (Italian, left)[2] and the Vaganova method (Russian, right)[3] in Figure 3.1; and yet, notice also slight differences in, for example, 1st and 4th position of the arms.

Ballet's strict, outwardly defined codification sparks from the context of the first performances and the importance of etiquette during that time. Under King Louis XIV, ballet master Raoul Feilleut (among others including Pierre Rameau and Pierre Beauchamp) helped transform classical ballet from *la belle danse* into an art, a technique, with a great interest in "categorization and codification". He took a bird's-eye view to the performance floor, designing symmetrical figures (see Figure 3.2 (Zbikowski, 2014)) for dancers to follow, and not forgetting to begin and end the performance facing the king (or each other). He also defined positions of the body so that the dancer's posture would portray a sense of ease, "to avoid falling into the 'humiliation' of stiff, harsh, or affected movements." Following the initial codifications by Beauchamp, Feuilleut laid out the five noble positions of the feet, all with a 45 degree angle outward, to avoid seeming awkward. These five positions, among other ensuing definitions, sourced from the hierarchies and rules of the men and women of the court, and began the creation of classical ballet as a dance technique (Franko, 2012).

However important it was for dancers to keep to the correct positions of the body and the defined directions of movement to follow the rules of etiquette, the story and the potential to get closer to God were also important. During the 16th century in France, which was riddled with civil and religious conflicts, the Academics of the *Académie de Poésie*

[2] https://balletclassroom.wordpress.com/positions-of-the-feet-and-arms-cecchetti-method/

[3] https://balletaz.org/classical-ballet/

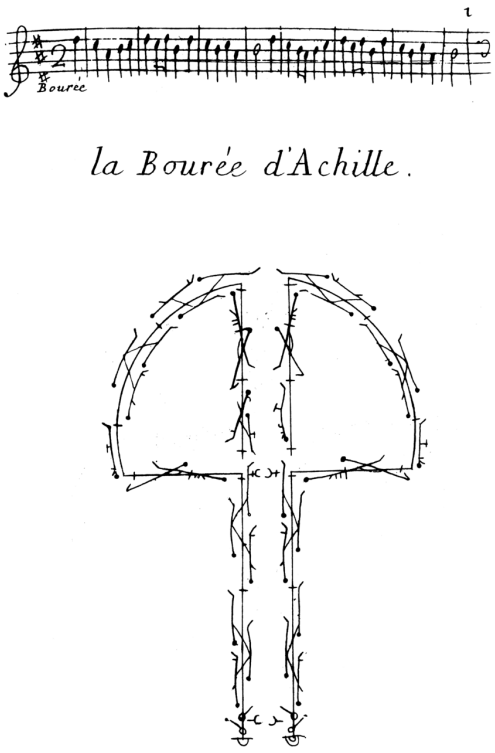


Figure 3.2. Example Score by Feilleut for a the ballet *La bourée d'Achille*

et de Musique, among others, "saw ballet as a chance to take man's troublesome passions and physical desires and redirect them toward a transcendent love of God." As Homans states: "The movements of the body, disciplined with poetic rhythm and meter and brought into accord with musical and mathematical principles, could tune him (man) into celestial harmonies." Therefore, for both the viewer and the dancer, stories like *Ballet comique de la Reine*, which recounted the tale of the gods Jupiter and Minerva defeating the enchantress Circe, had a greater meaning (Franko, 2012). Alongside the work to learn the developing technique, ballet performers also had the job of creating an experience during which themselves and the audience ascend beyond the earthly, bodily realm and closer to the realm of the angels.

Today, as we can view the ballet technique outside of the court context, dancers train the positions so they can move beyond them. As Wayne Byars[4] (world-renowned ballet teacher, based at *le Studio Hamonic* in Paris, France) recounts in his book *Leçons de danse, leçons de vie* (Byars and Karam, 2017)[5], training in ballet means training the body to be strong in the set positions and movements in order for the body to find total trust in itself and therefore, a sense of liberty, an ability to fly. He gives the example of the exercises at the bar, in which a dancer lightly rests one hand on the bar while working the other side

[4] `https://www.studioharmonic.fr/professeur/24-wayne-byars/`

[5] Dance Lessons, Life Lessons

of the body, used to structure the "warm-up" exercises in the class (see Figure 3.3[6]). He says: "The bar illustrates and highlights one of the great truths of the classical technique: this freedom of movement that we seek and that is rooted in the constraint." He then adds that by continuously developing and strengthening the dancer's roots in the constraints of the technique, and at the same time, while keeping the self listening and open to new sensations, the body can find total mobility and experience novel and rich sensations, letting the person be transported to the unknown. In the end, he describes the relationship between technique and sensation, between training outer-recognized forms and inner felt sensations, and notes the importance of involving both: "You have to know how to position yourself between the two poles: sun and moon, intellect and intuition, knowledge and feeling."

[6] https://www.royalballetschool.org.uk/2020/08/16/online-summer-intensive-2020-your-response/

Figure 3.3. Members of the National Royal Ballet Summer Intensive Completing Exercises at the Barre in a Ballet Class

At the turn of the 20th century in the United States, modern dance emerged as a rebellion against the two major dance forms present at the time: classical ballet (see above) and vaudeville (theatrical dance of the time[7]). These artists "rejected what they interpreted as the rigid and imperialistic nature of ballet"[8]. Modern dance artists wanted to be considered as serious performance artists, so they had to fight to position themselves in relation to the current techniques of the day.

[7] http://web-static.nypl.org/exhibitions/vaudeville/dance.html

[8] https://artsintegration.com/wp-content/uploads/2015/05/Modern.pdf

In renouncing the strictness of the developed ballet technique, each modern artist developed a structure through which they shared their ideas or created performances. For example, Martha Graham, a first generation modern dancer, developed a system of movement called "contraction and release" which led to her angular looking movement. Lester Horton developed the Horton technique, which includes 17 fortification studies, each exploring a different idea like laterals or ascent/descent. The Horton technique manifests on stage through pre-

cisely defined shapes and forms, with different energies and qualities defining the trajectory[9]. Horton rejected the themes of classical ballet as well, often exploring political subjects in his works. Second generation (after World War II) modern dance choreographer Merce Cunningham dropped the dramatic aspects of ballet in favor of exploring the impact of chance procedures in his work. His developed technique emphasizes spatial and rhythmic awareness[10], in order to be able to divide and quantify order and directions of a performance piece that can change according to the numbers the dice roll right before. Whether focused on body tension or geometric forms, modern dance artists codified movement around different themes than classical ballet, which led to not only novel inner sensations, but also outwardly viewed qualities.

[9] https://www.dancespirit.com/horton-technique-2326036575.html

[10] https://www.mercecunningham.org/the-work/cunningham-technique/

Contemporary dance techniques (literally meaning the dance techniques being developed today) continue to push the limits in terms of how to structure and define movement; nonetheless, choreographers re-approach the tension between the viewed and the sensed through different methods. Ohad Naharin, creator of the Gaga movement language[11], structures his warm-up classes around a vocabulary specifically meant to activate physical sensations. As a result, audience members describe Gaga dancers as having "liquid" movement [12]. Myriam Gourfink writes scores in her compositional language, based in Labanotation[13] with additional signs representing concepts in energy yoga, to structure the overall trajectory of a dance piece[14]. During choreographic creation, dancers frame self research around these scores, a structure through which the dancer can follow inner urges of the body. The labanotation represents the third-person viewable part of the dance (which arm is in motion, the direction in which the body is facing, etc.) (see Figure 3.4 bottom half) while the energy yoga symbols represent bodily-based visualizations which support the inner urge research (see figure 3.4 top half). By creating scores or vocabularies which evoke specific sensations, contemporary dance continues to question the relationship between the captable and the sensable.

[11] https://www.gagapeople.com/en/

[12] https://artsintegration.com/wp-content/uploads/2015/05/Modern.pdf

[13] https://labaninstitute.org/about/laban-movement-analysis/

[14] http://www.myriam-gourfink.com/biography.html

As dance techniques develop in the western world, the relationship between the felt experience and the audience-viewed structure has shifted, but remained tense. In classical ballet, the urge to connect to the gods through the vocabulary of the technique transformed into the need to fly through developed movement liberty as the technique emerged from the royal court context. Modern dance techniques embraced new sensations through the structuring of other frames of seeing movement, like geometrical shapes or inner tensions. Contemporary choreographers, surprisingly similarly to the academics of the

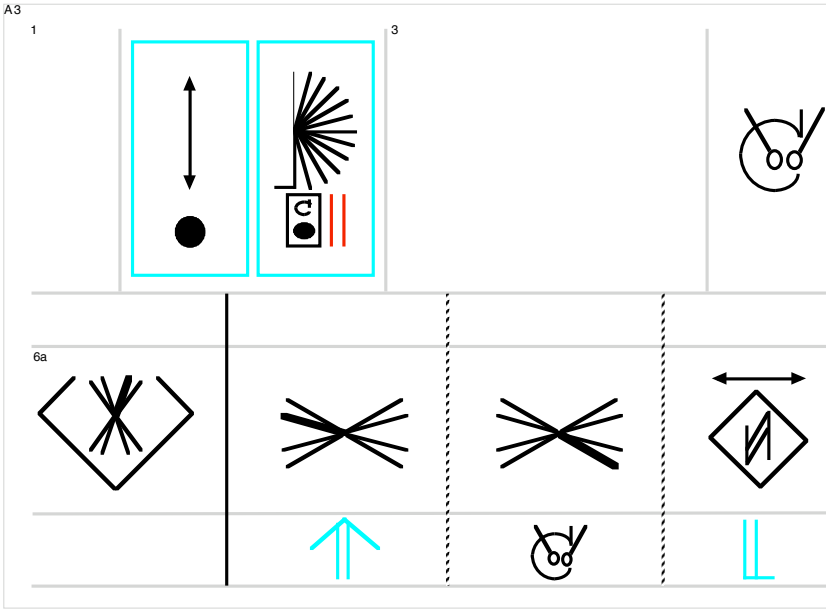


Figure 3.4. A page from the score of Myriam Gourfink's piece *Les Temps Tirallés*

17th century, sometimes even work to create structure that leads to specific sensations that then inevitably change movement quality. Therefore, over the centuries, dance artists have embraced and explored the tension between the first-person experience and third-person poses through technique and creation.

3.2 Dance and HCI

As Zhou et al. (2021) discuss, the HCI community often confronts the tension between the quantifiable and not-even-verbalizable. Strict dance techniques include vocabularies that can be segmented, defined, and analyzed, creating a straightforward springboard for technology design. However, systems which build from obvious dance structures risk excluding the sensorial experience of the body in motion. I demonstrate this tension in the HCI literature by reviewing technologies present in the studio, as a classroom or rehearsal space, and toward which tendency they lean.

Dance Learning Support Systems

In their literature review of "Dance Interactive Learning Systems" (DILS), Raheb et al. (2019) analyze the works in relation to, among other

things, the teaching approaches applied. They describe the approaches as follows:

- Mimetic: Students imitate the teachers movement
- "Traditional": Where the right/wrong paradigm is firmly present and precision of performance is king, the teacher makes decisions, and the students follow those decisions;
- Generative: Students learn through creation, based on a phrase or exercise given by the teacher
- Reflective: Students are given an open task, without a specific movement phrase to master, though the teacher can still give feedback throughout the exploration

They explain that over the years, generative and reflective approaches have emerged over the more traditional approaches; however, DILS tend to apply mimicry as a teaching approach.

Raheb et al. also divide the literature according to the type of technology used. They categorize them as follows:

- Desktop: "Support the more theoretical aspects related to dance practice" and take the form of "videos, audio, explanations of techniques, animation, annotation tools"
- Mobile Apps: Similar to desktop applications, but allow for smartphone capture of movement
- Whole-Body Interaction: These technologies capture detail in movement; therefore, they are able to provide specific feedback about a specific movement feature
- Augmented Reality (AR) /Mixed Reality (MR) /Virtual Reality (VR) Environments: Support real-time capture for feedback and allow for visualization of the teacher

As will be presented, the capabilities of each technology form support different types of teaching and what type of feedback is given to the dancer based on the type of data that can be captured.

Mimicry and Right/Wrong Feedback: When capturing full-body movement with a Kinect or MoCap system, researchers have the techno-

logical capabilities to present the student with an expert example of movements and correctional feedback to the student, usually with the goal of teaching a specific technique. Marquardt et al. (2012), Anderson et al. (2013), and Trajkova and Cafaro (2018) build off of the mirror idea in a studio context to create Kinect-based tools and feedback to teach classical ballet. To teach movement shape (Aristidou et al., 2014) and rhythm (Kitsikidis et al., 2015) in traditional Greek dances, students follow the teacher avatar and receive corrections on their desktop, along with deeper historical information, among other things, about the dance itself. Alexiadis et al. (2011) built a similar system to the previous two, but did not test it with a specific style of dance. Thiel et al. (2014) used accelerometers to track movement data for basic ballet movements and compare that data to that of an expert, studying the possibility to give biofeedback in ballet training. Students can also follow an avatar in a virtual reality, correctly learning classical ballet (Kyan et al., 2015), hip-hop, or Go-go moves (Chan et al., 2011). With advances in deep learning, some question the possibilities for sharing objective feedback of tacit knowledge (Trajkova, 2020) while others question the smooth integration of AI into the dance class structure (Wang and Zheng, 2020). For now, to support dance video tutorials (which inevitably come in specific dance styles), Lee et al. (2020) built a mobile application which incorporated deep learning for pose recognition to evaluate and share with the user movement similarities between user and teacher. In each of these examples, movement capture systems track, recognize, and compare movements and poses between an expert and a novice, so that the student can mimic the teacher and the system can tell the student how to perform the movement better.

For partner dance styles, completing a step correctly means having the right rhythm and understanding how to use feedback from the partner. Researchers used sensors on the shoes (Drobny et al., 2009) and smartphone accelerometers (Dias Pereira dos Santos et al., 2017) to sense user steps, and then gave musical and visual feedback to emphasize and keep the user moving to the beat while latin dancing. Researchers also built robot partners (Kosuge et al., 2003; Nakamura et al., 2005) or used a combination of haptic, visual, and audio feedback to act as the feedback from a partner (Drobny and Borchers, 2010; Saxena et al., 2014). Lastly, the creators of Happyfeet (Alizadeh et al., 2016) used body capture to display on a screen the user's feet with a partner's feet to dance together when they are not in the same shared space. When researchers build off of partner styles of dances, mimicking the teacher is not enough, as the student must learn how to dance with another body as well, even as a beginner.

Learning Choreography: Mimicry of Video with Annotated Feedback Technological tools aid with learning pre-set movement by allowing for teacher feedback to overlay video content that the dancer needs to mimic and then embody. The Choreographer's Notebook (Singh et al., 2011) and DanceNote[15] are two video annotation platforms studied in the context of choreography re-setting for future performance. dos Santos et al. (2018) and Hsia et al. (2016) explored how teachers can assess their students or how peers can give corrective feedback through video annotation. Developers of both Piecemaker[16] and Moveon (Rivière et al., 2019) deployed their tools in a greater variety of research settings, to better understand the greater relationship of annotated video, scores, and archiving, and how dance students learn choreography. Overall, these tools support choreographers in adding more information to a pre-developed phrase or piece that the student learns. This information could go beyond critique of the student movement into movement quality, imagery, or sensation, for example.

[15] https://www.lafabriquedeladanse.fr/dancenote/

[16] http://motionbank.org/en/content/education-piecemaker.html

Supporting the Teacher: Open-Ended Feedback Some tools have the goal of supporting the teacher within the classroom; therefore, researchers design them to give open-ended augmented feedback, which gives additional information without specifically telling the dancer whether their movement is correct or how to improve it. Open-ended feedback visualizes or sonifies movement to give new information for discussion among teachers and students during class. Defined by Turmo Vidal et al. (2020) open-ended augmented feedback is: "feedback that is open to interpretation, and upon which trainers and trainees can construct their own meanings, that can be leveraged during training." For example, Hallam et al. (2014) created a suit with lights on it for the teacher to wear during a ballet class to highlight specific features of movement the teacher wants to teach. Camurri et al. (2016) built a system with inertial sensors and sonar feedback to help teach coordination and dynamics of the body. Großhauser et al. (2012) sonified ballet jump landings. With open-ended feedback, researchers design systems to capture or track defined movements or parts of the body, but present the user with visualizations or sounds that teachers can use in classroom settings to teach correct movements in specific techniques.

Supporting Self-Reflection with the Reflective Teaching Approach: Systems which integrate a reflective learning approach usually quantify movement during movement capture, but support sensation exploration through the method of information presentation to the dancer. Capabilities of mixed reality (MR) technology allow for dancers to view themselves and a partner or teacher from both the first and the

third-person perspective (Hachimura et al., 2004; Yan et al., 2015). Mobile augmented reality (AR) also allows a student to watch and learn from an avatar expert (Iris and Liarokapis, 2020). Choreomorphy (Raheb et al., 2018), which can interface with multiple motion capture and visualization systems (big screen, AR lens, etc.), allows the dancer to view an augmented self with different visualizations. Molina-Tanco et al. (2017) took a different approach to the ballet mirror by creating the Delay Mirror which projected completed exercises of the students but with a small delay, for student and teacher viewing and reflection. Alaoui et al. (2015a) created an reflexive system with an interactive mass-and-spring visual to support expert dancers in understanding Emio Greco's movement qualities. Leijen et al. (2009) studied video annotation specifically for individual student self-reflection. Reflective systems capture dance movement quantitatively, but present the user with visualizations specifically for exploration and contemplation, outside of any specific dance technique or goal-focused activity.

Generative Learning: Tools and Potential Tools Not many dance tools within HCI incorporate generative teaching methods, and when they do, often it is to replace the generative activity itself. At Ohio State University, dance majors utilize LabanLens[17] which supports students creating scores to analyze dance by augmenting reality with Labanotation[18]. Ramadoss and Rajkumar (2007) created a data base tool for annotating, searching, and accessing audio-visual dance media, which could be used as source material for student-generated phrases. The Ballet and Contemporary Composition systems (Soga et al., 2009; Umino et al., 2009) generate logical combinations of movements for ballet and contemporary students to practice exercises. Yang et al. (2013) created a system that generates lesson plans for beginner dance students to learn on their own. These tools offer students not only content for practice at home, but act as a base for solo-generation of new dance phrases.

[17] https://dance.osu.edu/labanlens

[18] https://www.britannica.com/art/labanotation

Conclusion Dance learning support tools tend to take a third-person view of the body, leaving sensation exploration up to the dancer or potentially the teacher. When evoking learning through mimicry, especially with traditional methods of correction, technologies build upon systems to capture, quantify, recognize, and track different bodies for comparison and terminal feedback. Even with systems designed to give more open-ended feedback instead of giving the dancer the red or green light, the use context remains a corrective setting, where the teacher can use the visualization or sonification of movement to tell the dancer how to improve. The technology or design used in reflective tools intend to support exploration in an open space, which works well

for experienced dancers, but does not openly attend to the first-person perspective, meaning those less knowledgeable might not be able to follow along. Therefore, the overall tendency in the context of dance movement learning leans toward body capture and tracking from the outside perspective, structured around a specific technique.

Dance Choreographic Systems

Alaoui et al. (2014) categorized choreographic, compositional tools into four categories:

- Reflective: "abstract movement material provides new options for perception of movements"
- Generative: "creates new movement material"
- Interactive: "transforms movement material based on user interaction"
- Annotative: "annotates and views movement material"

Systems in each of four categories have different goals, and each integrate structure in different ways.

Reflective Reflective choreographic support tools visualize inner structures of movement to bring awareness to potentially unnoticeable patterns and habits within a piece. The tool *Synchronous Objects*[19] overlays video of William Forsythe's piece *One Flat Thing Reproduced* with visuals, bringing cues and initiations of movement to light (Palazzi et al., 2009). The CD *Improvisation Technologies*[20] and the DVD *Capturing Intention* (Sicchio, 2014) work similarly, overlaying video with geometrical shapes representing Forsythe's beliefs on the relationship between movement and space, or Emio Greco's defined movement qualities. ActionPlot (Carlson et al., 2011b) codifies and plots data points seen by expert viewers in choreographic pieces in order to find patterns. These tools facilitate reflection by plotting or augmenting third-person viewed video movement with visual structures reflecting first-person experiences or exteriorly-viewed patterns across pieces.

[19] https://synchronousobjects.osu.edu/

[20] https://www.williamforsythe.com/filmspaces.html

Generative These tools generate new material based on pre-defined libraries or rules for choreographers to use and meld. Researchers at the Simon Fraser University created LifeForms, now called DanceForms, a software built for Merce Cunningham which animates possible phrases in the Cunningham technique (Schiphorst et al., 1990)

or, in the *Tour, Jété, Pirouette* (Yu and Johnson, 2003) project, the Cecchetti ballet technique. The CorX system (Bradford and Côté-Laurence, 1995) generates instructions for a dancer while performing, giving new direction, speed, pathway, or action to integrate. The Scuddle system (Carlson et al., 2011a) generates movement catalysts made up of information on body posture, height of execution, and movement qualities meant to support choreographer reflection of movement habit. Advances in artificial intelligence allows for tools that are both generative, feeding the choreographer new movement material, and interactive, responding to the choreographer's movement in the moment. Researchers at Georgia Institute of Technology created LumenAI (Liu et al., 2019), a creative collaborative agent that improvises with the choreographer. Google and choreographer Wayne McGregor explore this technology in their Living Archive project[21], in which they trained a neural network on McGregor's vast database of rehearsal and performance video. Other researchers trained similar systems on other choreographer's works (Crnkovic-Friis and Crnkovic-Friis, 2016)[22]. Generative tools need a structure through which to define and generate new movement, but depending on the defined scheme and inputted data, can change according to the choreographer's or designer's interests.

[21] https://artsexperiments.withgoogle.com/living-archive

[22] https://peltarion.com/customer-stories/teaching-ai-to-dance

Interactive Interactive choreographic tools support movement exploration, receiving new information from the system through system reaction to movement. For example, Hsueh et al. (2019c)'s Choreoprobe presents dancers and choreographers with improvisation support through visualizations that replicate users' movements, but with different qualities. EyesWeb (Camurri et al., 2000) works similarly, responding to the dancer by providing real-time animations with specific movement qualities, defined with Laban Movement analysis (LMA) movement components. These interactive systems track the dancer's movement and use this information to influence the next action of the presented output, which in this case, is a different visualization.

Annotative Video annotation tools utilise similar technologies for both dance learning and dance creating, but include utensils that support idea reflection and generation rather than correction. Modalities of annotation included in Transmedia Knowledge Based creation tool (Cabral et al., 2011) and the Video Traces system (Cherry et al., 2003), which include text and pen-based input or verbal and gestural input, support choreographers in noting important parts of dance movement creation on live streamed or pre-recorded phrases. Ciolfi Felice et al. (2018) integrated video and annotation into their constraint-based tool Knotation, which allows choreographers to sketch the structure of their

piece. These annotation tools support choreographic reflection by allowing users to instantaneously add thoughts to video-recorded movement in and out of the studio.

Conclusion Within the field of choreographic support tools, there is a still a large focus on visual tools, inherently leading to a third-person perspective view. Instead of a technique, researchers design structure around a choreographer's style, meaning a basic understanding of the style is necessary. For some choreographers, this means a specific structure to make visual the first-person perspective to appeal to the felt experience. However, I question how to make these developing choreographic methods for accessing the felt experience and exploring movement in the flow approachable for non-knowledgeable dancers without defaulting to mimicry or well-known techniques (e.g. the ballet vocabulary) and generalizable so that any dancer can appropriate and make these methods their own.

Even though western dance styles inherently recognize and play with the link between movement as seen by the audience and movement as it is felt by each dancer, the HCI community, with a focus on supporting specific tasks through specific technological attributes, usually address one or the other (or generally, one over the other). Dance learning support systems focus on teaching techniques with defined movement vocabularies without touching on the liberty, release, or constant openness to new sensation that arrives with technique development. Choreographic tools, mostly implemented for modern and contemporary dance, build upon specific choreographer style which, though it may swing between the the inner and outer views, rests exteriorly and visually defined. I believe that understanding modern-day dancers who approach this tension in their daily lives will present opportunities to design for the first-person-third-person link in movement-based design. Therefore, the next chapters explore how dancers of these styles work with the ever evolving tension between these two viewpoints practically in their personal practice, outside of a specific technique or context.

4

Dance Style Transitions: Understanding Professional Dancer Movement Learning Beyond a Particular Context

This chapter investigate how professional dancers learn a movement in a new style of dance after years of previous training in another style. I explore themes including body habits, learning approaches, and changing mentalities.

This chapter contains written material from an article accepted at the ACM CHI Conference on Human Factors in Computing Systems 2022, entitled ***Dance Transitions: What Forms of Technology Best Support Professional Dancers as They Learn New Movement Styles?****, by Wendy Mackay and myself.*

4.1 Introduction

We are motivated by a dance phenomenon previously unexplored within Human-Computer Interaction (HCI), but extensively present in professional dance: the transition from one dance style to another. Whether due to personal interest in dance (Wulff, 2020) or parental interest in the benefits of dance training (Chatzopoulos, 2019), children usually start studying ballet at a young age. Classical ballet is gener-

ally considered a good foundation for dance technique (Aalten et al., 2014), so students interested in pursuing dance professionally tend to start with ballet training. However, not only is ballet very challenging technically, but jobs with professional ballet companies are scarce and highly competitive (Wulff, 2020), and many careers are interrupted due to injuries (Allen et al., 2012) that can shorten or end a dancer's career (Wainwright and Turner, 2004). Dancers, therefore, may choose to leave ballet at some point in their career and transition to another style of dance. We argue that better understanding how people adjust to such transitions offers an opportunity for fundamentally reassessing the design of dance support tools.

Trained dancers inevitably face different challenges learning new movement styles than those they faced as novices learning to dance for the first time. Even though professional dancers who decide to transition styles need to transition successfully in order to continue their performance career, the transition process itself remains unsupported in HCI. We therefore see an opportunity not only for the design of supportive technology, but also to add to our understanding of how to design for dance training in general.

In order to create effective technology, we must first understand dancers' lived experiences as they transition from one dance style to another. Our research questions are:

- What specific steps do dancers take to transition from ballet to a new dance style?
- What are the key obstacles they face?
- What are their key strategies for overcoming these obstacles?

Our goal is to use the insights gained from this analysis to inform the design of future technologies that can support such transitions. After first reviewing related work, we describe the results of an interview study with 12 pre- and fully professional dancers who transitioned from classical ballet to a new dance style. We conclude with three main implications for design and directions for future research.

4.2 Related Work

Most dance support systems focus either on helping dancers learn new movements or helping choreographers create new works. Here, we focus on dance learning and choreography tools specifically assessed by pre-professional and professional dancers (see a complete overview of dance learning and choreography tools in chapter 3). Though some choreographers have embraced technology in their creation practice, many choreographers (Singh et al., 2011) and teachers (Trajkova and Cafaro, 2021) remain wary of integrating tools into the studio. We thus finish with a summary of the tools available to support dancers outside of the studio in their professional careers.

Dance in HCI: For Pre-professionals and Professionals

Learning Dance. In pre-professional training contexts, technological tools with more traditional teaching methods take the form of augmented mirrors ((Marquardt et al., 2012), (Trajkova and Cafaro, 2018)) and wearables (Thiel et al., 2014). Some tools for reflection and self-evaluation take similar augmented mirror (Molina-Tanco et al., 2017) and wearable (Großhauser et al., 2012) forms. Others build upon different forms of current technologies including large-screen, interactive displays ((Raheb et al., 2018), (Alaoui et al., 2015a)) and augmented [1] and mixed reality ((Yan et al., 2015), (Hachimura et al., 2004)). Video annotation tools, like MoveOn (Rivière et al., 2019) and the Choreographer's Notebook (Singh et al., 2011) are commonly studied in pre-professional, ecologically valid settings, such as piece re-staging (Rivière et al., 2021).

[1] https://dance.osu.edu/labanlens

Teaching technologies build on tools for movement training already present in the studio, such as the mirror and the "music" of the movement. More reflective tools employ technologies that offer new visuals or viewpoints for dancers to explore. Annotation tools smoothly replace paper note-taking during choreography re-staging. However, none of these tools focus on the "unlearning" that is required when transitioning from one dance style to another, nor do they account for the evolution of learning over long periods of time.

Choreography. Generative, interactive tools, like the Living Archive [2], utilise advances in AI to generate new movement content in the style of a specific dancer or choreographer and respond to the dancer during the interaction (Crnkovic-Friis and Crnkovic-Friis, 2016). Beyond a specific choreographer or style, tools generally support video anno-

[2] https://artsexperiments.withgoogle.com/living-archive/

tation for rehearsal documentation[3,4] (Cabral et al., 2011) score creation (Ciolfi Felice et al., 2018), or choregraphy reflection[5].

[3] http://motionbank.org/en/event/pm2go-easy-use-video-annotation-tool.html

[4] https://www.lafabriquedeladanse.fr/dancenote/

[5] http://badco.hr/hr/publications-item/whatever-dance-toolbox/

HCI researchers study dance creation, creativity, and collaboration in the wild (Rogers, 2011) through the deployment of creativity support tools (CSTs) for choreography. Felice et al. (2021a)'s deployment of Knotation in a choreography course highlights the role of the technology and its impact on the definition of other roles within the players and their notated artefacts. Hsueh et al. (2019a) worked with this theme thoroughly when studying real-world collaborative choreography and composition with artefacts. Masu et al. (2020) studied an ecology of interactive sonic artifacts in choreography, uncovering the mutual influence of technology and choreography and the added necessity for the dancer to learn the inner workings of the technology well enough for playful interaction. Exploring the development of technology with performers also reveals play and tension between the body and the system, whether they develop together through intercorporeality (Eriksson et al., 2019) or limit each other (Fdili Alaoui, 2019). Rodger et al. (2020) study music instruments beyond the *musician-as-user* and *instrument-as-device* paradigm. Similarly, these works move beyond developing the best tools for the most creativity by studying how choreographic creativity unfolds in the real-world.

These tools either offer the professional choreographer a specific way to explore and implement their individual choreographic style; or provide any choreographer with basic support for documenting and noting choreographic ideas. Research on similar tools in the wild highlights the greater complexity of roles and relationships between players and artefacts within a specific context. However, they do not address the needs of dancers who search for new, interesting movement with their bodies with previously trained movement patterns, nor do they question the professional practice of a dancer in a personal, developmental context.

Outside the studio: How Professional Dancers Use Technology

The global pandemic required dancers to revert to training from home, with a corresponding change in their use of technology. Dance classes became virtual, such as the postmodern Trisha Brown Dance Company's[6] and the contemporary Batsheva Dance Company's[7] use of Zoom[8]. Social media pages became a space for more than marketing and event planning. Companies began giving live performances online as well, either through their Facebook pages, such as at the Opéra de Paris Ballet Company[9], as well as other platforms like Insta-

[6] https://trishabrowncompany.org/education/intensives.html

[7] https://www.gagapeople.com/en/ongoing-classes/

[8] https://explore.zoom.us

[9] https://www.facebook.com/operadeparis/events

gram and Youtube, like with performances of the contemporary dance company Rosas[10]. Dancers had access to pre-recorded performances on Netflix-like platforms such as Marquee TV[11].

[10] https://www.rosas.be/fr/news/855-idrummingi-live-stream

[11] https://welcome.marquee.tv/

Outside of appropriated social networks and video streaming platforms, few tools exist to support dancers in their professional career outside of the studio. One such tool, numeridanse[12] is a community-based platform that not only contains a library of recorded dance performances in a variety of styles, but also podcasts, compiled documents, virtual expositions, and more. To support artist networking, artists and co-founders Ramita Ravi and Nick Silverio, created Artswrk[13], the professional network for artists. We include the potential for technological support in this form when examining the dance transition process.

[12] https://www.numeridanse.tv/accueil

[13] https://artswrk.com/

Although the above tools have helped mitigate the challenges posed by the pandemic, it is uncertain whether or not they will support the professional careers of dancers in non-pandemic life. We therefore believe that it is necessary to uncover the needs of professional dancers in their personal practice as it develops over time. To do so, we search for answers directly at the source: by talking to the professional dancers themselves.

4.3 Interview Study: Dance Transitions

Current dance support technologies take advantage of each technology's specific capabilities, especially the capture and representation of movement. However, simply because the technology *can* do something does not mean that that functionality is appropriate. One strategy for uncovering what dancers *actually* need is to move away from the well-defined characteristics of a particular dance style, and instead study the details of how dancers transition from one style to another, with particular emphasis on the process they follow, the obstacles they face and the strategies they develop to overcome those obstacles.

We identified pre-professional and professional dancers who had transitioned from ballet to a new style of dance, and interviewed them to discover how they managed the transition process. We were interested in collecting detailed stories of their process, especially actions taken during classes or rehearsals and the moments when they found the new style particularly difficult, in order to inspire ideas for the design of new dance support technology.

Recruitment

We developed the following specific career-related criteria for recruiting participants:

- at least four years of training in classical ballet at a high level, pre-professional program;
- a complete break from classical ballet, including an end to performing, although we included participants who continued studying ballet as a form of body strengthening; and
- at least five years of studying, performing, or teaching in a new dance style.

Our goal in choosing the above three recruitment criteria was to select truly expert dancers who have successfully completed a major style transition, while ensuring diversity across their experiences. We chose participants with a minimum of four years of high-level classical ballet training, since this generally aligns with a four-year high school or college program. Note, however, that their training usually began much earlier, as a child. We did not require dancers to have danced ballet professionally, which allowed us include dancers who recognized the need or were forced to change styles, e.g. due to injury, before beginning a professional dance career. The third criterion was influenced by creativity research by Ericsson et al. (Ericsson et al., 1993) and Weisberg (Weisberg, 2006), which requires a minimum level of study to ensure expert-level experience. We required a minimum of five years of study of the new dance style in a qualified program, and a successful first step towards a professional career in the new style.

In order to avoid designing a one-design-fits-all system for a single teacher's or choreographer's practice, we wanted to uncover themes that span diverse practices, in a variety of contexts, and examine how they affect the dancer professionally, in their personal practice and their career. We chose to interview 12 expert dancers who all fit the criteria, to obtain a diverse range of experiences.

We initially recruited dancers who were acquaintances, after which recruitment "snowballed" (Handcock and Gile, 2011) as dancers volunteered the names of friends and colleagues who fit the profile and were willing to participate.

Participants

We recruited 12 pre-professional and professional dancers (7: she, 5: he) based in France (6), the United States (3), the Netherlands (2), and Belgium (1). All dancers had begun as classical ballerinas who then shifted to: professionals working in modern/contemporary dance(4), experimental/contemporary dance(5), tango(1), folk(1), and Alexandre-infused ballet(1). Dancers held roles as university students in pre-professional programs, professional dancers, choreographers, and/or teachers. Seven dancers held multiple positions, such as teaching while freelancing or dancing in their own works.

We sought, and achieved, rough gender parity, as well as a diversity of geographic ballet training, from both Europe and North America, and in participant roles, which ranged from advanced university students in pre-professional programs to practicing professional dancers, teachers and choreographers. Note that dance training, even that as highly structured as classical ballet, differs significantly across countries (Franko, 2012). The 12 participants in the study trained or danced at 53 different dance institutions in the United States and Europe, including twelve ballet training programs, seven professional ballet companies, seven pre-professional "new style" training programs, and 27 professional "new style" choreographers/performance companies. Of these, only four institutions had more than one study participant, ensuring a high level of diversity in experience across participants.

All 12 dancers have in-depth knowledge of both ballet and a second style, with the latter clearly influenced by the former, as well as professional dance experience and their own personal practices. This allows us to see both the commonalities and diversity across their approaches, with rich details that can contribute to the design of interactive tools to support western professional dancers.

All participants agreed to having their interviews recorded and all signed an informed consent form. The procedures in this study were approved by COERLE, our organization's Institutional Review Board (IRB). Participants did not receive financial compensation.

Setup

Dancers chose the location of the interview, which took place in a café (5), over Skype (4), in a dance studio (2), or the dancer's apartment (1). Although we preferred that interviews take place where there was space to move, we ultimately allowed the dancers to choose, since:

- renting studio space is both expensive and competitive (Singh et al., 2011);
- finding a time to talk with dancers is a challenge, since they often travel when working with multiple choreographers[14]; and
- discussing the transition experience can be very personal, and we wanted the dancers to feel as comfortable as possible.

[14] https://www.danceinforma.com/2015/05/05/working-as-a-freelance-dancer/

Procedure

We conducted 12 semi-structured, story interviews (Mackay, 2002; **?**), a version of the critical incident technique (Flanagan, 1954). Each interview lasted between 50 and 110 minutes. We asked dancers to describe recent, specific moments when they were confronted with the challenge of learning a movement or concept that differs between ballet and the new style. We focused on these because dancers must directly confront their previous ballet experience in the context of the new style. We framed each interview in relation to the dancer's previous ballet training, and probed deeply into the approaches they tried. We also asked dancers about the role of others in the transition process, particularly teachers, choreographers and fellow students.

Data Collection

We collected background information through a pre-question-naire that asked about their training in both ballet and the new style, as well as their career path and current role. We audio recorded each interview and took hand written notes.

Data Analysis

We first transcribed the audio from each interview and gave each dancer a unique code, from D1 to D12. We then conducted a reflexive thematic analysis (Braun and Clarke, 2019) using a mixed approach, with both deductive (top-down) and inductive (bot-tom-up) approaches. The deductive themes were: specific transition steps from ballet to a new style; key pain points or challenges; key strategies for overcoming these challenges; and the role of external input. One co-author read through all of the stories and created codes to identify key themes, which were then discussed and verified with the other co-author. The deductive analysis focused on the specific approaches each dancer used during the transition process, including when and why they were used. We developed these themes from author brain-

storm based on the objectives and research questions of this work. During the coding process, we remained open to emerging bottom-up themes, especially those related to the initial research questions. We considered the location of the interview in our analysis, but we did not include it in the results since it does not relate to the objectives of this paper.

4.4 Results

We identified three major challenges faced by the dancer: overcoming previous dance habits, learning new movement styles, and supporting transitions over time. For each of these challenges, we first describe the specific strategies they use, then who they turn to for guidance, and how they create a long-term practice that supports their growth as dancers. We conclude by mapping the overall transition process and discussing the dancers' need to change both their movements and their mentality in order to successfully transition to the new style.

The Dance Transition Process

Each dancer described the progress of their careers, with a specific focus on when they first tried the new style, when they committed to it, and their current activities, professional or otherwise, in the new style. Most dancers (11/12) enrolled in ballet classes at a young age, before switching to a pre-professional training program (10/12) at a conservatory, specialized dance high school, or joint program with a professional company. Half the dancers entered a professional company directly (6/12), the rest studied at a university (6/12) before searching for professional opportunities. Dancers had their first exposure to the new dance style at different points during their career: One was a child (1/12), others experienced it during their pre-professional training (5/12), university studies (4/12), early professional experience (1/12), or afterward, while teaching (1/12). A few dancers officially switched to working and performing in the new style directly after their pre-professional training (3/12). Others shifted while in a university (4/12), during their professional career (4/12), or after they finished performing professionally (1/12). For some dancers, the style transition began within the past five years (2/12) while others began the transition ten (2/12), twenty (5/12), twenty-five (1/12), thirty (1/12), or even forty (1/12) years before.

Table 4.1 summarizes the career of each dancer, including their current

style, the context of their transition, and how long ago they transitioned. The last column shows the technology they used, if any. Note that their limited use of technological support aligns with findings in the research literature about the low rate of technology adoption in dance practice (Calvert et al., 2005).

ID	New Style	Transition Timing	Years	Current Role	Technology Used
D1	Modern/Contemporary	Post Pre-Professional Training	10	Auditioning	Youtube, Music Players
D2	Modern/Contemporary	University	20	Teacher	Video camera, VHS/DVD
D3	Modern/Contemporary	University	5	Auditioning	Youtube, Music Players
D4	Contemporary	Mid-Professional Career	5	Dancer	None
D5	Contemporary	Post Pre-Professional Training	20	Dancer/Choreographer	None
D6	Tango	Post Pre-Professional Training	30	Dancer/Choreographer/Teacher	None
D7	Contemporary	University	20	Dancer/Choreographer	Excel Spreedsheets
D8	Folk Dance	Mid-Professional Career	20	Teacher	Video camera, Internet
D9	Contemporary	Mid-Professional Career	10	Dancer/Teacher	Video camera, Audio recorder
D10	Ballet/Alexander	Post Career	40	Teacher	None
D11	Modern/Contemporary	University	25	Dancer/Choreographer/Teacher	None
D12	Contemporary	Mid-Professional Career	20	Dancer/Choreographer	None

Table 4.1. Dancer's career paths, including the new dance style, when they transitioned, their current role, and any technology they used during the transition.

Overcoming Dance Habits

A key part of classical ballet training is to establish specific movement habits that become second nature to the dancer. When new dance styles require different types of movements, dancers have to work hard to overcome their ballet-centric habits. The dancers reported that their most successful strategies involved either getting completely lost in something outside their body, or conversely, paying close attention to specific details of their body. These strategies open the dancer to experiencing new sensations and developing new movement instincts.

Strategies. When trying to unlearn a particular movement habit, all dancers (12/12) shift their focus from their own bodies to something outside the dance. For example, some increase the speed or frequency of a particular movement, or concentrate on the music's rhythm or melody. Others consider social aspects, such as interacting with their partner, or explicitly create physical constraints, such as restricting their ability to release their hands. D5 described creating a character and a specific context, and then mentally writing and revising a monologue. For example, he described a scenario involving movement at a café: *I'm going to take the glass, and all my fingers are touching the glass, and I feel the contact of the glass on my fingers, and now I'm going put it in my mouth...* He explained that he updates this monologue continuously so it remains novel and interesting, which lets his "movement instinct" take over: *For instinct to appear, you need to cheat on your brain...like keeping your brain really busy with simple tasks (D5).*

D6 also talked about "getting out of her head" by working with her partner: *You dive into the other. In tango, at once you have a bond with another body, you are not in a vision of you, you are in a relation to the other. [It] opens this channel...from there, I can escape in my head.* By focusing outside their bodies and how they look, dancers escape from constantly checking themselves and thus begin to experience new sensations.

Another strategy involves turning inward and developing a hyper focus on the inner workings of their body. For example, most dancers (8/12) described using specific, anatomically correct imagery to visualize their body; scanning their body and its circulating energy; or following the chronology of body parts shifting which make up a movement. D9 described working with a choreographer who integrates energy yoga with extreme slowness, so that dancers remain immobile for hours before moving in the final 30 minutes of a workshop: *It was only with this slow work that I could really feel...the weight of things, what it takes to raise an arm and feel...For me, that was the only way to feel that. (D9).* This strategy of hyper-listening to their bodies while resting or moving helps dancers reject over-learned movement habits and explore new sensations associated with the new dance style. Both strategies—focusing on aspects beyond the dance and looking inward to the workings of the body—challenge the assumption that optimal dance support technologies should focus attention on the dancer's movements.

External Guidance. Many participants are also teachers or choreographers who develop methods for exposing dancers to new movement styles, and guiding them away from existing movement habits. Several teachers (7/9) described their tricks and methods for opening dancers to new ideas, including leading dancers into a relaxed state, probing for their personal goals, and avoiding criticism. D10 explained that dancers aren't necessarily *open to something that might be completely the opposite of what they've heard their whole lives. [They'll just] consciously or unconsciously reject it...* His strategy is to *find out what their priorities are. If I can address one of those priorities...even if I don't think that's the most important thing...they'll open their feedback loop to me [and] start listening.* Similarly, D5 and D7 are choreographers who develop methods that guide their dancers to perform with the movement qualities they seek in their dance pieces. For example, D7 created a piece which explores the movement learning process and muscle memory. She developed an exterior focal point: a lexicon based on the structure of verbal language and a dependency parsing algorithm from natural language processing: *This idea of taking the sort of linear, two-dimensionality of language, and putting it into your body so you're in this three-dimensional relationship*

to it. (D7). Throughout the piece, dancers 'cheated their brains' by focusing on this lexicon and the sentence they were performing over and over. In this way, the lexicon developed by D7 guided the dancers so they could overcome their habits.

Long-term Practice. Dancers seek new strategies for breaking their habits over time. They may study Alexandre technique[15] to lose habits and find more relaxed movement or study Gaga movement language[16] and yoga, to focus awareness on sensations within the body. They may try the Feldenkrais method[17] to improve self-awareness or other techniques that force them to radically question their assumptions about ballet. Some dancers work with teachers and choreographers who integrate such techniques into their classes or creation process; whereas others study these techniques themselves as a self-improvement process.

[15] https://alexandertechnique.com/at/

[16] https://batsheva.co.il/en/gaga

[17] https://feldenkrais.com/

Learning New Movement Styles

All dancers (12/12) developed individual strategies for learning new movements, and established their own personal development processes. Strategies included reusing, then redefining known movement ideas; learning from the bodies around them, including their own; and imposing structure on themselves to help them better understand and explore new movements.

Strategies. All dancers (12/12) reported trying to understand new movements through the lens of their previously learned movements and definitions. They reapplied advice from former teachers, reused easier exercises, re-appropriated terminology and body knowledge from their ballet training, and re-connected with basic features of the body, especially breathing, walking, and falling. D11 relies on body directions, drawn from classical ballet training (see Figure 4.1 (**?**)), to position her body in space even when performing modern dance: *Modern dance [involves] changing spatial orientation all the time...Knowing body positions has really taken the challenge out of learning movement in modern dance.*

D7 said she picked up movement strategies from her first contemporary dance classes: *To learn this movement phrase...I could try to parse out the shapes that I can see, that I recognize because of whatever training I've had, relying on some of these other tools that I have developed, and being able to learn classical movement.* D4 relies on her classical training and body functions such as breathing, to learn new movement styles. For example, she connects her breath to release her muscles, which facilitates

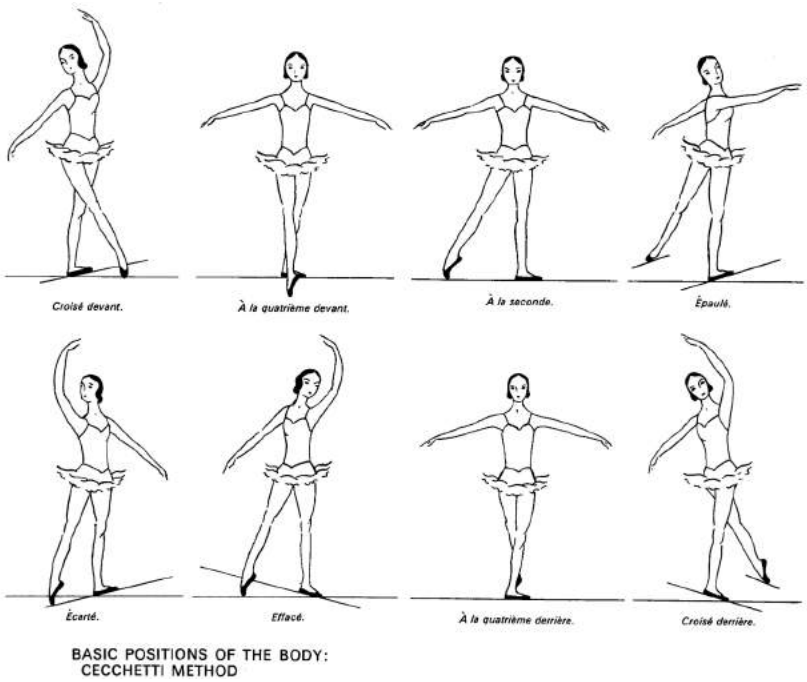


Figure 4.1. Cecchetti Body Positions: An example of the highly codified nature of ballet movement training.

falling during a performance: *Breathing, that's something that I think of a lot, how to dance with your breathing and how to make it help the movement."*

Most dancers (8/12) look to their own bodies and the bodies around them to gain information and validation about their movement. When they enter the studio every day, dancers examine their aches and bruises to assess the success of previous attempts. They also watch each other to discover nuances in correctly performed movements. D8 described three phases for learning movement through observation: Analyze, Copy, Improve. He tries to teach students to: *Learn to visually recognize motion and movement: analyze, copy, and then transfer it into your own body, [until] it becomes natural.* This and other self-developed strategies help dancers gain information about how the bodies around them move, which helps them transfer external guidance from others to their own bodies.

Most dancers (9/12) described creating their own structures that help them understand new movements more deeply, such as questions and self-imposed constraints. For example, D12 established rules to help him improve his floor work, such as "glueing" certain body parts to the floor and then trying to complete certain movements. *[I] keep my head on the ground all the time and to go from one part to...the other part of the room. How do I do to keep my attention just on that, so that the rest of*

the body adapts? It gave me some kind of rules to play with, that allow you to find this kind of relationship with the ground. Creating such challenges lets dancers explore and play different aspects of each new movement.

External Guidance. Dancers attempt guidance strategies both inside and outside of structured class or rehearsal time. In particular, dancers with teaching or choreographic experience (6/9) develop strategies for guiding their students to discover new movements, such as using hand-picked imagery, posing questions, and providing history and context to specific movements or techniques. They also set aside space and time for exploring without pressure. For example, D8 encourages dancers in his folk class to examine themselves as he teaches a new movement phrase: *I ask them to talk, to tell me what I was doing...I say "Okay, what do you think yourself? How do you think you can solve your own question? Start by analyzing. 'What did I do? Where did I go? What can help you?' " It only takes 15 minutes and I do budget that time.*

Long-term Practice. To reinforce the process of relearning, dancers seek strategies that enhance their training outside of rehearsal. Dancers take a variety of classes to train their bodies, especially those that encourage body awareness, such as the afore-mentioned Gaga movement language, yoga, and the Feldenkrais method. D11 highlighted the importance of hearing familiar advice reformulated in a new way: *There are things I had been doing for years and somebody would say it in a different way, and I would be like 'Huh.'...an oral cue like that, something different, just made a difference.* Dancers also expand their movement understanding by cross training with non-dance techniques. D12 tries new sports, such as underwater diving and rock climbing, to discover new ways to use his body: *I'm trying to do more climbing now, and it makes me discover another relationship with my weight... and I think that informs me as a dancer.*

Supporting Transitions Over Time

Dancers engage in activities outside of the studio and beyond their roles as dancers to facilitate their transitions over time. They question their beliefs by exposing themselves to new works and styles beyond classical ballet, seeking clarity in interest and different strategies. According to D12: *It's difficult to change one's tastes because it requires...requestioning them [which] puts in doubt all the learning. It requires rebuilding something else. It's also why I went to see a lot of different styles.* For these dancers, discovering new artists and styles means deconstructing and reconstructing ideas about movement possibilities and approaches. Of course, this may include seeking guidance from others, and the process

is fundamentally about making changes in their long-term practice.

Strategies. Dancers work to develop themselves as dancers throughout their careers, by exposing themselves to a diversity of works and exploring their own work through different channels outside of dance performance and creation. Dancers need diversity in classes, teachers, and audiences (such as dancers from other styles as well as other artists and non-artists), with differing levels of radicality. Additionally, dancers mentioned exploring other channels beyond dance to develop their practice including: creation, teaching, academic studies, verbalization and discussion, as well as developing their own, proper language to put body knowledge into words. D9, who had completed a master's degree as well as dancing professionally, explained how his academic studies feed his career: *I'm studying more theories and being in other environments. I realize I can push my creativity by being in another landscape, too.* Dancers find new sources of creativity even outside of the studio, exploring other channels to frame and talk about their work.

Figure 4.2 summarizes the key findings with respect to the challenges dancers face during style transitions. In order to overcome unwanted movement habits, dancers either "cheat their brains" by focusing on external features, such as rhythm, speed, or a movement script, or focus intently on the inner workings of their body. External guidance from teachers and choreographers helps dancers open up and find external or internal focuses. Over longer periods of time, dancers study specific techniques for breaking habits and increasing body awareness. When learning new movements, dancers re-examine their previous training, as well as analyze and translate the movement of their own bodies and those around them. They also develop questions and challenges to better understand the new movements. They rely on external guidance to create a space for self discovery, where teachers and choreographers prompt them with guided questions, imagery, or history, and develop classroom or studio environments that encourage exploration. Over time, dancers expand range of movement by working with new teachers and choreographers, or trying non-dance body training, such as sports. To facilitate style transitions over longer periods of time, dancers seek diversity in their dance experiences, working with new people and radical styles, but also exploring new creation, teaching, discussion and academic channels, in- and outside the arts community. Before examining how these results might affect the design of dance support technology, we need to address one key additional element: changing the dancer's mentality.

	Overcome habits	Learn new movements	Transition sustainably
Strategies	• **Outer** body focus	• Relate to **previous training**	• **Diversity** in experiences
	• **Inner** hyper body awareness	• Draw from the **body(s)**	• Explore other **channels**
		• Explore through **structure**	
External Guidance	• Help dancers **open up**	• Create a **space for self discovery**	Not applicable
	• **Guide** through practice		
Long term	• Study **specific techniques**	• Diverse **cross training**	Not applicable
	to break habits		
	to increase body awareness		

Table 4.2. Dancers adopt various strategies to support their style transitions, with external guidance from teachers and choreographers, as well as adopting new techniques to support the long-term evolution of their dance practice.

Changing Ingrained Mentalities

A key observation is that transitioning to a new movement style causes dancers to fundamentally question their ingrained assumptions about dance and its greater context. Dancers develop a "ballet mentality" surrounding the intense training they experience as children. Pre-professional dancers must commit 100% to their training, partly because of ballet's difficulty and need for precision, and partly because they start very young and develop their personalities and life expectations during this time. D12 described how, in certain intensive, boarding school training centers, *either you go all the way through it, or you completely break.*

The dancer's ballet mentality encapsulates not only ballet itself, but also the context of training in technique, choreography and performance. When former ballet dancers face a transition to another movement style, due to injury, age or lack of adequate level, they find themselves fundamentally questioning values they previously accepted without thought, reassessing their assumptions about the body, performance, training and relationships, as well as the codification of ballet and its emphasis on creating the perfect image. Ballet focuses on externally visible results and the necessity of providing a "good" performance for the audience. It emphasizes aesthetics, as dictated by an "all-knowing guru", and values a single, standardized language the captures the essential components of ballet.

However, when encountering other dance styles, either equally formal such as tango, or more open-ended, such as contemporary, dancers must reassess their own assumptions about dance. Each new movement forces them to confront their earlier beliefs and challenge or accept guidance provided by teachers and choreographers. Their daily experiences with the new dance form contributed not only to learning specific new skills, but also served to change their dance mentality.

Explaining movements in terms of the new style also helped expand their understanding of their own ballet training, and reconstruct their beliefs. For example, D2 spoke of learning to place her arms in second position in both ballet and contemporary dance, using the metaphor of jellyfish suckers on her arms: *They lengthen, they slurp... so your arms are gathering the oxygen*. She explained that metaphor encourages contemporary dancers to open their arms wider than in ballet and move them into "sensing mode", where the view of one's arms shifts from holding to sensing. *It's not like you're moving your body but your body is moving the air. You really get this in sensing mode, and if they're in this sensing mode, they'll use the broadness. (D2)* She noted that using this metaphor changed how she viewed her body in space—the new imagery accompanying the movement sparked an "aha" moment with a new understanding.

Every period of time spent working on a new technique, or with a new choreographer creating a new piece, offers new opportunities for questioning their existing beliefs. For example, D3 studied the Graham technique[18] for four years at a conservatory. Her professor taught her new ways of visualizing and using her body that caused her to question key beliefs about ballet:

[18] https://marthagraham.org/history/

- A new definition of alignment led to a new view of the perfect body for ballet.

- A new way to use the pelvis led to a new "goal" of movement (to eat up space vs. to control the movement).

Figure 4.2 shows D3 demonstrating the differences in alignment between ballet and Graham Technique. Dancers in this situation acquire new movement examples and develop a deeper understanding of the new movement style, which they compare and analyze with respect to their ballet training.

As time passes, dancers begin to break down their old beliefs and develop new ones, which fundamentally changes their mentality concerning professional dance. D5 laid out a timeline of this change:

"Prince of ballet" → *pushing my limits inside the ballet vocabulary → using the pain I knew how to handle from ballet → the somatic approach that I'm now in...to let the body take control over you.*

These dancers all questioned assumptions grounded in their ballet training at different times in their careers, before settling on an ap-

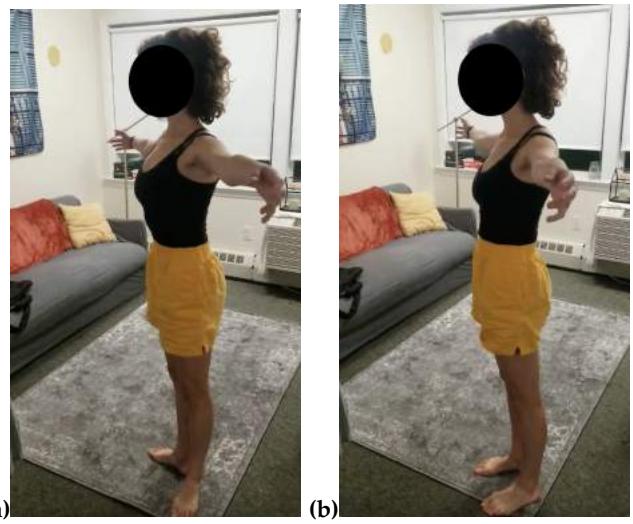


Figure 4.2. D3: Comparing ballet alignment vs Graham alignment

proach that makes sense for their current dance practice.

Dancers felt they had to change their mentality in order to "succeed" in performing movements in their new style. D1 hesitated when first confronted with a new *frufru* movement approach in a workshop about the Rubberband method[19]. She constrasted the presentational focus of ballet to the Rubberband method's focus on movement influenced by internal systems within the body. However, as she watched company members, she realized that this new approach allowed dancers to move with vastly different qualities: *I didn't realize how much of a difference approaching it that way changes your aesthetic...it sounds silly: 'Oh I'm just doing this imagination thing, like, it's fun', but when you watch people, it completely changes how they execute everything and how it looks.* (See Figure 4.3 where D1 illustrates the difference in the tendu movement.) Dancers need to accept or believe in the teacher's or choreographer's approach, before they can fully commit to and perform the movement "correctly".

[19] https://rbdg.ca/en/rbdg-method/

A dancer's mentality develops over time, through new experiences or taking classes where the dancer encounters a movement or idea that makes them reflect on their existing beliefs before performing it. The dancer deconstructs their mentality and then rebuilds it into a new one, influenced by the context in which they learned the movement. Different aspects are deconstructed and reconstructed over time, according to the particular experiences of each dancer. Experiences such as studying the Graham technique offer opportunities for deconstructing and reconstructing different concepts of dance.

(a) (b)

Figure 4.3. D1: Comparing ballet tendu vs Rubberband tendu

4.5 Implications for Design

Table 4.3 summarizes the key design considerations associated with each of the three key challenges faced by dancers. Next, we suggest three possible design directions that are inspired directly by the study results, and encourage designers to explore other possibilities that go beyond the traditional focus on capturing and correcting individual movements.

	Overcome dance habits	Learn new movement styles	Support sustainable transitions
Design Considerations	• Support **inner reflection**	• Incorporate **previous experience**	• **Beyond** dance training
	• Support **outward reflection**	• Include multiple **bodies**	• Explore other **channels**
		• Offer **challenges**	
Role of Technology	• Guide dancers	• Support **experimentation**	Not applicable
Long term Use	• Variety of **specific techniques**:	• **Diversity** in techniques	Not applicable
		• **Diversity** in teachers	

Table 4.3. Designing for the real-world, transition process requires actively considering the strategies dancers adopt in both the short and long term and reflecting on the potential role of technology.

Design for Multiplicity of Movement Representations. For a sustainable style transition and career, professional dancers continuously explore novel approaches, and therefore novel frames through which to view movement. For habit breaking, dancers study specific techniques focused on developing body awareness. For relearning different movements, dancers search for a variety of teachers, techniques, and even movement activities beyond dance to gain novel descriptions, viewpoints, and sensations. Throughout their careers, dancers explore their practice even beyond the dance studio, re-questioning their beliefs through interaction with non-dancers. Approaching each transition challenge expands their movement experiences at some level.

Current dance support tools usually focus on a single style, such as

classical ballet ((Marquardt et al., 2012), (Trajkova and Cafaro, 2018)) or Double Skin/Double Mind (Alaoui et al., 2015a). However, comparable movements, such as relevé and expanding, exist within both of these dance styles. This suggests that tools for supporting transitions by professional dancers should include a multiplicity of movement representations, from a variety of sources, ideally from each of the fundamental movement styles, plus other, different dance styles. This offers dancers a space for questioning their current understanding of each movement, and allows them to compare or combine multiple frames, including their previous framing.

Some dance styles do not include comparable movements. In such cases, we recommend that designers identify diverse other sources, such as approaches by different teachers or diverse ways of visualizing the body, so dancers find new ways to perceive and describe each movement. Exploring multiple viewpoints, including first and third person, can help dancers explore the mapping between their proprioceptive sense of their own movement, and the movement as it is viewed by others. Increasing the number of modalities lets dancers better define movement through their different senses, thus increasing their understanding. We argue that, instead of focusing on single 'correct' movements, professional dance support systems should instead offer a multiplicity of movement representations that allow the dancer to explore, reflect and more deeply understand each movement being learned.

Balancing Learning and Reflection Within a Single Session. When dancers acquire novel movement phrases, either to overcome habits established from an earlier dance style or to learn completely new body movements, they come up with personal strategies for exploring and understanding them. For example, D5 and D7 define a new movement phrase by writing a relevant monologue or developing a corresponding vocabulary. They explain that dancing these phrases from an exterior focus effectively "cheats the brain" and opens the body up to new experiences.

Learning movement in the new style requires two contrasting activities: learning and adopting the basics of the new phrase as required by the new dance style, and exploring and gaining a deeper understanding through self questioning (D8), searching for information through nearby bodies (D8), or exploring and leveraging previous knowledge (D4, D7). Although these goals differ, each movement learning action involves aspects of both: dancers structure movement to explore, and explore to improve movement structure.

Unlike current interactive dance systems, which usually focus on a single teaching method (Raheb et al., 2019), these findings suggest that a single dance support tool should include both traditional/mimesis and reflective/generative teaching methods, ideally within the same session. For example, dancers could interact with different approaches, perhaps beginning with mimesis for basic movement acquisition, followed by activities that encourage reflection and further exploration. Designers could develop a logical chronology and timing for each phase, depending on the dancer's specific goals and preferred styles of interaction. Learning a new style of dance requires dancers to appropriate movement structure from the exterior and use it to explore sensations within themselves; therefore, we recommend supporting both phases, with differing methodologies, in one support tool.

Creating Definitions for Movement— Through Movement. During their transition between dance styles, dancers must deconstruct and reconstruct ideas about dance movements and concepts, and give them new names and definitions. Defining movement through body scans and monologues, for example, can help break undesired movement habits. When learning new movements, dancers often draw from their existing dance vocabulary to understand the new style. Over the long term, dancers develop their own practice, which includes developing methods of verbalizing their approach and beliefs, with their own personal vocabulary, which they use to discuss the new style with other dancers, teachers and choreographers. Changing mentalities requires changing how each dancer thinks about and discusses movement, training, context, and relationships, and redefining movements at each challenging point during the transition.

We recommend systems to support this re-defining process through movement-based demonstration and reflection. Dancers could demonstrate different variations of movement to the system and have that reflected back to them in any of a number of different media. This back-and-forth would give dancers an 'outside' perspective of their own movement, but in different forms. This communication of set movements through movement does not put words in the dancer's mouth, but instead gives them new ways to view their own body and the ability to develop words themselves from what they see and feel from imitating, embodying, or reacting to the system's interpretation.

4.6 Discussion

This study offers a deeper understanding of the process of transitioning from one dance style to another, and adds to our understanding of the longer-term evolution of a professional dancer's career. It also reveals promising directions for design that go beyond the conventional paradigms of dance learning support tools. It participates in the discussion of current challenges in dancer-system interaction design. The next section discusses how the results of the study nuance current habit breaking literature and can help us imagine novel structures for designing dance learning support and continue to develop an understanding of the balance of control for dancer-system interaction. We finish with an overview of our study limitations due to methodological choices.

How Style Transition Results Nuance Habit Breaking in the Literature

Research in contemporary dance, especially improvisation, examine habitual and inhabitual movement. Researchers talk about training in somatic practices for dancer re-education away from codified styles and the implicit ways of behaving that arise when training in the cultures of different styles of dance (Ehrenberg, 2015), like our described "ballet mentality." I describe below two different ways my results nuance current research, related to the focus of attention that dancers develop and the moment of openness before dancers can experience new movement.

My results distinguish focal points of attention into exterior and interior categories and how they implicitly or explicitly arise. Previous literature talks about a "kinesthetic mode of attention" (Ehrenberg, 2015) or a "performative pre-reflective awareness of the body" (Legrand, 2007) employed by contemporary dancers, especially during improvisation. When Bergonzoni dances her walk, (outer) foci like weight and gravity, rhythm, her environment, and performance, as well as (inner) foci including heightened sensing arise (Bergonzoni, 2017). Similarly, Ehrenberg (Ehrenberg, 2015) touches on the various dimensions of movement for which dance experience develops an awareness (Parviainen, 1998), and argues that contemporary dancers sense the mechanics of the movement when walking (both inner and outer foci) when taking the kinesthetic mode of attention. I found that dancers can actively employ these focal points when exploring new movement possibilities and improvising, and note the difference between external and internal focal points.

I agree that dancers need to be in an open mental space to experience new movements, and I add an additional description on how teachers can get dancers into that place. Ehrenberg (Ehrenberg, 2015) described "crash to create", a "creatively interesting point" right after a mistake, a moment of being off balance, when the dancer finds herself in a place in which anything they do is novel. Kronsted and Gallager (Kronsted and Gallagher, 2021) touch on Manning's concept of "the gap": the moment when a dancer resists the impulse to complete habitual movement, and instead creates an inhabitual movement. D10, among others, described methods for getting the dancer into a place of openness so they can be aware of their habitual movements, by understanding the dancer's priorities and interests, for example. By simple asking a few questions, I found that teachers can get into the feedback loop of the dancer, and bring awareness then offer new imagery in the moment of mental openness, described in the literature as "the gap" and the moment after a mistake.

Movement Substrates Support Diverse Movement Representations

We use a generative theory approach (Beaudouin-Lafon et al., 2021), based on the concept of *substrates*, to provide a theoretical foundation and generate a flexible structure for managing the proposed multiplicity of movement representations. A substrate *contains information and applies constraints to it, reacting to changes in both so as to generate new information* (Ciolfi Felice, 2018). Substrates also define relationships between data within and across different substrates. When designed well, substrates offer a simple and flexible interactive structure for representing different types of user-relevant data, in a form that users find easy to understand and manipulate. For example, Garcia et al. (2012) developed interactive paper substrates that let contemporary music composers generate their own interactive structures to create highly diverse music compositions; and Maudet et al. (2017) developed graphical substrates that offer designers powerful, interactive structures for creating and manipulating different layouts for both paper and digital formats.

We propose a novel approach—**movement substrates**— that contain representations of specific movements or dance phrases as information, and define the constraints and relationships among them. Constraints delineate what a movement is from what it is not. A single substrate, which represents the definition of a movement in a specific style or using a specific frame, is structured through constraints. Relationships arise within and across substrates, as common points within a single movement or phrase definition or across definitions of the

same movement in different styles or dancer experiences.

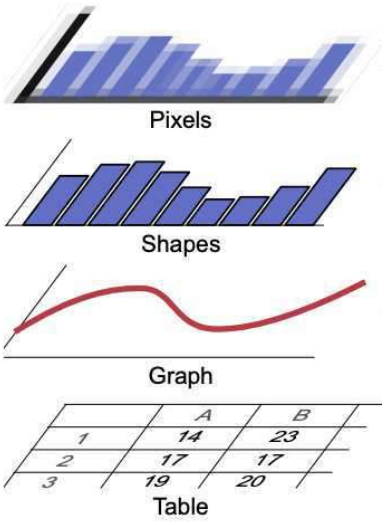


Figure 4.4. A graphical substrate from *Towards Unified Principles of Interaction* (Beaudouin-Lafon, 2017)

We clarify our definition through comparison with an example graphical substrate seen in Figure 4.4. In a movement substrate, the information filling up the cells in the table would equate to the initial definition of a movement itself, whether as motion capture or not. The other layers in the figure represent the other frames through which to describe a single movement across styles. With initial examination, relationships across each substrate later emerge in for example, shape.

The power of a movement substrate lies in its generation capabilities. Deeper examination of the figure highlights not only user generated constraints but also computer generated visuals, e.g. the graphed data in layer two. Structuring movement in substrates therefore allows for an exchange between users and system via movement frame generation and novel relationships to be explored.

We imagine movement substrates could take the following forms. A text-based movement substrate would provide each movement with a name and a third-person text definition. A visually based movement substrate could include visual representations of the above movements, either with real-world video clips, motion-capture representations, animated illustrations, or computer-generated visualizations. Similarly, an auditory movement substrate could include diverse sonic representations of the movements, from recorded sounds and music to computer-generated audio. All of these substrates, if linked, would offer dancers a wide range of possibilities for exploring new movements, from a wealth of different perspectives.

Beyond a single user, movements would then be cross-linked to other definitions of the "same" movement as defined by other dance styles, teachers, sensations, etc. Dancers and choreographers could apply constraints that would reveal novel frames for viewing and understanding each movement, creating space for surprises. Building a platform that supports these movement substrates would allow dancers to communicate with the system, without being forced to follow a particular technique or teaching method.

Movement substrates could also take advantage of different external views to define movements, and allow dancers to store and define personal movements, inspired by their own internal sensations. The "Moving and Making Strange" methodology (Loke and Robertson, 2013) defines three perspectives necessary for movement-based design: The mover, the observer, and the machine. Movement substrates would use the observer definition to enhance communication between the user and the machine; and both the user and the system could maintain movement definitions that map to the observer definition. Movement substrates could thus support efficient communication between dancers and the system, while also allowing for personal movement definitions.

A movement substrate platform could also support **definition-making**. Unlike sense-making, which is *"an activity in the analysis of a large or complex amount of information"* (Russell et al., 2018), definition-making occurs when dancers develop their own understanding of a movement and choose descriptive words that capture that understanding. Interacting with a single movement through different substrates would allow dancers to continually update their personal movement definitions. This would allow professional dancers to define and re-define movement, both as part of their own re-learning process, but also to support teaching and choreography.

We found that dancers continuously approached and re-approached movements in the context of their daily classes and rehearsals, in order to understand each movement more deeply. In particular, their experiences with movements in the new style led them to discover new insights about their ingrained beliefs with respect to the old style, which in turn helped them redefine those beliefs and the "successful" completion of the desired movement. Interacting with movement substrates would also provide a platform for helping dancers to question their beliefs about particular movements, both as they first learn them and over time. This would help them to break down and reconstruct their ballet mentality and make sense of each movement with

respect to the new dance style. Movement substrates could thus serve as a structure for helping dancers explore and re-interpret their beliefs about dance.

Shared Control Between Dancer and System

Studies of current dance learning highlight the challenges of balancing control between the dancer and the system. For example, Raheb et al. (Raheb et al., 2019) compare the traditional methods of teaching dance, *where the teacher makes all the decisions and the learner follows these decisions* to more generative and reflective methods, where the teacher proposes a task or time for improvisation, offering only a cue about where to start. They described their experiences with Choreomorphy (Raheb et al., 2018), a reflective system, and found that most expert dancers who interacted with it wanted to control the visualizations. However, one dancer said: *Each avatar triggered me in a different way. So, my movement was affected by the avatar. I really liked it, because I was discovering all the time new movements.* For this dancer, the surprising visualization led to discovering new movement. Trajkova and Cafaro (Trajkova and Cafaro, 2018) studied expert dancers' use of their more traditional, Kinect-based ballet teaching system, and found that they wanted to control the camera view so they could focus on known bad habits. However, they might have discovered other, more surprising perspectives on their movements if the system had proposed alternative camera views. These examples show the on-going tension between controlling the system to specifically address a known problem, and generating surprise that sparks new insights about each movement.

The results of the study highlight the challenge of choosing how to allocate control: Dancers are clearly willing to sometimes hand off control to an external guide when they are hunting for new movement possibilities. However, they are only willing to do this within the context of a temporally restricted session, after which they reassert control. Dancers also activity seek some methods, but are uncomfortable with or even fully reject other methods, even if suggested by an external expert, such as a teacher or choreographer. Dancers not only seek out specific teachers in order to challenge themselves, but also actively set constraints for themselves as they learn or relearn movements, and figure out personal ways of defining movements that make the most sense to them. This implies that dancers need to be able to choose when to accept external guidance, and when to maintain control over their own learning, especially with respect to their long-term definition of their own dance practice.

Successful systems for supporting dance transitions should thus offer dancers a choice with respect to their level of control. For example, delegating control to an external guide is most appropriate when helping dancers overcome unwanted habits, with either internally or externally focused directives. For example, a recommender system could ask questions or propose movement-specific challenges for the dancer to follow, based on their individual goals and past behavior, as well as more general recommendations from external experts. This would provide the dancer with new channels to explore and help them challenge their existing beliefs. By contrast, other systems could offer the dancer full control over which performances or academic programs to follow, and the dancer could decide how much time to spend exploring a particular movement, or experimenting with proposed questions, constraints or suggestions. Exploring a system based on movement substrates would allow dancers to pose their own questions, make their own comparisons, and allow themselves to be surprised by new associations and ways to approach dance learning.

Study Limitations

Choice of dance styles. We chose to focus on a previously unexplored aspect of professional dance training, the transition from one dance style to another. The advantage of this approach is that it can shed light on both the original dance practice, in this case classical ballet, and the new dance style, since dancers are, by definition, in a state where they are forced to reflect on each.

We chose ballet as the foundation dance style, because it is both very common, and because it provides a shared basis for comparison across dancers. Dancers who begin with other, less formal dance training may experience the transition to a new style differently. The majority of dancers in this study transitioned to modern or contemporary dance, which is perhaps not surprising given the roots of these styles as a rebellion against the perceived imperialism and rigidity of classical ballet (Thompson and Shott, 2015). However, even those dancers who pursued other dance styles described how they rebelled against ballet and sought to deconstruct it before reconstructing a new dance mindset. Thus these data should be viewed from the perspective of dancers who have, at least partially, rejected their original dance training. The perceptions of current ballet dancers may differ greatly.

Of course, all of the participants were trained in a western dance tradition, and dancers from non-western traditions may have very different experiences. We leave it as future work to study whether this process

of critiquing one's original movement training, with a corresponding need to learn new movements, break existing habits, and change mentalities, followed by a renewed appreciation of the original training, applies to other movement transitions.

Verbal Reports of Physical Activity. One of the difficulties in asking dancers to talk about dance is that dance is a very physical, embodied activity, and many dancers lack adequate words to describe their experiences, and may not even be conscious of their own learning strategies. However, one of the advantages of this particular study design is that participants have been forced to reflect consciously about each dance style, as they unlearn one and learn the other, thus making it easier for them to communicate their experiences.

Although it would have been easier for participants to reflect on specifics if they were physically in a dance studio, the private (7/12) or even public (5/12) locations did not necessarily inhibit physical demonstration, as seen in figures 3 and 4. We also argue that the story-based interview technique, which explicitly asks participants to walk through recent, memorable experiences step by step, largely mitigates these disadvantages, since dancers could describe, sketch, or demonstrate what they meant.

Research Design Limitations. The benefit of an in-depth qualitative study of a limited number of expert dancers is the ability to gain rich insights into both their common and unique experiences. In this case, the small number of participants has clearly demonstrated the highly diverse nature of dancers' experiences and needs, and suggests the need for correspondingly diverse interactive tools. This study offers a preliminary example of how studying the transition between two practices can shed light on each, but would require a much larger study to make strong claims about how all such transitions occur.

4.7 Conclusion

We are interested in designing more effective tools to support dance learning by pre- and professional dancers. We focus on a common but as yet unexplored phenomenon, i.e. when dancers transition from ballet to a new style of dance. This transition forces dancers to explicitly reflect on each dance style, making it easier for them to share their insights. We conducted a study with 12 dancers who had transitioned from early, intensive ballet training to a different dance style, due to

injury, ageing or lack of opportunities as a professional ballet dancers. We wanted to identify the specific steps they take during this transition, the key obstacles they face, and their strategies for overcoming those obstacles, in order to gather deeper insights for designing new dance support technology.

We found that dancers go through three key phases: overcoming ingrained habits developed during their original ballet training, learning new movements, and seeking external movement techniques to help them transition in a sustainable way. At each step, they develop their own personal strategies, within and outside the studio. Instead of focusing on the mechanics of each new movement, they instead look outward beyond the current dance, or develop a hyper-awareness of the inner workings of their body. They also seek external guidance from teachers and choreographers, who develop methods for challenging their existing beliefs and supporting experimentation. Finally, they all explore a wide variety of movement-based activities, including other dance styles, meditation techniques and sports, to give them a solid foundation for continuing to evolve their personal dance style. Critically, they all struggle to counteract their ingrained mentalities, before they can successfully perform the new style of movement.

These obstacles are not linked to any particular movement phrase, style, or choreographer, but rather to the dancer's personal practice. These results challenge the conventional wisdom about how to design technologies for dancers, which usually focuses on the aspect of dance that today's technology can most easily capture—the mechanics of the dancer's movement. For these advanced dancers, this approach is exactly the opposite of what they need. Instead, they need exposure to new ideas, with a space for exploration and a path for continuously learning new aspects of the dance style over time.

Studying this transition phase offers deeper insights than studying dancers who are fully committed to a single style of dance, since we can learn from the ways they question their own assumptions, both about ballet and the new dance styles they attempt. Even though this process of contemplation is most apparent during the transition period, we believe it is relevant for all dance learning.

We also suggest three key design implications for the design of learning tools for pre- and professional dancers. First, we propose a novel approach—**movement substrates**—that contain text-based, visual and auditory representations of specific movements or dance phrases, with a corresponding set of constraints and relationships to interconnect

them. This would allow dancers and choreographers to explore different representations of the "same" movement as defined by other dance styles, teachers, sensations, etc., and discover novel frames for viewing and understanding each movement, creating space for surprises. Second, we argue that dancers should be able to choose their level of control over the system, from explicitly delegating control to an approved external guide, e.g., to overcome unwanted habits; to actively exploring the movement space, and experimenting with new constraints or alternative movement representations. Third, we propose letting dancers define and demonstrate their own movement variations, which would create a personal movement space for them to explore. Their movements could be reflected back to them verbally, graphically, auditorily or tactically, using the "making strange" approach to gain an outside perspective and deeper insights.

In the future, we argue that designers should look beyond current systems that prioritize movement capture, and instead create dance support tools that help dancers overcome ingrained habits, learn new movements, and find strategies for changing their mentality, both in the short and the long term. Beyond this, designers should consider supporting a full range of dancers' ways of interacting with movement, where learning dance is not viewed as simply the physical act of moving one's body through space, but rather as a rich, complex and ever-changing set of strategies for sensing, describing and embodying movement, that can benefit from a highly diverse set of multi-modal interactive tools.

5

ImproviGrid: Modality Effects on Cue Perception in Expert Movement Improvisation

This chapter examines the dancer perception of different output modalities during movement exploration. After reviewing literature on creativity in HCI and choreography, I describe the ImproviGrid tool. I present results from a structured observation study I conducted with expert, transitioned dancers, during which a choreographer gave cues to the dancers using ImproviGrid while they improvise.

5.1 Introduction

Since Fischer (2004) and Shneiderman (2002)'s work in the early 2000's, HCI researchers have explored how support tools for creativity can help creatives such as dancers generate more novel ideas in less time (Shneiderman et al., 2006). Tools like Knotation (Ciolfi Felice et al., 2018) and the Choreographer's Notebook (Singh et al., 2011) support dance choreography by making the score creation process interactive or augmenting video recordings with commentary for collaborative choreography. Recently, HCI researchers developed data-driven partners who, in a perfect world, react and generate new movement content with the dancer (Jacob et al., 2013; Liu et al., 2019). These creativity support

tools (CSTs) support the creation process from early-stage ideation and divergent thinking to later stage idea narrowing and selecting like setting structure for a specific piece.

Though it seems obvious to format output information visually in these choreographic CSTs (both Knotation and the Choreographer's Notebook are tablet and desktop compatible with multimedia), in a real-life context, dancers receive information through multiple channels. In the studio, dancers receive verbal input from choreographers and teachers. Music and sound are also inherently a large part of dance. Even without sound, dancers describe movement by its rhythm or the soundscape of a real-life setting to develop imagery. Visual input from replicating a choreographer's movement or defining movement vocabularies from a third-person perspective commonly exist, of course, but we see opportunity in expanding beyond visual output modalities in dance CSTs.

The problem becomes more urgent with the increasing presence of co-creative agents, which: "directly collaborate with users on creative tasks as an equal partner or colleague in the creative process by making independent contributions to a shared creative product" (Davis et al., 2016). These CSTs remove the role of the mediator, the choreographer, who makes decisions about use, adapting the CST to a specific use context. With other CSTs, an expert choreographer chooses to represent information as a video or description, for example, based on their experience and personal preference. They decide how to share information to their dancers in order to maximize comprehension or exploration. We, as HCI researchers, need to understand when and how to share information with a dancer if we want to design effective co-creative agents.

Just as choreographers know when to give musical, image, or descriptive cues, we want to understand how potential output modalities influence creative exploration with a future CST. We pose the following questions to structure our research:

- How does the dancer's perception of a co-creative agent differ when the system is able to express itself in multiple distinct modalities?

- How does that perception compare to their current experience improvising with a choreographer in-situ?

This chapter presents a structured observation study which employs the Wizard-of-Oz methodology to explore how dancers interact with

CST-given cues in the real-context of an improvisation session. The goal of this study is to offer design direction for co-creative agents that potentially use more than one modality, beyond vision-based, as means to express their decisions.

5.2 Related Work

I review current dance practices for supporting inspiration during choreography. Then, I present how the HCI community approaches the same problem, integrating technological tools into these choreographic processes. I remark on whether or not the approaches in these two communities align. Then, I discuss communication and perception between interactive systems and dancers by giving an overview of modalities in movement-based systems.

Sources of Inspiration for Dancers

Butterworth and Wildschut (2017) describe the contemporary dance choreographic process which include the following four stages that necessitate inspiration and ideation of some sort:

- Stage 1: Stimulus/Conception/Intention
- Stage 2: Dance Content
- Stage 4: Dance Content Development
- Stage 5: Structuring

During stage 1, choreographers develop the starting point, the initial idea of the piece, which includes defining the concept, context, and aim of the piece. Choreographers find inspiration for this stage from reading on specific subjects like mediation and yoga passages (Ciolfi Felice et al., 2016), photograph collections [1], musical compositions [2], or even their surroundings (McGregor, 2012), among other things.

When exploring dance content (stage 2), choreographers create their movement vocabulary for a specific piece, either with or through their dancers. As Gavish and Stevens (2020) note, improvisation is a popular example of an approach to movement language creation. Choreographers support inspiration in improvisation in a variety of ways, including creating more-or-less-modular generative scores, which define and

[1] http://www.wldn.fr/index.php/eng/people-united-en

[2] https://www.kennedy-center.org/education/resources-for-educators/classroom-resources/media-and-interactives/media/dance/music-as-dances-muse/

(a)

50/50 Doubling system	Body	Voice	Sound	Face	No face
Body			Scene 7: Tits/drums	Scene 5: body going first/face following	Scene 7: Tits/drums
Voice	Scene 2: Recorded voice/ Embodied rock-star	Scene 3: Recorded voice/live voice reproducing			
Sound	Scene 1: Drums/ass			Scene 5: body going first/face following with opera	
Face	Scene 4: Face/body going through expressions				
No face	Scene 6: Wig/ Pantomime body		Scene 6: Wig/ Pantomime body		

(b)

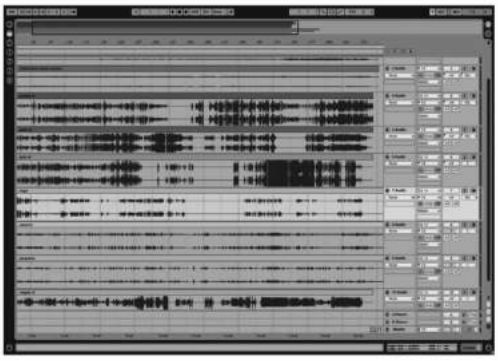


Figure 5.1. Example Movement Generative Scores Presented to the Dancer during Choreographic Creation: The left image is a part of the score for Mette Ingvartsen's piece *50/50*. On the right is the audio score of one dancer in Andros Zins-Browne's piece *Second Life*.

structure their inspired ideas from stage 1. We can equate these scores to musical partitions; however, instead of noting a piece for musicians to read and performing it directly as done by classical composers for classical music, choreographers use generative scores to explore new movement possibilities with dancers through the constraints given for a specific piece. For example, Hsueh et al. (2019b) cited a choreographer who created written Labanotation-based scores to express movement trajectories and indications for different breathing techniques and yoga focal points. Then, during rehearsals, dancers explored and questioned the score, which the choreographer updated through this research process. Other choreographers create scores in other formats, including a set of constraints in the form of verbal directives (Hsueh et al., 2019b), grids with accompanying directions (Chauchat et al., 2010) (see Figure 5.1 left), audio scores (Chauchat et al., 2010) (see Figure 5.1 right), and written monologues (see input from D5 in the *Results* section from chapter 4). (Note that the format of all these sources of inspiration for improvisation can be presented visually since they are shared through print media, but this does not imply that they exist for the dancer in print.)

Stage 2 blurs with stage 4, as choreographers manipulate their movement language to continue to develop it into movement phrases. Choreographers can maneuver movements through elements of dance, also called RADS (relationships, actions, dynamics, spaces)[3], or by Laban Movement Analysis and Bartenieff Fundamentals movement categories which include body, effort, space, and shapes. Choreographic devices, like the terms *abstraction*, *accumulation*, and *retrograde*, depict possible manipulations of movement which lead toward new viewpoints[4]. These tools, which exist as vocabulary sets used and shared as words in both written and spoken formats, give choreographers and

[3] https://www.turton.uk.com/wp-content/uploads/sites/2/2020/02/Dance-Key-Words.pdf

[4] https://k10outline.scsa.wa.edu.au/home/p-10-curriculum/curriculum-browser/the-arts/dance2/arts-overview2/glossary2/choreographic-devices

dancers instant directives for how to transform movement or what aspect of the movement on which to concentrate and explore.

During stage 5, "choreographers consider the structure of the piece both on a macro (how different parts relate to the whole) and micro level (the logical structure of smaller parts)" (Gavish and Stevens, 2020). As with dance content development, Gavish and Stevens found different strategies for playing locally, transitionally, and procedurally with the choreographic material (see Figure 5.2). Again, we see prewritten and verbalizable directives to explore potential ways of expressing structure which portrays the aim and context chosen by the choreographer.

Structuring Strategies		
Local Strategies (changes within a single design)	**Transitional Strategies (changes between designs)**	**Process Strategies**
■ Apply changes that relate to time/ space/dynamics	■ Add/remove sections ■ Lengthen/shorten sections	■ Brain-write ■ Contextualize ■ Assign form to each function
■ Add/remove/replace features/dancers	■ Repeat sections ■ Replace sections ■ Change the order of sections ■ Attach/detach ■ Overlap	■ Evaluate ■ Synthesize ■ Change focus ■ Propagate ■ Analyze morphology ■ Prioritize constraints

Figure 5.2. Gavish and Stevens' local, transitional, and procedural strategies for choreographic material manipulation for piece structuring

Here, we focus on stages 2 and 4, dance content creation and development, since co-creative agents at the moment focus on the activity of dancer improvisation and movement creation. As seen, artifacts used by choreographers for inspiration during these stages take a variety of forms, as written scores and monologues to audio scores and verbally-directive devices. This observation inspires us to explore alternative designs.

CSTs in HCI

Creativity research within HCI often focuses on the development of CSTs or Creativity Support Tools. Though we do not currently have an agreed definition for a CST, Frich et al. (2019) offer a tentative version: "A Creativity Support Tool runs on one or more digital systems, encompasses one or more creativity-focused features, and is employed to positively influence users of varying expertise in one or more distinct

phases of the creative process." They highlight the trend in supporting the idea generation phase, followed by implementation then evaluation. They comment that within HCI, in contradiction with creativity research, the expertise of the user is not always taken into consideration. They conclude that even with the many years of research, the variety of CSTs developed seem to be made and stay within the lab.

Of the 143 CST papers reviewed, Frich et al. (2019) include three specifically for choreography: Knotation (Ciolfi Felice et al., 2018), The Choreographer's Notebook (Singh et al., 2011), and the Tele-immersive dance environment presented by Sheppard et al. (2008), which offers choreographers and dancers a virtual space for collective creativity when physically distanced, supporting multiple viewpoints for creation as well. Unlike CSTs for other audiences, researchers in each of these projects worked closely with pre-professional dance students and professional choreographers, dancers, and musicians. Therefore, of the CSTs reviewed, the choreography tools support real-life practices of experts.

An up-and-coming category of choreographic CSTs is co-creative agents. For the application of dance, this collaboration usually happens during improvisation, not necessarily with the goal of choreographic creation. Systems like LumenAI (Liu et al., 2019), ViewpointsAI (Jacob et al., 2013), and InterACTE (Batras et al., 2016) all allow dancers to improvise with a virtual partner, present on a screen or in a VR environment, who analyzes the dancer's movement and has the potential to not only mimic their movement but offer new movement. The Living Archive[5] takes this interaction a step further by offering novel movement based on the specific style of each specific dancer in a company. Other systems like EVE (Jégo and Meneghini, 2020) or the project AI_am (Berman and James, 2015) integrate audience interaction by either adding the audience member as a third partner in improvisation or studying how audience members understand a virtual improviser. Lastly, Jochum and Derks (2019) study human-robot improvisation during three different performances, in break dancing, physical theatre, and modern dance, all during which the dancer and robot responded to each other, but rarely came into physical contact with the other. Though each agent implemented movement recognition and generation using different algorithms of analysis and altered the interactive installation during which dancers and/or audience members moved with the partner, the form of expression for the partner remained skeletal, mostly on a tablet, wall-sized display, or virtual headset.

[5] https://experiments.withgoogle.com/living-archive-wayne-mcgregor

For creating and developing dance content (choreographic stages 2 and 4), co-creative agents present an interesting possibility to support improvisation; however, the removal of the choreographer as a mediator, choosing how to best express different pieces of information, still poses a question for future integration of such a tool into the practice. Knotation (Ciolfi Felice et al., 2018) and the Choreographer's Notebook (Singh et al., 2011) both supported choreographic choice in format of the information choreographers want to share with their dancers and collaborators, describing the *quality* of a movement sequence as text or number or giving a correction to a dancer through text or a self-recorded video. The TED environment (Sheppard et al., 2008) allowed for identical creation interaction among choreographer, dancer, and musician in comparison to the real-world, changing only the location of each collaborator. However, if, during interaction with a choreographic CST, expert choreographers do not decide through which channel to share information to a dancer, how do we design the output of improvisation partners, potentially alternating among modalities depending on the expression type, for successful integration into a real-life use case?

Modalities and Movement

We employ Nigay and Coutaz (1993)'s definition of modality: "Modality refers to the type of communication channel used to convey or acquire information". We can view modalities in relationship to our senses and the technological displays with which we utilize each sense to interact: "vision (screens, head-mounted displays), hearing (speakers, headphones), haptics (robots, vibrotactile actuators), or a combination of them." (Sigrist et al., 2012) The term modality also implies that both communicators, system and user(s), can extract and transmit information through these channels, not just save or store information in a certain format (media).

In the case of using augmented feedback to support movement learning, the choice of modality in specific contexts transmits information more or less well. For example, vision-based modalities work best to support the user in perceiving spatial information, while hearing-based modalities are better at conveying information indicating movement error and single movement variables through sonification. For each modality, the timing and the design of the augmented feedback is also very important, especially in relation to task difficulty. For example, while visual concurrent augmented feedback, which is "provided during motor execution", leads to dependency for simple tasks, it creates a focus of attention outside of the task for complex tasks,

preventing cognitive overload (Sigrist et al., 2012). Inversely, for auditory augmented feedback, movement sonification supports simple task completion, while Sigrist et al. (2012) speculate that alarms and error sonification support single movement features for tasks of all difficulties. Effectiveness of modalities in transmitting useful information to the moving user differs depending on the type of information, and depends heavily on how well the feedback is designed.

Modalities are the channel of communication between user and system. This channel of communication is something previously chosen by the choreographer using a CST. However, designers of co-creative agents do not leave this decision up to the choreographers, but decide on the modality during system development. We focus on exploring the impact of modality on dancer-system CST interaction. To do so, we need a tool to compare modality perception and use during professional dancer improvisation in a real-life context.

5.3 ImproviGrid: Investigating Feedback Modality for Movement Improvisation

In this section, I present the design considerations and software implementation of ImproviGrid. Figure 5.4 gives an overview of the design schema.

Design Decisions

We designed ImproviGrid as a tool to be used by a choreographer. With ImproviGrid, the choreographer communicates to the dancer during improvisation, using technology as a medium. We partnered with a choreographer based in Paris who has experience using improvisation in her choreographic process, and developed the ImproviGrid interaction and modality vocabulary together.

We used a form of participatory design (Muller and Kuhn, 1993) between the choreographer, who would use the system during our studies, and us. Through discussions and pilot tests over a three-month period, we developed the feedback for each modality and the chosen structure of the study. The first implementation of ImproviGrid was designed for contemporary dancers who specifically work with choreographers who use improvisation for choreographer creation. We chose this population because of their comfort and experience with improvisation practices, avoiding unease in exercise commencement

and increasing depth in self-reflection.

Modality Choice. ImproviGrid supports visual and auditory feedback modalities due to the nature of current dance practices, and especially practices with Covid-19 restrictions. As previously stated, the visual modality supports the learning of spatial information. Plus, most co-creative agents for dance improvisation using deep learning express information visually. However, between music and the sounds of bodies against the floor, sound floods every dance creation space. Auditory feedback generally has a large presence in the dance studio. Also, we wanted to avoid heavy, wearable equipment since we know it can encumber the dancer (Liu et al., 2021; Trajkova and Cafaro, 2021) and to avoid contact with a shareable technology during the global pandemic. Additionally, to compare each modality individually, we did not include multi-modal feedback (though building to do so would be possible.) Therefore, we decided to support both visual and auditory feedback with ImproviGrid.

We chose to implement both verbal and non-verbal sounds in ImproviGrid. We were inspired by the presence of sound in the dance studio, as dancers receive information both through the music and through input from an external point of view, e.g. a choreographer or a teacher. Additionally, we were interested in integrating both more directive feedback that might replace the teacher, as well as drawing from the recent, open-ended augmented feedback alternative (Turmo Vidal et al., 2019,2). Dancers receive both in real-world, and therefore, we believed it necessary to include both in the design and to see how they are received.

The final design of ImproviGrid therefore supports 3 types of visual and auditory feedback: *visual*, *audio*, and *verbal*.

- *Visual* : short videos
- *Audio* : sound clips
- *Verbal* : sound clips of spoken phrases (computer generated)

For the visual modality, we chose short videos instead of images to highlight the movement. We additionally drew inspiration from GIFs [6] or short videos on applications like tiktok [7], a social media platform used by dancers of all styles and levels. We chose to use computer voices instead of recording a human speaking because of the interest in portraying the system, not the choreographer, as giving the input.

[6] https://giphy.com/

[7] https://www.tiktok.com/

We limited each file to less than 45 seconds of information, though some consisted of only 3-5 seconds of content that could be easily repeated. We chose to keep pieces of information short to avoid information overload and to support clearer communication (one piece of information communicates one idea).

Information Design: Vocabulary. How the information is represented greatly impacts its utility. Unclear or inappropriate feedback can counteract the potential positive effects (Sigrist et al., 2012). Therefore, we diligently designed each piece of information with the choreographer. We developed the feedback so that each piece of information translated the most clearly among the visual, verbal, and audio modalities.

We used a well-known, often performed variation from the classical ballet repertoire as a source for our vocabulary design: the Lilac Fairy variation from *The Sleeping Beauty* [8]. As stated in chapter 4, dancers trained in western countries who want to be professionals often have experience studying classical ballet. Additionally, ballet is a highly codified dance technique, in which each movement vocabulary term has a clear meaning. Plus, since classical ballet began in the 16th century, there is a lot of known history surrounding it. With this decision, we had the ability to recruit from a larger pool of contemporary dancers, and to source feedback ideas from many aspects of this ballet variation, meaning from the variation directly, the ballet vocabulary, or images that relate to actions or themes of the variation or performance context.

[8] https://www.youtube.com/watch?v=t0eqzWD1HH8&ab_channel=RoyalOperaHouse

We drew from the methods dancers used to break their movement habits in the style transition study in chapter 4 to develop interesting/reflective guidance for the dancer. We chose to pull from strategies for this challenge because of the nature of improvisation. Improvisation, as a training practice, helps dancers to "gain an awareness of their own sensorimotor habits and how to move against those habits" (Kronsted and Gallagher, 2021). We wanted to design our vocabulary to support the habit-bringing awareness process that is already a part of improvisation.

Rows one through four of ImproviGrid (counting up from the bottom) are based on strategies for outer body focus (see Figure 5.4). The first row brings aspects of the variation story and Lilac Fairy character to the dancers' eyes. The second row reminds the dancers of the performance and historical context in which they perform the variation. Row three alters the speed of the variation or repeats certain movements

Figure 5.3. Clips from the video recording of the Lilac Fairy from the classical ballet *The Sleeping Beauty*, used as a source of vocabulary for this design of ImproviGrid. This specific version of the variation is performed by the Royal Ballet in London, England.

from the variation (rond de jambe en l'aire, sissonne, and fouétté). Lastly, the fourth row draws from ch. 4's D10's use of Alexandre technique to get into the dancer's feedback loop and add new imagery for specific movements found in the variation.

The seventh column in each row is "chance". These "chance" pieces of feedback kept with the themes of each row, but were specifically not related to the variation. For example, in row two, "Context", we decided to use a sci-fi theme, which could give the dancer a new, rich setting unrelated to the variation in which to explore. (Row three does not include a "chance" because this category has a clear seven part division in relation to how the variation is constructed so we used all seven spaces.)

We decided to include a "chance" row during system implementation because of our emphasis on the richness of the information and the dancer's experience rather than the need to stick tightly to the variation framing. Even though our participants knew the Lilac Fairy variation, we labored to find commonly-known variation references that would speak to many. For example, when I learned the Lilac Variation, I knew about the character in that moment, while she gives her gift to the baby Aurora through dance; however, I did not know about her role in the rest of the performance. When designing the

(a) 

(b)

Choreographic Tools	Augment	Diminish	Retrograde	Mirror	Accumulate	Isolate	Remove Color	
Getting into the Feedback Loop and **Commonly Used Imagery**	*Feedback Loop:* Hey	*Feedback Loop:* Today-Date/time	*Feedback Loop:* No	*Imagery:* Spiral	*Imagery:* Up and Forward	*Imagery:* Card Flip	*Imagery:* Plop	Augment
Speed (1-4) and **Repetition (5-7)**	*Speed:* Half Time	*Speed:* Super Slow (.25x or .10x)	*Speed:* Double Time	*Speed:* Super Face (4x or 10x)	*Repetition* : Rond de jambe en l'air	*Repetition* : Sissonne	*Repetition* : Fouetté	Hey
Context	Clapping	Theatre	Breathing	Entrance (Trumpets)	Court Dance	Banquet	SciFi UFO	*Speed:* Half Time
Character	Gift	Doorbell	Whisper	Blessing	Call your Animal Helpers	Keys	Keyboard	Clapping

Figure 5.4. The ImproviGrid Design: The buttons on the MIDI Grid Controller on the left (a) correspond to the colors on the feedback outline on the right (b)

vocabulary for the "Character" row, we chose to structure vocabulary around major actions of the Lilac Fairy in a more universal telling of *the Sleeping Beauty*, beyond a single version of the variation or ballet. We hoped that this design decision would increase recognition and use of vocabulary across dancers with different experiences. The "chance" column allowed us to break from our strictly-imposed design structure to explore row vocabulary beyond the variation. We also hoped that the "chance" column would inject some surprise for the dancers and allow for comparison with variation-sourced vocabulary. We focused on finding appealing and intricate visuals and sounds to feed the dancer's creativity instead of digging for another Lilac fairy reference that may or may not be recognized by the dancer. We decided on the column seven vocabulary through personal use of the system. We supported movement exploration through the "chance" column which used a more open design space.

We made several design alterations after completing some pilot tests. First, we added the fifth row on top of the others which included contemporary choreographic devices[9]. The choreographer pointed out that for dancers who currently study techniques very different from classical ballet, they might need more support from time to time for creative exploration beyond ballet terms. Second, we decided to use 35 buttons, instead of filling the 56 total buttons on the board, because of an alteration in study structure. Instead of limiting the choreographer with a time restrictions (giving one piece of input every 15 seconds, for example) and button-use restrictions (giving a piece of input only once during an improvisation session), we decided that she could give any piece of input when she felt necessary. Beyond giving more freedom to the choreographer, the potential for repetition would allow for better dancer comprehension of an input through repetition of that input.

[9] https://artsintegration.com/wp-content/uploads/2014/09/Dance_Glossary_2012_for_2013-2.pdf

This decision lead to a smaller implemented vocabulary.

Figure 5.4 shows the final design of the first version of the ImproviGrid prototype. The image on the left (a) is the Midi grid controller that we used. The design on the right (b) gives an overview of all the information stored in each of the buttons for each modality. For example, in the "Context" row, we included:

- *Clapping:* as an audience would clap after a performance
- *Theatre:* as a theatre would feel with people entering before a performance
- *Breathing:* as the dancer would after they exit the stage after performing
- *Entrance (Trumpets):* as the royals at the time of the variation would enter the court
- *Court Dance:* as during a party in the 16th century
- *Sci-fi UFO:* as "chance"

We developed this vocabulary set from personal experience performing ballet in a theatre, the memories we have from that experience, and the video of the variation.

Figure 5.5 shows how we translated pieces of information across modalities. (Though I use an image to present the visual examples, the dancers received short videos of the action being performed.) For example, we translated the "pressing a doorbell" visual into the sound of a doorbell ringing and into the phrase "Ring the doorbell". We translated the "giving a blessing" visual into the sound of church chanting, and into the phrase "Give your blessing". Other translations can be found in the appendix.

Overall design choices developed from personal practice in improvisation and with the prototype. I tested the vocabulary implementations each time on my own, during my own improvisation practice. I discussed vocabulary with the choreographer and co-author, then continued developing the vocabulary from there. Design inspiration came from a mix of our personal experience performing ballet, the video of the variation, and personal preferences of the research team for interesting input, developed over an iterative process.

We focused on vocabulary implementations that were relatable and culturally relevant for western dancers of today, like myself and the choreographer. When a category of vocabulary related to movement, we directly manipulated the variation to communicate the information to the dancer. For example, when communicating a changed speed or transformation (as with the choreographic tools), the vocabulary implementation built off of the variation video itself. When bringing awareness to parts of the variation beyond the movement, we chose to take inspiration from the variation, but implement the vocabulary through relatable, common day images and sounds outside of the variation for the western dancers of today. Instead of the fairy giving baby Aurora a blessing with her movement, the "give your blessing" visual and audio input finds inspiration in a modern-day context for blessings: the church. We knew that dancers participating in the study would be coming from certain locations and cultures, like the research team. Therefore, we used specifically western cultural references for vocabulary design. Designing for the self translated to designing for the others (Vandenberghe and Slegers, 2016) when our dancer participants had similar backgrounds.

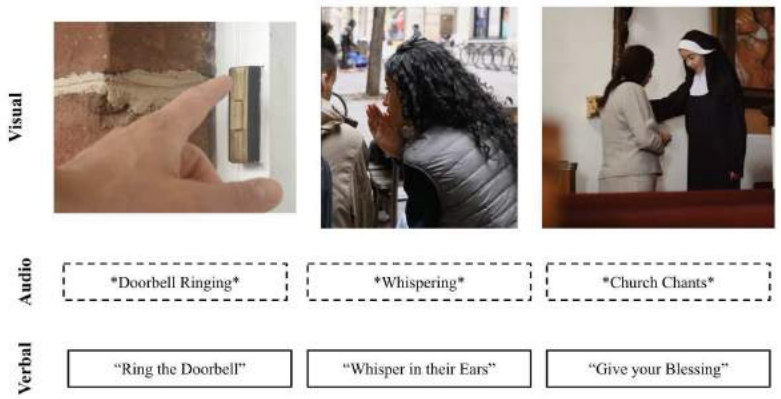


Figure 5.5. Example Translation Among Visual, Audio, and Verbal Feedback

ImproviGrid Implementation

I built upon electronic music technology, normally used to create musical sounds and electronic instruments, to create a tool for accessing and feeding pre-saved information to a dancer in real-time. I used a Novation Launchpad X MIDI grid controller with 64 buttons [10]. I implemented the corresponding program using the Max/MSP [11] visual programming language for multimedia and music, using specific functions in Jitter which support video. Max/MSP/Jitter programs, called patches, directly interface with the Lauchpad X, making for a seamless setup.

[10] https://novationmusic.com/en/launch/launchpad-x

[11] https://cycling74.com/

I used open source stock footage and built-in Mac programs to create the feedback information. For both the visual and audio feedback, I used open source stock sounds and videos that I cropped or transformed (speed, color, volume, etc.) using iMovie [12]. For the verbal feedback, I employed the 'say' command in OS X, using *Alex* and *Samantha* voices in English and *Thomas* and *Amelie* voices for the French dancers. Then, I used Audacity [13] to record the verbal file and Quicktime player [14] to cut and otherwise alter the file. (Note: For the ballet terms in French, I used a French-speaking voice for the verbal feedback for both the French-speaking and English-speaking dancers.)

[12] https://www.apple.com/imovie/

[13] https://www.audacityteam.org/

[14] https://support.apple.com/downloads/quicktime

In summary, we designed ImproviGrid to study dancer perception of different modalities of communication, from choreographer to dancer. Each button represents one piece of information, no matter the modality, allowing for memorizable interaction for the choreographer. The grid shape gives structure to that information. We integrate this technology into a focused study, as explained in section 5.4.

Technical Constraints of Design Decisions. Our choice in implementation by appropriating an electronic music tool led to design constraints. For example, rows equated to musical octaves, which include eight notes in total, the first and the last being the same note but in different octaves. This translated to the first button in each row storing the same information as the eighth button of the previous row. Instead of 64 buttons holding distinct information, we could only program 56 vocabulary terms.

Using an on-the-market system also decreased design possibilities, which inevitably impacted interaction. The grid controller had a square form factor and included 64 buttons with some surrounding buttons for setting control. We chose this piece of hardware because of our technical experience and knowledge at the time of development. We noticed the tool's limitations. We implemented the prototype as a technical probe (Hutchinson et al., 2003), focusing the study primarily on the experience of the dancers rather than designing a tool for a choreographer. We acknowledge that the form factor and unused buttons do not align with the spontaneous and ephemerality of improvisation and dance in general. Further research is needed to understand how the ImproviGrid shape and size impacts and could be improved for the choreographer experience during use.

5.4 Structured Observation Study: ImproviGrid in the Real World

The goal of this study is to compare the effects of different modalities in cues from the choreographer/teacher on dancers' ability to improvise. We conducted a structured observation (Garcia et al., 2014; Koch et al., 2020; Liu et al., 2021) with twelve pre-professional and professional contemporary dancers. This quasi-experiment (Cook and Campbell, 1979) creates a structure through which to observe novel user actions by combining controlled conditions of an experiment that support comparison while in an ecologically valid context, similar to an observation study. Here, we want to observe how the dancers process and use the interactive input and to compare how technology-mediated feedback giving and receiving alters the relationship between dancer and choreographer or teacher.

We adopted a Wizard-of-Oz methodology (Connell et al., 2013; Weiss et al., 2010) to support ecological validity and the pre-experimental stage of structured observation, and to observe how a choreographer perceives the changed relationship with a dancer when communicated through the technology. Since we build upon an already-existing practice, using improvisation for finding novel movement for choreographic creation, we preferred having an experienced choreographer give input to the dancer, when they felt the dancer needed or wanted new information, instead of codifying movement and setting responses into a system. Additionally, as structured observation generates testable hypotheses rather than testing pre-determined hypotheses, we chose to create an earlier stage prototype than to develop a final product. Plus, we do not need a a full system, which would support movement detection, to study our research questions. Implementing high-quality movement detection could hamper communication, interfering with our controlled variable comprehension. Lastly, we needed a choreographer in the loop, giving the feedback to the dancer, in order to uncover how their relationship develops when the dancer believes the system is giving interactive input while the choreographer stays behind the curtain, observing, interacting, and available for post-discussion.

Participants

We recruited twelve pre-professional and professional contemporary dancers (10 she/her; 1 he/him; 1 they/them) from the USA (7), France(4), and Greece(1) (see Table 5.1). Each dancer trained in classical ballet as a student before studying and/or performing professionally in con-

temporary dance. Dancers currently held roles as university students in pre-professional programs, professional dancers, choreographers, and/or teachers. 6 dancers held multiple roles, such as performing professionally while going back to university (like D4). None of the participants engaged in the interview study from chapter 4. All participants agreed to being observed, recorded and supplied informed consent before any session began. The procedures in this study were approved by COERLE, our organization's Institutional Review Board (IRB). No participant received monetary compensation for their participation.

	Pronoun	Timing Ballet -> Contemporary	Current Role	Years Working in Contemporary	Technology Use	Interest in Technology
D1	She/her	University	Dancer/ Teacher	20	Film - Performance GarageBand - Performance, class Zoom - Performance	Yes
D2	She/her	University	University Student	-5	Video Recording- personal practice Zoom-training	Yes
D3	She/her	University	Dancer/ Choreographer/ Teacher	5	Video Recording- personal practice	Yes
D4	They/them	Conservatory	University student/Dancer/ Choreographer/	-10	Video Recording- creation	Not really
D5	He/him	Post-Studies	Choreographer/Teacher	-10	Cell phone- selfie camera in recent works	Not really
D6	She/her	University	Dancer	5	Zoom- training	Yes
D7	She/her	University	Teacher	-5	Youtube- learning/ teaching variations Video Recording- creation Zoom- training	Yes
D8	She/her	Conservatory	Dancer/ Choreographer	-10	Program for randomness- created herself for creation Movement sensors and sound processors programs- experimentation, sound and improvisation, IRCAM	Yes
D9	She/her	Reprise	Dramaturge/ collaborator	-10	Light and sound- performance	Depends
D10	She/her	Post-Studies	Dancer	10	Light and sound- performance	Yes
D11	She/her	Conservatory	Dancer	-5	Cell phone camera- personal practice, music	Yes
D12	She/her	University	Dancer	5	Video Recorder- screendance (performance in front of camera) Ableton- music mixing for performance	Yes

Table 5.1. Summary of Dancer's training and career, both in ballet and contemporary dance, when they transitioned, any technology they used, and their future interest in dance technology

Setup

The study took place over a video call. At least one researcher and the choreographer (wearing masks) were set-up in a conference room with ImproviGrid. The researcher sat in front of the computer, controlled the modality software and video call screen, with the questionnaires to fill out, while the choreographer sat in front of the MIDI controller

Figure 5.6. Setup from Researcher View

(see Figure 5.6). The researcher pulled the video call up onto the two computer screens in the conference room. On the screens, the research team could see not only the dancer, but the timer and the mapping of the information of the controller (as a reminder) (see Figure 5.7).

We asked the dancers to pick a location in their home or otherwise in which they had the space and felt comfortable to move around and be recorded. Dancers were asked to place laptops or other large screens where they could be easily seen during improvisation (see Figure 5.8). As many took classes or had rehearsals over video call during the pandemic, they already had experience with this sort of setup, so we asked them to copy the setup that they previously applied. Additionally, we specifically asked dancers not to use cell phones or other screens of that size so that the video clips would be large enough and easily seen.

Procedure

The study lasts around 60-75 minutes, and is broken into five parts: Introduction, Modality 1, Modality 2, Modality 3, and Final Interview. Before the study itself, the research team sends dancers a pre-questionnaire and a video link of the variation, for memory refreshing purposes. After a set of participant sessions, the main researcher interviews the choreographer. For each dancer to test each modality, we apply a within-dancer design and counter balance for order.

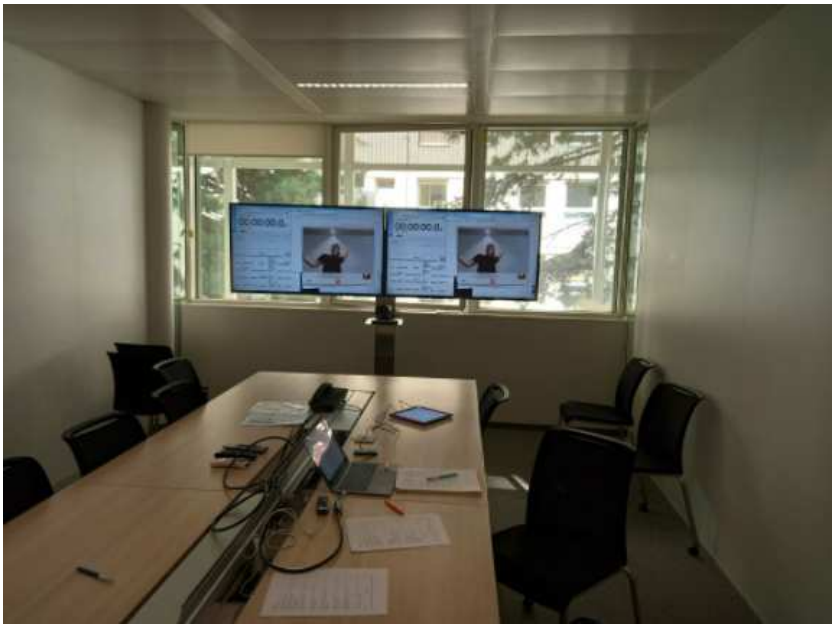


Figure 5.7. This is the exterior view of the study setup. The researcher sits in front of the laptop, the choreographer to the seat to the right, in front of the MIDI controller.

(a) **(b)**

Figure 5.8. The Dancers' view: D11 and D12 took photos of the view call from their point of view

Introduction: Dancers are presented with an example of each modality, but with a unrelated topic: the ocean. These first 5 minutes allow for a technology test, to assure screen sharing capabilities and high volume. The research team is also able to delineate with the dancer the viewable space in which the research team can see the dancer moving and within the space that the dancer can still hear and see the information being given. Dancers improvise for a short moment to the feedback, first as visual, audio, then verbal, to get an initial understanding of each modality.

Improvisation with Feedback in One Modality: Dancers improvise for eight minutes, timed by the research team. Each eight minute session is supported with feedback in one modality. At the end, a researcher delicately asks the dancer to finish. A researcher then asks the dancer a short Likert-style questionnaire with seven questions, and uses that as a base for deeper discussion, depending on the responses of the dancer. The questionnaire focuses on the experience while improvising with feedback in the specific modality, especially in comparison with the traditional context. Each session, in total, takes around ten to twelve minutes, and therefore, the three sessions back-to-back last around 30-40 minutes.

To ensure a real-world context, the choreographer gives feedback as she would in her personal practice, like in a creation process. Therefore, she is not constrained in frequency (how often to give a piece of information to the dancer) nor in buttons used (how many of the buttons she exposes to the dancer). She also repeats whichever piece of information she wants the number of times she wants. She gives feedback tailored to the dancer at that moment, but the board and information used remain the same throughout the study, for each session.

Semi-Structured Interview: After improvising with each modality, dancers are then again asked a five-point Likert-style questionnaire with seven questions, which fed into a more open-ended discussion about the overall experience using the system. Discussion focuses on comparison among the modalities, and future use and context for a tool such as ImproviGrid.

Researchers and Choreographer Discussion: After multiple sessions in a row, the research team and the choreographer discuss the experience of the choreographer throughout the studies for the day. A researcher focuses this discussion on the experience giving feedback, especially related to her real-life experience and her thoughts about

the responses of the dancers.

Data Collection

Before a session with a dancer, we asked them to complete a pre-questionnaire to gather information about their training and work both in ballet and contemporary dance, as well as experience and future interest in technology use in their career and personal practice. During each study, we collected video and audio recording of the video call as well as hand noted questionnaire responses and other additional thoughts.

Data Analysis

We first transcribed the audio from questionnaire-supported discussion and gave each dancer a unique code, from D1-D12. We then conducted a reflexive thematic analysis (Braun and Clarke, 2019) using a mixed approach, with both top-down (deductive) and bottom-up (inductive) approaches. The deductive analysis focused on differences among feedback modalities, specifically in relation to clarity, influence, and inspiration of information presented, constraint of the modality, and the development of the relationship between dancer and technology in comparison to the real-life situation with a choreographer/teacher. We remained open to inductive themes, especially those related to the research questions.

5.5 Results

We see patterns among how dancers perceive and use system feedback, in relation to each modality and overall. Additionally, dancers recognize different forms of constraint in each modality, but also discuss how constraint as a concept can aid in creative practices. Dancers compare feedback from each modality to experiences in their professional life, finding similarities and differences in comparison to receiving information from a choreographer or teacher. Finally, we comment on dancer response when imagining future use of a system like ImproviGrid, which reveals how dancers balance control while using such a system.

Dancer Use of Each Modality

Dancers overall preferred receiving the audio (8/12) and verbal (5/12) feedback to the visual (1/12) feedback. (Two dancers (D3 and D11)

Figure 5.9. D11 (left) responding to the visual cue of paint splotches (see bottom right corner of left screen) and D5 (right) exploring levels with audio input

equally enjoyed audio and verbal feedback.) Beyond preference, dancers noted that the audio feedback communicated more clearly the information stored in each clip than visual and verbal. On the other hand, dancers felt equally inspired to explore new ideas and to change their movement path because of the feedback across modalities. The following sections detail how dancers relate to the feedback in each modality.

Visual: At first glance, some dancers (6/12) acquire an idea from the visual with which to explore. Dancers either have an immediate reaction to the visual, as D12 said: *One look at the visual cue and you would know where to go*; or immediately identify the content of the visual, as D11 explained: *Because a picture, right away, you look at it and you say 'That's it'. You see? This is a chair.* With a short video clip, dancers express a sense of clarity that makes content of the visual easily recognizable or provoking.

Dancers (5/12) find the more abstract clips allow for more exploration. Dancers manage to abstract something from a clip and put it into or probe it with their body. D2 stated: *I think for a lot of the visuals, I took and abstracted, or it was already abstracted and I explored what it would be like in my body. So the first one was the swirl, and I just took that as having like a lot of swirls and rotations and circulations in my movement.* Left up to personal interpretation, abstract videos, like a water spiral or sci-fi swirling tubes, support improvisation

Conversely, dancers (5/12) tend to imitate the movement and actions of visuals of other dancers and people. The Lilac Fairy variation and the other visuals with people, like the soldiers, evoke similar movements or movement qualities from the dancer on screen. As D7 noted: *Anytime the Lilac Fairy videos would come up, I would jump a little bit more*

because I saw her jumping. Whether to dance the variation with Claire Calvert or join friends in whispering, dancers often copy a visual with other people in it.

Dancers also take movement shape and direction from the visual cues or connected visuals to previous memories. A few dancers (3/12) shared specific examples of exploring direction and shape, like bleeding out when seeing color splotches (D2) or *taking up space and spreading and spiraling* when seeing the airplane take off (D7). Visual cues reminded a few other dancers (3/12) of previous dance experiences. For example, the variation in black and white reminded D10 of her times studying dance history in school: *So when the variation was in black and white, it took me back to my dance history days and studying the origins of classical ballet and the long skirts and a lot of focus on the feet so it got me thinking about 'Okay, well if I was moving this way, now I'd really be thinking about my feet and wanting the audience to know that that's important.'* Connecting cues to previous dance experiences, as well as the shape and direction of the item moving in the visual, inspire dancers with new ideas for exploration.

The one dancer who favored visual cues, D12, prefered the visual cues because of the number of ideas she could generate from each cue. She explained that she had experience using visual input during improvisation, and had always preferred using visual cues: *That's again my preference as a visual person, but that input, automatically I had like 3 ideas pop up from one image whereas audio is pretty singular for me, same with the vocals, but (with the visuals) I could almost hear the lilac music, hear the people talking, which gave me like 2 things to off of, so it just felt like more information for me.* Therefore, though a majority (11/12) of the dancers did not prefer the visual cues, D12 shows that for visual learners, visual cues could be of interest.

Dancers usually quickly abstract an idea from each short video clip, with the more abstract videos specifically supporting exploration and the visuals with other people leading to movement imitation.

Verbal: Dancers (5/12) let the words of the verbal cues take them as they move, allowing for continuous exploration. D3 commented on how easy it was to get lost in another world with the verbal cues. Even when words are incomprehensible, dancers took the verbal sound clips as cues. D12 explained: *I mean, some things, I didn't understand what it was saying or I missed it, but that's also a cue, right? That's something to do.* Verbal cues, even when unable to be understood, supported dancer exploration while in the zone.

Other dancers (4/12) perceive the cues as clear instructions. As D1 explained, verbal cues avoid ambiguity in instruction: *You can still interpret it differently, but 'squeezing' is 'squeezing' and 'flopping' is 'flopping'* Dancers who prefer the verbal cues prefer their instructive nature. D6 explained: *I just liked the words. I liked hearing words and having them give me a specific direction to go in, even though I could take those words and go in whichever direction I wanted to...* When dancers view verbal cues as instructive, they appreciate the clarity and structure on which to improvise.

The choreographic devices, row five in the ImproviGrid prototype, stand out greatly to dancers as verbal cues. Most dancers (8/12) remembered specific choreographic devices, and recounted how they reacted to these cues. For example, D7 explained her need to slow down and reflect on her past movements when hearing the cue 'retrograde' (which 6/12 dancers in total specifically referenced): *Any time you said retrograde, I automatically slowed down because I always have to slow down when I retrograde things because I have to think.* Whether because of their logic as verbal cues or their presence in real-world improvisation, dancers know what to do with the choreographic devices.

Descriptions of images gave direction to the dancers. Some dancers (5/12) explained that phrases like "The UFO is landing" and "Spiral to the floor" prompted movement to the ground (D12 and D1). Similar to the visual cues, dancers abstracted direction from the verbal imagery.

One dancer, D3, experienced the verbal cues in a particular fashion because of her love and experience using words in improvisation. She lost herself in the rhythm of the a word or a string of words rather than in the meaning of the words. She felt that she did not have time to process the meaning of the word. As stated, other dancers agreed with her on the ability to let the words take them and their movement, but D3 was alone in having a love and experience working with words, therefore, highly preferring and using verbal cues differently.

Overall, dancers received verbal cues as instructions, through the choreographic devices, without distracting them from being in the zone of exploration.

Audio: The dancers who prefer audio input like that the abstractness of the sound allows for freedom in exploration. Half of the dancers (6/12) expressed this freedom from the abstractness of audio, like D9 did: *Because it's easier when it's completely abstract... it's completely free and in fact, for it to be completely free, it has to be completely abstract.* These

dancers appreciate the openness for interpretation that the non-verbal cues allow, that then supports exploration.

Similarly to the verbal input, the audio cues allow the dancer to get lost in their own world of exploration. Some dancers (6/12) mentioned the continuity of movement exploration. D8 recounted her experience: *it was easier to stay in what I was, more to maintain a kind of continuity and have the information coming in...* In this world, the dancers' bodies react to the input without the dancer thinking too much. D4 spoke about their experience: *Somehow, it's quite amazing how my body reacts to it (the audio cues) instantly and physically so movement comes out of it which I do not expect to come out of, did not realize that it would come out of.* With the audio cues, dancers have the opportunity to truly lose themselves in the zone of inner exploration and reflection, during which time the body subconsciously reacts to the non-verbal sounds from the system.

Dancers use the audio input in many different ways. Beyond taking qualities, direction, vibe, and rhythm from the sounds, dancers use the audio cues as follows:

- To guide their movement (D10)
- Each sound developed the last, as if the many different sounds combine to create one sound (D11, D5)
- Connecting sound to the environment then reacting to the environment (D3)
- Allowed the body to take the lead, reacting instantly to potentially pre-set associations with the sound (D12)
- Trying to find the dance of each sound (D5)
- Chaining the sounds become a sequence that command change in the body, where different sounds connect to different parts of the body (D9)

The abstractness of the sounds allow for dancers to relate and use them in a larger variety of ways than with visual and verbal feedback.

The chaining and timing between the sounds affects the dancers' exploration. Dancers (4/12) like D10 specifically point to the influence of the silence between the sounds, and the temptation in waiting for the following sound. As she explained: *As a dancer, you can make the choice*

to hold or keep moving and how do you keep moving when there's no sound and you're not sure what's coming next, lilac variation to a car starting. Though a couple of dancers referenced the chaining or timing among input when received through the other two modalities, this impact is more common in the case of audio input.

With non-verbal audio sounds, some dancers (4/12) find inspiration in the real-life reference of the sound. For example, D11 found inspiration from her experience in nature when she heard the bird sing in an audio cue: *For example, when it had the nature, a little bit of the birds, that really influenced me because it's a sound that I can relate to. It's a familiar thing so it really brought me into an atmosphere that I knew.* The airplane take-off sound reminded D6 of a tube man often found outside of car dealerships (see Figure 5.10 [15] for an example). Dancers explore their movement with these real-life references.

[15] https://www.spotpromotions.net/images/slideshow/dancing-inflatables/century-chevrolet-waving-inflatable-600.jpg

Dancers find liberty for exploration with the audio cues, using the cues in a diverse set of ways and allowing them to get lost in their own first-person, inner world in which their body physically reacts to cues.

Figure 5.10. An Example of a tube man found outside car dealerships; An audio cue of an airplane taking off reminded D6 of this real-life reference.

Overall Choice of Input Use

Dancers make a variety of choices about how to relate to the received input, no matter the modality. For example, some dancers allowed themselves to be impacted by each piece of information, letting the input *completely change my (D12's) direction* (D12). Others committed to using each piece of information, trying *to take it all in...*(D8). Others

felt obligated to take each piece of input into consideration (D1, D6, D12). Some even became upset when receiving certain pieces of input, responding with thoughts like *don't tell me (D3) what to do...*(D3). Each dancer relates to the input and their choice to use it differently, even across different modalities.

One pattern emerged between modality and choice to use input: dancers freely choose to use or let go of input for auditory modalities. D6 expressed that if a sound played that she didn't vibe with: *I'd hear them, they'd go off, then I'd go back to thinking about a sound that I liked.* Not once did a dancer express this sort of free choice to integrate or ignore input when receiving visual cues. Therefore, the verbal and audio cues allow the dancer more freedom to choose when to integrate a piece of input into their exploration or when to let it pass.

Modality and Constraint

Dancers expressed feeling more constrained with the visual input than both audio and verbal. On average, dancers scored between 'neutral' and 'agree' for feeling constrained by the visual input, while they generally 'disagreed' that the verbal and audio input constrained exploration.

Visual: Dancers feel that the visual modality constricts their exploration on two different levels. Firstly, in order to receive the information, the dancers need to be facing forward, toward their computer, inhibiting free movement in the body. D1, among many others (8/12), felt constricted by the necessary direction her body had to face to receive input: *I'd get involved in something, and then 'no I have to look and make sure that I'm getting the impetus for something else'... It feels very frontal.* Dancers feel the cognitive load of reminding themselves to look at the screen to receive new information.

Additionally, the clarity of how the dancer perceives the visual information, that what they see is the way it has to be, turns the cue into a command for the dancer, constraining the exploration direction. As D5 stated: *I was totally aligned with the instructions even though they were open, they were not direct instructions, but it much influenced my movement and since my movement was improvisation, it had a lot to do with it so it creates a strong impulse.* The dancers sensed a similar impression that obligated imitation inhibits exploration. Not only does the nature of how the dancer receives visual information negatively constrain exploration, but how the dancer processes this information does as well.

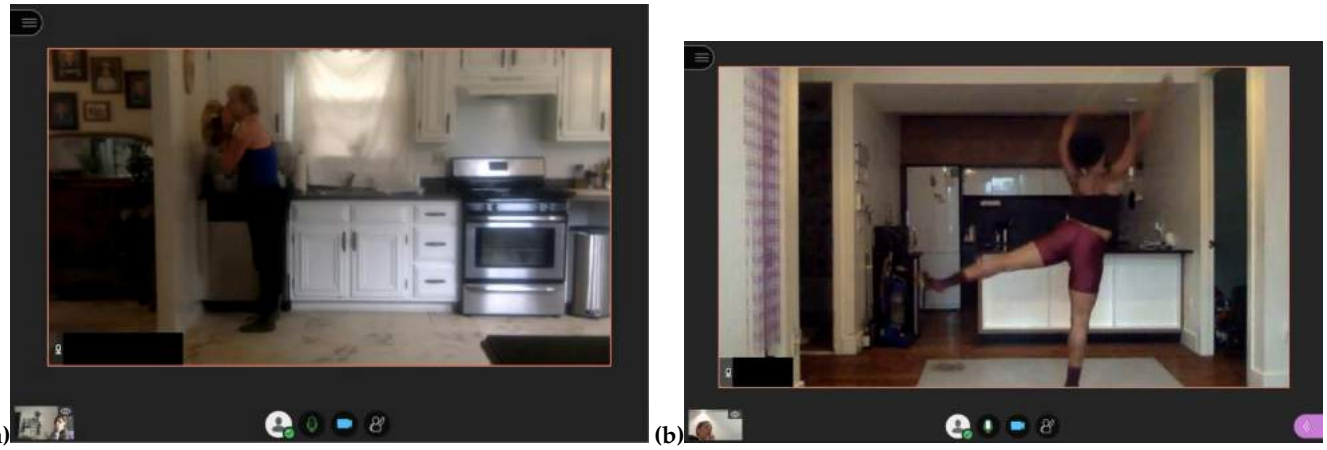


Figure 5.11. D1 (left) interacts with her environment, whispering to a piece of art on the wall, when responding to audio input and D6 (right) imitating balletic movements from the Lilac Fairy Variation

Verbal: Dancers often feel a gap in the verbal communication between the dancer and the system. Many dancers (7/12) complained that they did not understand the information being given because of the use of the computer-generated voice. D2 recounted her experience: *It might have been the computer voice because I'm so used to the natural inflection of someone talking so for it to be so monotone or kinda choppy, it's a lot of different sounds merging together for the system I'm guessing that it was hard for me to first of all listen to it and then process it, put it into movement.* The lack of intonation or even the knowledge of a non-human speaker disturbs the dancers, constraining exploration.

One dancer, D5, had a very horrible experience with the verbal feedback. He commented that the non-human voice altered his perception of himself: *It was so intense, the energy of the voice in the non-human way that it felt like I was almost a non-human, not in a good way. Yeah, I felt like I was part of the connection almost, the internet connection...* For D5, the non-human, unsuccessful communication of the verbal modality pushed him to such a negative place, rendering exploration almost impossible.

Audio: Audio input does not constrain the improvisation. Many dancers (7/12) explicitly stated that the input as a sound clip did not constrain their experience, and, if anything, expanded exploration instead. D7 explained through comparison with her everyday experience improvising: *I'm so used to improvising in silence, so having it there was an extra bonus because I could use the sounds to help further explore, like reacting from the sounds, rather than just listening to my breathing and the silence.* Dancers view the audio input as aiding with exploration, not constraining.

Constrain: Positive or Negative?

Though the word "constrain" has a generally negative connotation, dancers refer to it in a positive sense as well. Many dancers (8/12) mentioned on their own accord how beneficial constraints are for choreography and creativity. For D5, constraints are necessary for more creativity. For D8, constraints open doors. For D12, constraints *gave me a container for movement which I personally like in improv(isation) because if you just told me to do anything, I would lay on the ground, so I like having that container of something.* The context of interrogation by the researchers implied a negative connotation of the word "constrain"; however, dancers also relate and use constraints constructively, highlighting the complicated nature of the term and concept.

ImproviGrid vs. Real-Life

Dancers find audio and verbal feedback more similar to a choreographer than the visual feedback. However, for all modalities, dancers had mixed feelings about this comparison, either rating the comparison as 'disagree' and 'neutral' (visual) or 'neutral' and 'agree' (audio and verbal). Interestingly, dancers generally agreed that they used input from ImproviGrid similarly to input from a choreographer or teacher, in the real-world.

Visual: Dancers compare the visual input to other visual methods for inspiring new movement. Dancers find similarities between the visual cues and photo boards and collages, verbal descriptions of images, images or videos themselves, and copying a dancer, but without the three-dimensionality. Conversely, dancers also point out differences, including: the forced screen observation while moving (D6, D8); the increased interruptive nature (D1); and the increased objectivity (D3). A few dancers (4/10) noted the novelty in the experience, being unable to compare improvisation with the visual input to a real-life experience. Overall, dancers could compare their experience with the visual cues to professional experiences, but no one could make a direct comparison.

Verbal: Dancers find the verbal cues similar to the general experience of receiving information from a choreographer, however, with some disagreement in the specific terms used. D7 really summarized the opinions of the group when she stated: *I'm used to people talking to me while I'm doing things, so maybe some of the words weren't exactly what my teachers were used, but the concept of listening to what they are saying and then doing it while I'm listening to what they are saying is not new to me.* Most dancers (11/12) agreed that generally, this experience was

analogous with the real-life experience. Half the dancers (6/12) found the specific words in the verbal cues, like the choreographic devices, comparable to those used in the real-world, whereas 4/12 dancers disagreed. D8 explained: *In the indications that were more really related to the movement, it can be more like what I could be given as information by a teacher or a choreographer, but it's more the other indications that were more related to the variation, I understood less in general but I perceived that there were images a little more poetic. After that it depends, it could be just someone I haven't worked with, it's more like a new person I don't have a relationship with yet or I don't know.* Though most dancers equate verbal output from the ImproviGrid to a real-world experience, they disagreed on the real-world presence of the specific terminology used.

Audio: Similar to the visual cues, dancers relate the audio cues to other audio-based tools used in a real-life, choreographic setting. Half of the dancers (6/12) compared the experience to working with scores, soundscapes, improvising with transformed sound snippets, and dancing to the music in general. Unlike with the visuals, instead of pointing out the differences between audio cues and audio inspiration in real-life, dancers find similarity between the interaction with ImproviGrid and with a real choreographer. Dancers mention similarities in the information being communicated (D2), the back-and-forth with the guidance (D1, D10), the "gaze" of the outside view (D5), and the fluid reaction to the cues (D4). D4 further explained how the fluidity in their reactions reminded them of working with a choreographer who knew them well: *but in the way that I react to the audio, it's way more fluid which could make it more similar to someone I work with a lot that would know how to trigger those kinds of reactions, really fast and really smoothly.* The audio feedback reminds dancers of not only previous used forms of audio information for inspiration but also the interactions encountered with the choreographer during those experiences.

While the visual cues remind dancers of other visual forms of creativity support for improvisation, dancers see a mirrored experience with the verbal cues, though disagree on the set of terms previously experienced, and find similarity in interaction with the audio cues as with a real choreographer.

Other: Future Use and Control

When asked about future use, dancers have different opinions about who chooses the modality during an improvisation session. 4/12 dancers wanted to be in charge of that choice. 5/12 dancers would prefer that the system decide. 4/12 dancers are interested in the modality

selection happening at random. These differences in future use impact the role that the system plays: as a tool, a choreographer, and a collaborator.

Dancer-Controlled: Dancers who want to control the modality would use ImproviGrid as a tool, and choose modality based on the context. Dancers referenced how different modalities would afford different projects, or how even just the day or the mood of the dancer would demand for a different modality. D9 discussed how the uncomfortable modalities could hinder improvisation as they need a time to adapt and hesitation time, which hinders exploration since: *the longer you take to get into it, the less fluidly you get into it.* These dancers prefer to define for themselves when and how to use each modality.

System-Controlled: Dancers who prefer the system to choose the modality say that this case allows for surprises for the dancer, which pushes them; the difference between the system and random is that the system reflects the real-life scenario of having a choreographer, and some dancers prefer that. D2 explained: *I would like to see the combination, and like I said earlier when I talked about instructors basing the prompt of the dancer, I think the system choosing that would kind of be the same thing.* Additionally, one dancer, D7, noted that in the context of teaching, having some control of the how the system is developed would give her some control in how the system "chooses" the modality at any moment. As she said; *I don't think that I would totally want to chance just in case there are certain factors going into whatever it's doing that I didn't... like if I was going to use the system for a teaching moment, I would probably want to have like some control over it without having total control over it as opposed to just letting it happen.* These dancers are interested in ImproviGrid's capabilities to act as a choreographer, giving input to the dancer for specific reasons and reacting to the dancer's movement.

Random Control: Dancers who prefer the modality be chosen at random also say that this case allows for surprises for the dancer, which pushes them; however, in this case, these dancers like that neither the system nor the dancer how control, that there is a sense of lost control. Additionally, D12 noted that the random case would be less work for everyone and still lead to the same amount of surprise and pushing than the case in which the system leads. Like D6 said, the random modality choice would: *Keep me on my feet, mix it up, and then neither of us have control. It's like rolling the dice or random number generators.* These dancers prefer exploiting the technology's ability for randomization, keeping the control away from either party.

Dancers remain divided on the future use of ImproviGrid (as a tool, choreographer, or equal) and the control it holds over an improvisation session.

5.6 Conclusion

Results from the structured observation study of ImproviGrid suggest that designers would benefit from expanding the modality beyond visual to communicate co-creative agents decisions. Except for the one dancer who preferred working with visuals, dancers generally find the verbal cues more helpful for more structure in exploration, while audio cues allow for free exploration while staying in the zone of the first-person perspective. The verbal and audio feedback also allow dancers to filter and choose which cues to take and which to ignore. The visual modality constricts improvisation in its necessity to face the screen and its definitive communication, while the verbal and audio cues present less constraints or positively-viewed constraints. Dancers also find the verbal and audio feedback more similar to inspiration support tools in the real-world, and for the latter, similar styles of interaction.

6

Implications for the Design of Gesture-based Methods for Exploring Movement

In this chapter, I discuss how to translate the findings from the professional dancers' practices of the previous two chapters into methodologies to support everyday users in exploring new and interesting movement.

As mentioned in the conclusion of chapter 2, I see opportunity in integrating the first-person perspective into methodologies like gesture elicitation, possibly in the form of a movement exploration phase. This proposal responds to the difficulty overcoming industry standards when procuring gestures from users (Ruiz et al., 2011; Wobbrock et al., 2009). The technology-driven design approach places the importance on system-recognizability, defining gestures through the third-person perspective. When a user creates gestures for the observing researcher and the tracking system, movement possibilities remain constrained and limited. I am therefore not surprised that the users draw from their experience with pre-defined gestures for those current technologies.

A movement exploration phase would: a) allow the opportunity for users to focus on their sensations, getting into the first-person zone; b) clean the body of movements from the day; and c) offer surprises

by creating a space for discovering new sensations. The studies in chapters 4 and 5 offer insights into how exactly to structure such a movement exploration phase.

I propose building upon techniques for breaking movement habits used by the dancers interviewed to design input for the user during exploration. I suggest starting with a base movement or gesture phrase, to give the user some structure, unless they are comfortable with improvisation. Then, the user repeats the movement with an exterior focus. For example, the user could focus on an increased or decreased the speed, repetition of certain movements, or a user-written script of their movements to act out through the gestures. Users could alternatively adopt a highly acute inward focus, scanning the body or digesting body-base imagery associated with the performed movements. With this approach, overcoming industry standards means structuring movement exploration using dancer and choreographer methodologies for opening the body and listening to its reactions.

Researchers can guide the user through this exploration with non-visual support. I found that audio cues allow for more liberty in exploration, while dancers perceive verbal cues, if comprehensible, more as instructions. Those who preferred verbal cues enjoyed the instructive structure the cues offered. I see similarity between verbal, instructive feedback in dance and other activities, like sports. Therefore, I recommend beginning with instructive, verbal cues, using a known vocabulary of the user, before branching into audio sounds. More research is necessary to know if input modalities should be mixed or kept separate after the initial change from verbal to audio.

With this approach, researchers act as guides or facilitators who help users shift between first and third-person perspectives on their movement. I compare this role to that of a choreographer guiding the dancer to find new movement and meaning. Acting as this type of guide takes years of practice, as choreographers show, which gesture design researchers do not have nor might be interested in developing. An automated ImprovidGrid would incorporate this knowledge and ensure consistancy in exploration guidance across users. The researcher would facilitate the guidance. In either case, the user acts less as a specimen, being observed from the third-person perspective, and more as an knowledgeable body and mover.

This approach transforms procuring gestures from the user into generating *choreographic gestures*. I compare the movement exploration phase to the improvisation that occurs in stage 2 of the contemporary chore-

ographic process, during which dancers approach and re-approach movement surrounding the dance concept, context, and aim each day for a period of time. Improvisation then transforms into movement vocabulary definition, deciding and naming which movements to use in the piece. This transformation of actions reflects a transition from the first-person perspective to the third-person perspective. Similarly, eliciting gestures that begins with guided movement exploration mirrors stage two of a contemporary choreographic process, justifying the name choreographic gestures.

I argue that the process of generating choreographic gestures supports the creation of more expressive gestures. Mackay (2020) mentions three major themes of (gesture) interaction: *discoverability, appropriability and expressivity*. As she says, an expressive gesture *reveals their (users') personalities.* When creating choreographic gestures, users look more deeply inward for movement inspiration than when they learn gestures designed for them. In this case, choreographic gestures support novelty in a user's personal movement vocabulary and also represent the user, since they come from somewhere within the user. So generating choreographic gestures during which the user focuses on the first-person experience before taking a third-person perspective could support more expressiveness in gesture vocabularies for gesture-based interaction.

Limitations to this Approach Proposal

Two major limitations to this approach are the difficulty of applying it to novice movers and the timing of technology integration.

The methods of movement professionals to explore and learn new movement might not apply directly for novice movers. Movement experts such as professional dancers spend massive amounts of time exploring these themes. Therefore, they offer us with unique insights. However, dancers have a base of knowledge on which to explore that novices lack. For example, as seen previous experiential design works (Loke et al., 2013), it takes a certain level of curiosity to explore new movement in a new style of interaction. A more relatable environment similar to that of "traditional" styles of dance teaching or even sports training might be needed to support novice movement exploration. Further research is required to determine whether or not these approaches need to be altered, if some need to be favored over others, or if they need to be applied after an initial time of instruction when the audience changes from expert to novice mover.

Secondly, this proposed approach to user-centered interaction design also does not necessarily pertain to movement exploration and learning framed by a piece of technology for a certain space. Methods of professional dancers for breaking movement habits and learning new movements generally do not include technology. Though these methods could be helpful for novices in exploring movement, they do not take into consideration the eventual technology's presence. For example, would users during the exploration phase be expected to wear a movement capture suit or move in front of a Kinect? I predict that the transition from the absence to the presence of technology would alter the user's perception of the body and the experience, limiting the proposed approach. A limitation of this work therefore lies in understanding how, when, and the impact of movement capture technology integration.

This discussion just scratches the surface of a large research space for integrating expert movement knowledge to attend to both the first and third-person perspective for novice movers exploring movement. I hope this work contributes to the conversation of the challenging questions that arise in how best to benefit from interactive technology that supports the creation and learning of novel forms of movement.

7

Conclusions

Traditional methods for finding "natural" gestures result in vocabularies that reflect user habits with existing technologies. For example, gesture elicitation studies procure gestures that reflect industry standards (Ruiz et al., 2011; Wobbrock et al., 2009). Users draw gesture inspiration from what they know, routine interaction with everyday technologies, like cellphones. I began my research by comparing these traditional approaches with third-wave focused approaches, which foreground the felt experience and support the experience of the body. This comparison offers approach and design ideas for how to integrate movement sensitization into gesture elicitation, going beyond the movement habits to support self-reflection in gesture formulation.

This led me to explore how movement experts understand and reflect on their own movement. My work centered around the idea of a dance style transition, when a dancer trained in a formalized technique like ballet switches to professionally performing in another style of dance. During this time, dancers have to transition from old movement habits into moving in a new and different manner. From there, I expanded beyond movement re-learning into questioning system feedback design for supporting expert movers in movement exploration. In these latter projects, I developed a better understanding of the experiences of movement connoisseurs. I drew from the knowledge of expert movers to better design for the real-world movement exploration, understanding, and development process of any user.

7.1 Thesis Contributions

I compare trends in gesture- and movement-based design within the context of the third wave of HCI (Bødker, 2006) to try and reconcile the quantitative and qualitative approaches to interacting with movement. I propose the terms *technology-driven design* and *experiential design* and define them with example literature. I extract the target users, study context, design phase, focus of movement, and study goal, to facilitate comparison, and to bring to light the greater context, roles, and relationships that make up studies in these two design communities. I found that during technology-driven design studies, the researcher remains distant, observing an untrained user create gestures implicitly constrained by the device and its position. By contract, an experiential-design environment supports exploration for both the user and researcher alike, with a complete openness to movement, unfortunately causing problems with system approachability. Integrating activities that favor the first-person perspective into the technology-driven design methodologies offers a potential approach to uncover more personal gestures. Integrating structure outside of technological motion capture, such as an LMA analyst observer for all movers, could assist in comparison by offering standardized interpretation of movement. I suggest that these cross-approach integrations offer one alternative for reconciling the technology-driven and experiential design trends in the third wave of HCI.

I also studied the process of *dance style transitions* by professional dancers, which is currently unsupported by technology, to explore design opportunities for aiding dancers in their personal training practice. I present our analysis of the interview study, which reveals that: dancers use external or hyper internal foci to overcome movement habits; they lean on previous movement definitions, bodies, and self-developed structure to learn new movement styles; and they explore their practice through external channels, within and outside of artistic settings, to support their dance style transition overtime. I recommend designing for multiple and many representations of movement; mimesis and reflection learning methods within one tool; and supporting *definition-making* through movement. I argue that building on *movement substrates* can support dancer interaction with this multiplicity of representations. We discuss the challenge of designing control between the dancer and system, maintaining that dancers are interested in losing control to the system for habit-breaking activities for precise periods of time.

I designed and deployed *ImproviGrid*, which mediates a choreographer giving cues to a dancer during improvisation. I compared how modality (visual, verbal, and audio) affects dancer perception and use of cues. Dancers prefer the liberty they receive with the audio cues, but some like the structure and direction given with verbal cues. Dancers agree that the visuals negatively constrain exploration. They relate non-visual cues more to the real-life improvisation experience. I assert that researchers who design current CSTs for choreography, co-creative agents for movement, could find opportunity in expanding upon visual forms of agent communication to include other modalities.

I discussed the application of findings from studies in chapters 4 and 5 to everyday users in user gesture creation studies. I suggest that *choreographing gestures* instead of eliciting gestures could improve expressivity and personalization in user created gestures.

7.2 Directions for Future Research

Designing Feedback Vocabularies. As briefly mentioned in chapter 5, the vocabulary itself, the overall set of vocabulary, and list of vocabulary a dancer receives affects their experience during improvisation. For example, an abstract clip produces a different reaction to a clip of the Lilac Variation. The developed set included imagery and directives, and the order in which the dancers received them, classical music followed by ambiguous sound, disturbed some of the dancers. The vocabulary set may have affected the results and the conclusions drawn.

Like Felice et al. (2021b), I am interested in exploring ImproviGrid in the wild over a period of time. What vocabulary would be chosen based on a new audience? How would that vocabulary change over time? How does dancer perception of certain vocabulary sets or modalities change over time? Does changing the goal (choreographic creation, training) and the users (beginners, dancers in other styles) change the interaction and vocabulary used? Using ImproviGrid to mediate interaction between a dancer and choreographer and changing context, user, and time period, would lead to more expansive insights about this process and how to design for it wholly.

Study Transitions in Other Contexts. Studying other kinds of movement transitions allows researchers to reflect on other support tools for physical activities. Dance style transitions cause dancers not only

to break their ingrained movement habits and muscle memory, but also to directly question their previous experiences. Applications that could benefit from understanding similar movement transitions include support for sports training or rehabilitation. Transitions exist in technology use as well, for example when users move between technology brands of computers or cellphones. Investigating user reflection toward habits in technology use offer insights into design for interaction in general.

Re-imaging Dance Support Tools: Finding Patterns in Idiosyncratic Contexts. My approach to studying dance, through major dance career transitions, has the potential to inform researchers on designing tools to support dancers' practices beyond any specific technique or choreographic style. Dance learning support tools and CSTs for choreography are situated in specific teaching or creation contexts and are designed for the idiosyncrasies of individual choreographers and pieces (Ciolfi Felice et al., 2016; Felice et al., 2021b). Studying major moments of change in a dancer's training or career inherently brings reflection of practice(s) from an outside view. This experience allows for a comparison of techniques or contexts in which they work or study. Designers then have the opportunity to find patterns across contexts and choreographers, techniques and teachers, on which they can structure novel interactive systems. Researchers could shift from codifying then quantifying movement through a technique's or choreographer's vocabulary to loosely defining and continuously updating mappings of movement and sensation from multiple points of view according to the dancer's preferences and background. With this approach, designers can build systems which respect idiosyncrasies of dancers' practices, allowing for diversity in system use, while also building for the overarching dancer experience.

A

ImproviGrid Design Details

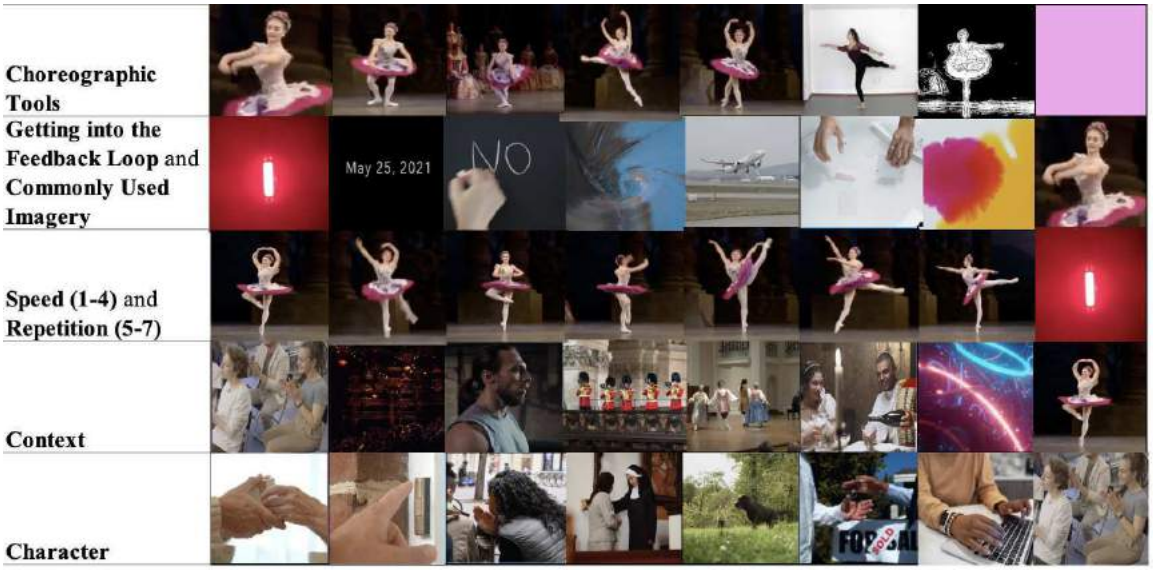


Figure 1 (above) show the design of the visual cues in ImproviGrid. The images are screenshots of the short video clips used. Therefore, some images do not entirely reflect the movement in the visuals.

Figure 2 (first below) presents the phrases spoken by the system as verbal cues.

Figure 3 (second below) presents the descriptions of the audio cues.

Choreographic Tools	*Augment the Movement*	*Diminish the Movement*	*Retrograde the Movement*	*Mirror the Movement*	*Accumulate Movements*	*Isolate a Movement*	*Remove Color from the Movement*	
Getting into the Feedback Loop and **Commonly Used Imagery**	*Hey*	*Today is June 21st. It is after 7am. You are in motion.*	*No*	*Spiral into the Floor*	*Up and Forward*	*Like Flipping a Card*	*Plop, plop, plo*	*Augment the Movement*
Speed (1-4) and **Repetition (5-7)**	*Move at Half Time*	*Move at a Quarter Time*	*Move at Double Time*	*Move at Quadruple Time*	*Rond de jambe en l'air*	*Sissonne*	*Fouetté*	*Hey*
Context	*The Audience is Applauding*	*The Theatre Begins to Fill*	*Breathing Heavily after the Variation*	*The Royal Party Enters the Court*	*The Royal Court Dances*	*Food and Drinks are Served*	*The UFO is Landing*	*Move at Half Time*
Character	*Give your Gift*	*Ring the Doorbell*	*Whisper in their Ears*	*Give your Blessing*	*Call for your helpers*	*Give the Keys*	*Type a Message*	*The Audience is Applauding*

Choreographic Tools	Variation Music- Increase Volume	Variation Music- Decrease Volume	Variation Music- Reversed	Echoing Voice	Accumulate Variation Music	Fouetté Feet Landing	Black and White Film	
Getting into the Feedback Loop and **Commonly Used Imagery**	Scream- "Hey"	Nature Noises	Scream- "No"	Gumball in Machine	Xylophone	Card Flipping	Water Drops	Variation Music- Increase Volume
Speed (1-4) and **Repetition (5-7)**	Variation Music at 1/2 Speed	Variation Music at 1/10 Speed	Variation Music at Double Speed	Variation Music at 10x Speed	Variation Music- Rond de jambe en l'air	Variation Music- Sissonne	Variation Music- Fouetté	Scream- "Hey"
Context	Clapping and Cheering	Intermission Sounds	Breathing	Trumpets Playing	Medieval Music	Banquet Soumds	Sci-Fi Sounds	Variation Music at 1/2 Speed
Character	Wrapping Paper Crunching	Doorbell Sound	Whispering	Church Chants	Princess Calling for Birds	Keys Jingling	Keyboard Noises	Clapping and Cheering

References

Aalten, A., Brown, D., and Vos, M. (2014). *Ballet, why and How?: On the Role of Classical Ballet in Dance Education*. Academia series. ArtEZ Press.

Alaoui, S. F., Bevilacqua, F., and Jacquemin, C. (2015a). Interactive visuals as metaphors for dance movement qualities. *ACM Trans. Interact. Intell. Syst.*, 5(3).

Alaoui, S. F., Caramiaux, B., Serrano, M., and Bevilacqua, F. (2012). Movement qualities as interaction modality. In *Proceedings of the Designing Interactive Systems Conference*, DIS '12, page 761–769, New York, NY, USA. Association for Computing Machinery.

Alaoui, S. F., Carlson, K., and Schiphorst, T. (2014). Choreography as Mediated through Compositional Tools for Movement: Constructing A Historical Perspective. In *Proceedings of the 2014 International Workshop on Movement and Computing (MOCO)*, Paris, France.

Alaoui, S. F., Schiphorst, T., Cuykendall, S., Carlson, K., Studd, K., and Bradley, K. (2015b). Strategies for Embodied Design: The Value and Challenges of Observing Movement. In *ACM Creativity and Cognition*, Glasgow, United Kingdom.

Alexiadis, D., Kelly, P., Daras, P., O'Connor, N., Boubekeur, T., and Ben Moussa, M. (2011). Evaluating a dancer's performance via kinect-based skeleton trackinga dancer's performance via kinect-based skeleton tracking. pages 659–662.

Alizadeh, H., Witcraft, A., Tang, A., and Sharlin, E. (2016). Happyfeet: Embodiments for joint remote dancing. In *Proceedings of the 42nd Graphics Interface Conference*, GI '16, page 117–124, Waterloo, CAN. Canadian Human-Computer Communications Society.

Allen, N., Nevill, A., Brooks, J., Koutedakis, Y., and Wyon, M. (2012). Ballet injuries: Injury incidence and severity over 1 year. *Journal of Orthopaedic & Sports Physical Therapy*, 42(9):781–A1. PMID:

22814244.

Anderson, F., Grossman, T., Matejka, J., and Fitzmaurice, G. (2013). Youmove: Enhancing movement training with an augmented reality mirror. In *Proceedings of the 26th Annual ACM Symposium on User Interface Software and Technology*, UIST '13, page 311–320, New York, NY, USA. Association for Computing Machinery.

Aristidou, A., Stavrakis, E., and Chrysanthou, Y. (2014). Motion analysis for folk dance evaluation.

Ashbrook, D. and Starner, T. (2010). Magic: A motion gesture design tool. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '10, page 2159–2168, New York, NY, USA. Association for Computing Machinery.

Batras, D., Guez, J., and Jégo, J.-F. (2016). Interacte: Improvising with a virtual actor. pages 1–2.

Bau, O. and Mackay, W. E. (2008). Octopocus: A dynamic guide for learning gesture-based command sets. In *Proceedings of the 21st Annual ACM Symposium on User Interface Software and Technology*, UIST '08, page 37–46, New York, NY, USA. Association for Computing Machinery.

Beaudouin-Lafon, M. (2017). Towards unified principles of interaction. In *Proceedings of the 12th Biannual Conference on Italian SIGCHI Chapter*, CHItaly '17, New York, NY, USA. Association for Computing Machinery.

Beaudouin-Lafon, M., Bødker, S., and Mackay, W. E. (2021). Generative theories of interaction. *ACM Trans. Comput.-Hum. Interact.*, 28(6).

Bergonzoni, C. (2017). When i dance my walk: A phenomenological analysis of habitual movement in dance practices. *Phenomenology Practice*, 11:32.

Berman, A. and James, V. (2015). Improvising virtual dancer meets audience: Observations from a user study.

Bernardet, U., Alaoui, S. F., Studd, K., Bradley, K., Pasquier, P., and Schiphorst, T. (2019). Assessing the reliability of the Laban Movement Analysis system. *PLoS ONE*.

Bødker, S. (2006). When second wave hci meets third wave challenges. In *Proceedings of the 4th Nordic Conference on Human-Computer Interaction: Changing Roles*, NordiCHI '06, page 1–8, New York, NY, USA. Association for Computing Machinery.

Bradford, J. and Côté-Laurence, P. (1995). An application of artificial intelligence to the choreography of dance. *Comput Hum*, 29:233–240.

Braun, V. and Clarke, V. (2019). Reflecting on reflexive thematic analysis. *Qualitative Research in Sport, Exercise and Health*, 11(4):589–597.

Butterworth, J. and Wildschut, L. (2017). *Contemporary Choreography: A Critical Reader*.

Byars, W. and Karam, O. (2017). *Leçons de danse, leçons de vie*. First éditions.

Cabral, D., Carvalho, U., Silva, J. a., Valente, J. a., Fernandes, C., and Correia, N. (2011). Multimodal video annotation for contemporary dance creation. In *CHI '11 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '11, page 2293–2298, New York, NY, USA. Association for Computing Machinery.

Calvert, T., Wilke, L., Ryman, R., and Fox, I. (2005). Applications of computers to dance. *IEEE computer graphics and applications*, 25:6–12.

Camurri, A., Canepa, C., Ferrari, N., Mancini, M., Niewiadomski, R., Piana, S., Volpe, G., Matos, J.-M., Palacio, P., and Romero, M. (2016). A system to support the learning of movement qualities in dance: A case study on dynamic symmetry. In *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct*, UbiComp '16, page 973–976, New York, NY, USA. Association for Computing Machinery.

Camurri, A., Hashimoto, S., Ricchetti, M., Ricci, A., Suzuki, K., Trocca, R., and Volpe, G. (2000). Eyesweb: Toward gesture and affect recognition in interactive dance and music systems. *Comput. Music J.*, 24(1):57–69.

Carlson, K., Schiphorst, T., and Pasquier, P. (2011a). Scuddle: Generating movement catalysts for computer-aided choreography. pages 123–128.

Carlson, K., Schiphorst, T., and Shaw, C. (2011b). Actionplot: A visualization tool for contemporary dance analysis. In *Proceedings of the International Symposium on Computational Aesthetics in Graphics, Visualization, and Imaging*, CAe '11, page 113–120, New York, NY, USA. Association for Computing Machinery.

Chan, J. C. P., Leung, H., Tang, J. K. T., and Komura, T. (2011). A virtual reality dance training system using motion capture technology. *IEEE Trans. Learn. Technol.*, 4(2):187–195.

Chatzopoulos, D. (2019). Effects of ballet training on proprioception, balance, and rhythmic synchronization of young children. 22:26–37.

Chauchat, A., Ingvartsen, M., and Zoë, P. (2010). *Everybodys performance scores*. Everybodys Publications.

Cherry, G., Fournier, J., and Stevens, R. (2003). Using a digital video annotation tool to teach dance composition. 5.

Ciolfi Felice, M. (2018). *Supporting expert creative practice*. PhD thesis.

Ciolfi Felice, M., Alaoui, S. F., and Mackay, W. E. (2016). How do choreographers craft dance? designing for a choreographer-technology partnership. In *Proceedings of the 3rd International Symposium on Movement and Computing*, MOCO '16, New York, NY,

USA. Association for Computing Machinery.

Ciolfi Felice, M., Fdili Alaoui, S., and Mackay, W. (2018). Knotation: Exploring and Documenting Choreographic Processes. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, Montreal QC, Canada.

Connell, S., Kuo, P.-Y., Liu, L., and Piper, A. M. (2013). A wizard-of-oz elicitation study examining child-defined gestures with a whole-body interface. In *Proceedings of the 12th International Conference on Interaction Design and Children*, IDC '13, page 277–280, New York, NY, USA. Association for Computing Machinery.

Cook, T. and Campbell, D. (1979). *Quasi-Experimentation: Design and Analysis Issues for Field Settings*. Houghton Mifflin.

Crnkovic-Friis, L. and Crnkovic-Friis, L. (2016). Generative choreography using deep learning. *CoRR*, abs/1605.06921.

Cronholm, S. (2001). Usability versus actability: A conceptual comparative analysis.

Davis, N., Hsiao, C.-P., Singh, K., and Magerko, B. (2016). Co-creative drawing agent with object recognition.

Delamare, W., Janssoone, T., Coutrix, C., and Nigay, L. (2016). Designing 3d gesture guidance: Visual feedback and feedforward design options. In *Proceedings of the International Working Conference on Advanced Visual Interfaces*, AVI '16, page 152–159, New York, NY, USA. Association for Computing Machinery.

Dewey, J. (2005). *Art as experience*. Penguin, New York, NY, USA.

Dias Pereira dos Santos, A., Yacef, K., and Martinez-Maldonado, R. (2017). Let's dance: How to build a user model for dance students using wearable technology. In *Proceedings of the 25th Conference on User Modeling, Adaptation and Personalization*, UMAP '17, page 183–191, New York, NY, USA. Association for Computing Machinery.

Donovan, J. and Brereton, M. (2004). Meaning in movement: A gestural design game. *Proceedings of PDC2004 Artful Integration: Interweaving Media, Materials and Practices*, 2:27–31.

dos Santos, A. D. P., Loke, L., and Martinez-Maldonado, R. (2018). Exploring video annotation as a tool to support dance teaching. In *Proceedings of the 30th Australian Conference on Computer-Human Interaction*, OzCHI '18, page 448–452, New York, NY, USA. Association for Computing Machinery.

Drobny, D. and Borchers, J. (2010). Learning basic dance choreographies with different augmented feedback modalities. In *CHI '10 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '10, page 3793–3798, New York, NY, USA. Association for Computing Machinery.

Drobny, D., Weiss, M., and Borchers, J. (2009). Saltate! a sensor-

based system to support dance beginners. In *CHI '09 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '09, page 3943–3948, New York, NY, USA. Association for Computing Machinery.

Ehrenberg, S. (2015). A kinesthetic mode of attention in contemporary dance practice. *Dance Research Journal*, 47:43–61.

Ericsson, K., Krampe, R., and Tesch-Roemer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review*, 100:363–406.

Eriksson, S., Unander-Scharin, r., Trichon, V., Unander-Scharin, C., Kjellström, H., and Höök, K. (2019). *Dancing With Drones: Crafting Novel Artistic Expressions Through Intercorporeality*, page 1–12. Association for Computing Machinery, New York, NY, USA.

Fdili Alaoui, S. (2019). Making an interactive dance piece: Tensions in integrating technology in art. In *Proceedings of the 2019 on Designing Interactive Systems Conference*, DIS '19, page 1195–1208, New York, NY, USA. Association for Computing Machinery.

Feld, S. (1992). Sharing the dance. contact improvisation and american culture, by cynthia j. novack. new directions in anthropological writing. madison, wisconsin: University of wisconsin press, 1990. xvii 258 pp., photographs, references, index. *Dance Research Journal*, 24(1):37–38.

Felice, M. C., Alaoui, S. F., and Mackay, W. E. (2021a). Studying choreographic collaboration in the wild. In *Designing Interactive Systems Conference 2021*, pages 2039–2051.

Felice, M. C., Alaoui, S. F., and Mackay, W. E. (2021b). Studying choreographic collaboration in the wild. In *Designing Interactive Systems Conference 2021*, DIS '21, page 2039–2051, New York, NY, USA. Association for Computing Machinery.

Fernandez, J. and Young, L. (2005). Comparative study of human computer interaction design and software engineering. *ASEE Annual Conference and Exposition, Conference Proceedings*, pages 1979–1988.

Fischer, G. (2004). Social creativity: Turning barriers into opportunities for collaborative design. In *Proceedings of the Eighth Conference on Participatory Design: Artful Integration: Interweaving Media, Materials and Practices - Volume 1*, PDC 04, page 152–161, New York, NY, USA. Association for Computing Machinery.

Flanagan, J. C. (1954). The critical incident technique. *Psychological Bulletin*, (4):327–358.

Franko, M. (2012). Apollo's angels: A history of ballet by jennifer homans. *TDR (1988-)*, 56:198–203.

Frich, J., MacDonald Vermeulen, L., Remy, C., Biskjaer, M. M., and Dalsgaard, P. (2019). *Mapping the Landscape of Creativity Support Tools in HCI*, page 1–18. Association for Computing Machinery,

New York, NY, USA.

Garcia, J., Tsandilas, T., Agon, C., and Mackay, W. (2012). Interactive paper substrates to support musical creation. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '12, page 1825–1828, New York, NY, USA. Association for Computing Machinery.

Garcia, J., Tsandilas, T., Agon, C., and Mackay, W. E. (2014). Structured observation with polyphony: A multifaceted tool for studying music composition. In *Proceedings of the 2014 Conference on Designing Interactive Systems*, DIS '14, page 199–208, New York, NY, USA. Association for Computing Machinery.

Gaver, B. and Bowers, J. (2012). Annotated portfolios. *Interactions*, 19(4):40–49.

Gavish, M. and Stevens, C. (2020). Thinking strategically about dance making: An analysis of the structuring stage and the strategies choreographers use for varying dance works. *Dance Research*, 38:41–64.

Giordano, G. (1992). *Jazz Dance Class: Beginning Thru Advanced*. Dance Horizons Book. Princeton Book Company.

Großhauser, T., Bläsing, B., Spieth, C., and Hermann, T. (2012). Wearable sensor-based real-time sonification of motion and foot pressure in dance teaching and training. *J. Audio Eng. Soc*, 60:580–589.

Hachimura, K., Kato, H., and Tamura, H. (2004). A prototype dance training support system with motion capture and mixed reality technologies. In *RO-MAN 2004. 13th IEEE International Workshop on Robot and Human Interactive Communication (IEEE Catalog No.04TH8759)*, pages 217–222.

Hallam, J., Keen, E., Lee, C., McKenna, A., and Gupta, M. (2014). Ballet hero: Building a garment for memetic embodiment in dance learning. In *Proceedings of the 2014 ACM International Symposium on Wearable Computers: Adjunct Program*, ISWC '14 Adjunct, page 49–54, New York, NY, USA. Association for Computing Machinery.

Handcock, M. S. and Gile, K. J. (2011). Comment: On the concept of snowball sampling. *Sociological Methodology*, 41(1):367–371.

Höök, K. (2010). Transferring qualities from horseback riding to design. In *Proceedings of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries*, NordiCHI '10, pages 226–235, New York, NY, USA. ACM.

Höök, K., Benford, S., Tennent, P., Tsaknaki, V., Alfaras, M., Avila, J. M., Li, C., Marshall, J., Roquet, C. D., Sanches, P., Ståhl, A., Umair, M., Windlin, C., and Zhou, F. (2021). Unpacking non-dualistic design: The soma design case. *ACM Trans. Comput.-Hum. Interact.*, 28(6).

Höök, K., Caramiaux, B., Erkut, C., Forlizzi, J., Hajinejad, N., Haller, M., Hummels, C. C. M., Isbister, K., Jonsson, M., Khut, G., Loke, L., Lottridge, D., Marti, P., Melcer, E., Müller, F. F., Graves Petersen, M., Schiphorst, T., Segura, E. M., Ståhl, A., Svanaes, D., Tholander, J., and Tobiasson, H. (2018). Embracing First-Person Perspectives in Soma-Based Design. *Informatics*, 5(1).

Hsia, L.-H., Huang, I., and Hwang, G.-J. (2016). Effects of different online peer-feedback approaches on students' performance skills, motivation and self-efficacy in a dance course. *Comput. Educ.*, 96(C):55–71.

Hsueh, S., Alaoui, S. F., and Mackay, W. E. (2019a). Deconstructing creativity: Non-linear processes and fluid roles in contemporary music and dance. *Proc. ACM Hum.-Comput. Interact.*, 3(CSCW).

Hsueh, S., Alaoui, S. F., and Mackay, W. E. (2019b). Deconstructing creativity: Non-linear processes and fluid roles in contemporary music and dance. *Proc. ACM Hum.-Comput. Interact.*, 3(CSCW).

Hsueh, S., Alaoui, S. F., and Mackay, W. E. (2019c). *Understanding Kinaesthetic Creativity in Dance*, page 1–12. Association for Computing Machinery, New York, NY, USA.

Hummels, C., Overbeeke, K. C., and Klooster, S. (2007). Move to get moved: A search for methods, tools and knowledge to design for expressive and rich movement-based interaction. *Personal Ubiquitous Comput.*, 11(8):677–690.

Hutchinson, H., Bederson, B., Druin, A., Plaisant, C., Mackay, W., Evans, H., Hansen, H., Conversy, S., Beaudouin-Lafon, M., Roussel, N., Lacomme, L., Eiderbäck, B., Lindquist, S., Sundblad, Y., and Westerlund, B. (2003). Technology probes: Inspiring design for and with families. *Conference on Human Factors in Computing Systems - Proceedings*.

Iris, K. and Liarokapis, F. (2020). Investigating the learning process of folk dances using mobile augmented reality. *Applied Sciences*, 10:599.

Jacob, M., Zook, A., and Magerko, B. (2013). Viewpoints ai: Procedurally representing and reasoning about gestures.

Jégo, J.-F. and Meneghini, M. B. (2020). Let's resonate: How to elicit improvisation and letting go in interactive digital art. In *Proceedings of the 7th International Conference on Movement and Computing*, MOCO '20, New York, NY, USA. Association for Computing Machinery.

Jochum, E. and Derks, J. (2019). Tonight we improvise! real-time tracking for human-robot improvisational dance. In *Proceedings of the 6th International Conference on Movement and Computing*, MOCO '19, New York, NY, USA. Association for Computing Machinery.

Kim, J.-W. and Nam, T.-J. (2013). Eventhurdle: Supporting design-

ers' exploratory interaction prototyping with gesture-based sensors. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '13, page 267–276, New York, NY, USA. Association for Computing Machinery.

Kitsikidis, A., Dimitropoulos, K., Ugurca, D., Bayçay, C., Yilmaz, E., Tsalakanidou, F., Douka, S., and Grammalidis, N. (2015). A game-like application for dance learning using a natural human computer interface. In *HCI*.

Koch, J., Taffin, N., Lucero, A., and Mackay, W. (2020). Semanticcollage: Enriching digital mood board design with semantic labels. pages 407–418.

Kosuge, K., Hayashi, T., Hirata, Y., and Tobiyama, R. (2003). Dance partner robot - ms dancer. In *Proceedings 2003 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2003) (Cat. No.03CH37453)*, volume 4, pages 3459–3464 vol.3.

Kronsted, C. and Gallagher, S. (2021). Dances and affordances: The relationship between dance training and conceptual problem-solving. *The Journal of Aesthetic Education*, 55:35 – 55.

Kyan, M., Sun, G., Li, H., Zhong, L., Muneesawang, P., Dong, N., Elder, B., and Guan, L. (2015). An approach to ballet dance training through ms kinect and visualization in a cave virtual reality environment. *ACM Trans. Intell. Syst. Technol.*, 6(2).

Lee, J.-J., Choi, J.-H., Chuluunsaikhan, T., and Nasridinov, A. (2020). Pose evaluation for dance learning application using joint position and angular similarity. In *Adjunct Proceedings of the 2020 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2020 ACM International Symposium on Wearable Computers*, UbiComp-ISWC '20, page 67–70, New York, NY, USA. Association for Computing Machinery.

Legrand, D. (2007). Pre-reflective self-consciousness : On being bodily in the world.

Leijen, A., Lam, I., Wildschut, L., Simons, P., and Admiraal, W. (2009). Streaming video to enhance students' reflection in dance education. *Computers and Education*, 52:169–176.

Lewis, L. (2013). *Beginning Tap Dance with Web Resource*. Beginning Tap Dance. Human Kinetics.

Liu, L., Long, D., Gujrania, S., and Magerko, B. (2019). Learning movement through human-computer co-creative improvisation. In *Proceedings of the 6th International Conference on Movement and Computing*, MOCO '19, New York, NY, USA. Association for Computing Machinery.

Liu, W., Dementyev, A., Schwarz, D., Flety, E., Mackay, W. E., Beaudouin-Lafon, M., and Bevilacqua, F. (2021). *SonicHoop: Using Interactive Sonification to Support Aerial Hoop Practices*. Associ-

ation for Computing Machinery, New York, NY, USA.

Loke, L., Khut, G., Slattery, M., Truman, C., Muller, L., and Duckworth, J. (2013). Re-sensitising the body: Interactive art and the feldenkrais method. *Int. J. of Arts and Technology*, 6:339 – 356.

Loke, L. and Robertson, T. (2007). Making strange with the falling body in interactive technology design. *Design and semantics of form and movement*.

Loke, L. and Robertson, T. (2008). Inventing and devising movement in the design of movement-based interactive systems. In *Proceedings of the 20th Australasian Conference on Computer-Human Interaction: Designing for Habitus and Habitat*, OZCHI '08, page 81–88, New York, NY, USA. Association for Computing Machinery.

Loke, L. and Robertson, T. (2013). Moving and making strange: An embodied approach to movement-based interaction design. *ACM Trans. Comput.-Hum. Interact.*, 20(1).

Mackay, W. (2020). Wendy mackay: Beyond "tap, pinch and swipe" [video file].

Mackay, W. E. (2002). Using video to support interaction design. Dvd tutorial, INRIA and ACM/SIGCHI.

Mackay, W. E. (2019). Designing with Sticky Notes. In Christensen, H. and Klokmose, C., editors, *Sticky Creativity: Post-It Note Cognition, Interaction and Digitalization*, Explorations in Creativity Series. Academic Press. In print.

Mackay, W. E. and Fayard, A.-L. (1997). Hci, natural science and design: a framework for triangulation across disciplines. In *DIS '97*.

Malloch, J., Griggio, C. F., McGrenere, J., and Mackay, W. E. (2017). Fieldward and pathward: Dynamic guides for defining your own gestures. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, CHI '17, page 4266–4277, New York, NY, USA. Association for Computing Machinery.

Marquardt, Z., Beira, J., Em, N., Paiva, I., and Kox, S. (2012). Super mirror: a kinect interface for ballet dancers. *ACM Annual Conference Extended Abstracts on Human Factors in Computing Systems*.

Márquez Segura, E., Turmo Vidal, L., Rostami, A., and Waern, A. (2016). Embodied sketching. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, CHI '16, page 6014–6027, New York, NY, USA. Association for Computing Machinery.

Maslon, L. and Kantor, M. (2008). *Make 'Em Laugh: The Funny Business of America*. Grand Central Publishing.

Masu, R., Correia, N. N., Jurgens, S., Feitsch, J., and Romão, T. (2020). *Designing Interactive Sonic Artefacts for Dance Performance: An Ecological Approach*, page 122–129. Association for Computing Ma-

chinery, New York, NY, USA.

Maudet, N., Jalal, G., Tchernavskij, P., Beaudouin-Lafon, M., and Mackay, W. E. (2017). Beyond grids: Interactive graphical substrates to structure digital layout. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, CHI '17, page 5053–5064, New York, NY, USA. Association for Computing Machinery.

McGregor, W. (2012). A choreographer's creative process in real time [video file].

Mentis, H. M., Höök, K., Mueller, F., Isbister, K., Khut, G. P., and Robertson, T. (2014). Designing for the experiential body. In *CHI '14 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '14, page 1069–1074, New York, NY, USA. Association for Computing Machinery.

Mentis, H. M. and Johansson, C. (2013). Seeing movement qualities. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '13, page 3375–3384, New York, NY, USA. Association for Computing Machinery.

Merleau-Ponty, M. (1996). *Phenomenology of perception*. Motilal Banarsidass Publishe.

Molina-Tanco, L., García-Berdonés, C., and Reyes-Lecuona, A. (2017). The delay mirror: A technological innovation specific to the dance studio. In *Proceedings of the 4th International Conference on Movement Computing*, MOCO '17, New York, NY, USA. Association for Computing Machinery.

Muller, M. and Kuhn, S. (1993). Participatory design. *Communications of the ACM*, 36:24–28.

Nakamura, A., Tabata, S., Ueda, T., Kiyofuji, S., and Kuno, Y. (2005). Multimodal presentation method for a dance training system. In *CHI '05 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '05, page 1685–1688, New York, NY, USA. Association for Computing Machinery.

Nigay, L. and Coutaz, J. (1993). A design space for multimodal systems: Concurrent processing and data fusion. In *Proceedings of the INTERACT '93 and CHI '93 Conference on Human Factors in Computing Systems*, CHI '93, page 172–178, New York, NY, USA. Association for Computing Machinery.

Palazzi, M., Shaw, N. Z., Forsythe, W., Lewis, M., Albright, B., Andereck, M., Bhatawadekar, S., Ban, H., Calhoun, A., Drozd, J., Fry, J., Quintanilha, M., Reed, A., Schroeder, B., Skove, L., Thorndike, A., Twohig, M., Ahlqvist, O., Chan, P., Cressie, N., Turk, S., Johnson, J., Roman, C., Waterhouse, E., deLahunta, S., Haggard, P., and Noe, A. (2009). Synchronous objects for one flat thing, reproduced. In *ACM SIGGRAPH 2009 Art Gallery*, SIG-

GRAPH '09, New York, NY, USA. Association for Computing Machinery.

Parviainen, J. (1998). *Bodies moving and moved: A phenomenological analysis of the dancing subject and the cognitive and ethical values of dance art*. Tampere University Press.

Raheb, K. E., Stergiou, M., Katifori, A., and Ioannidis, Y. (2019). Dance interactive learning systems: A study on interaction workflow and teaching approaches. *ACM Comput. Surv.*, 52(3).

Raheb, K. E., Tsampounaris, G., Katifori, A., and Ioannidis, Y. (2018). Choreomorphy: A whole-body interaction experience for dance improvisation and visual experimentation. In *Proceedings of the 2018 International Conference on Advanced Visual Interfaces*, AVI '18, New York, NY, USA. Association for Computing Machinery.

Ramadoss, B. and Rajkumar, K. (2007). Semi-automated annotation and retrieval of dance media objects. *Cybern. Syst.*, 38(4):349–379.

Rivière, J.-P., Alaoui, S. F., Caramiaux, B., and Mackay, W. E. (2019). Capturing movement decomposition to support learning and teaching in contemporary dance. *Proc. ACM Hum.-Comput. Interact.*, 3(CSCW).

Rivière, J.-P., Fdili Alaoui, S., Caramiaux, B., and Mackay, W. (2018). How do dancers learn to dance?: A first-person perspective of dance acquisition by expert contemporary dancers. pages 1–7.

Rivière, J.-P., Fdili Alaoui, S., Caramiaux, B., and Mackay, W. E. (2021). Exploring the role of artifacts in collective dance re-staging. *Proc. ACM Hum.-Comput. Interact.*, 5(CSCW1).

Rodger, M., Stapleton, P., Van Walstijn, M., Ortiz, M., and Pardue, L. (2020). What makes a good musical instrument? a matter of processes, ecologies and specificities.

Rogers, Y. (2011). Interaction design gone wild: Striving for wild theory. *Interactions*, 18(4):58–62.

Rothenberg, A. and Hausman, C. R. (1976). *The creativity question*. Duke University Press.

Ruiz, J., Li, Y., and Lank, E. (2011). User-defined motion gestures for mobile interaction. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '11, page 197–206, New York, NY, USA. Association for Computing Machinery.

Russell, D., Convertino, G., Pirolli, P., Kittur, N., and Watkins, E. (2018). Sensemaking in a senseless world (chi 2018 workshop).

Saxena, V. V., Feldt, T., and Goel, M. (2014). Augmented telepresence as a tool for immersive simulated dancing in experience and learning. In *Proceedings of the India HCI 2014 Conference on Human Computer Interaction*, IndiaHCI '14, page 86–89, New York, NY, USA. Association for Computing Machinery.

Schiphorst, T. (1993). A case study of merce cunningham's use of

the lifeforms computer choreographic system in the making of trackers.

Schiphorst, T., Calvert, T., Lee, C., Welman, C., and Gaudet, S. (1990). Tools for interaction with the creative process of composition. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '90, page 167–174, New York, NY, USA. Association for Computing Machinery.

Schleicher, D., Jones, P., and Kachur, O. (2010). Bodystorming as embodied designing. *Interactions*, 17(6):47–51.

Sheppard, R. M., Kamali, M., Rivas, R., Tamai, M., Yang, Z., Wu, W., and Nahrstedt, K. (2008). Advancing interactive collaborative mediums through tele-immersive dance (ted): A symbiotic creativity and design environment for art and computer science. In *Proceedings of the 16th ACM International Conference on Multimedia*, MM '08, page 579–588, New York, NY, USA. Association for Computing Machinery.

Shneiderman, B. (2002). Creativity support tools. *Commun. ACM*, 45(10):116–120.

Shneiderman, B., Fischer, G., Czerwinski, M., Resnick, M., Myers, B., Candy, L., Edmonds, E., Eisenberg, M., Giaccardi, E., Hewett, T., Jennings, P., Kules, B., Nakakoji, K., Nunamaker, J., Pausch, R., Selker, T., Sylvan, E., and Terry, M. (2006). Creativity support tools: Report from a u.s. . . .

Shusterman, R. (2008). *Body Consciousness: A Philosophy of Mindfulness and Somaesthetics*. Cambridge University Press, Cambridge.

Sicchio, K. (2014). (capturing intention). documentation, analysis and notation research based on the work of emio greco/pc, scott delahunta (ed.) (2007). *International Journal of Performance Arts and Digital Media*, 4:95–98.

Sigrist, R., Rauter, G., Riener, R., and Wolf, P. (2012). Augmented visual, auditory, haptic, and multimodal feedback in motor learning: A review. *Psychonomic bulletin & review*, 20.

Singh, V., Latulipe, C., Carroll, E., and Lottridge, D. (2011). The choreographer's notebook: A video annotation system for dancers and choreographers. In *Proceedings of the 8th ACM Conference on Creativity and Cognition*, Creativity and Cognition '11, page 197–206, New York, NY, USA. Association for Computing Machinery.

Soga, A., Umino, B., and Hirayama, M. (2009). Automatic composition for contemporary dance using 3d motion clips: Experiment on dance training and system evaluation. pages 171–176.

Svanæs, D. (2013). Interaction design for and with the lived body: Some implications of merleau-ponty's phenomenology. *ACM Trans. Comput.-Hum. Interact.*, 20(1).

Tennent, P., Marshall, J., Tsaknaki, V., Windlin, C., Höök, K., and Al-

faras, M. (2020). Soma design and sensory misalignment. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*, CHI '20, page 1–12, New York, NY, USA. Association for Computing Machinery.

Thiel, D. V., Quandt, J., Carter, S. J., and Moyle, G. (2014). Accelerometer based performance assessment of basic routines in classical ballet. *Procedia Engineering*, 72:14–19. The Engineering of Sport 10.

Thompson, M. and Shott, F. (2015). The history of modern dance. `https://artsintegration.com/wp-content/uploads/2015/05/Modern.pdf`. Accessed: 2022-03-24.

Toyama, K. (2010). Human–computer interaction and global development. *Foundations and Trends in Human-Computer Interaction*, 4:1–79.

Trajkova, M. (2020). Designing ai-based feedback for ballet learning. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems*, CHI EA '20, page 1–9, New York, NY, USA. Association for Computing Machinery.

Trajkova, M. and Cafaro, F. (2018). Takes tutu to ballet: Designing visual and verbal feedback for augmented mirrors. 2(1).

Trajkova, M. and Cafaro, F. (2021). *Current Use, Non-Use, and Future Use of Ballet Learning Technologies*, page 2052–2067. Association for Computing Machinery, New York, NY, USA.

Tsandilas, T. (2018). Fallacies of agreement: A critical review of consensus assessment methods for gesture elicitation. *ACM Trans. Comput.-Hum. Interact.*, 25(3).

Turmo Vidal, L., Márquez Segura, E., Boyer, C., and Waern, A. (2019). Enlightened yoga: Designing an augmented class with wearable lights to support instruction. In *Proceedings of the 2019 on Designing Interactive Systems Conference*, DIS '19, page 1017–1031, New York, NY, USA. Association for Computing Machinery.

Turmo Vidal, L., Zhu, H., and Riego-Delgado, A. (2020). Bodylights: Open-ended augmented feedback to support training towards a correct exercise execution. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*, CHI '20, page 1–14, New York, NY, USA. Association for Computing Machinery.

Umino, B., Longstaff, J., and Soga, A. (2009). Feasibility study for ballet e-learning: automatic composition system for ballet enchaînement with online 3d motion data archive. *Research in Dance Education*, 10:17–32.

Vandenberghe, B. and Slegers, K. (2016). Designing for others, and the trap of hci methods practices. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, CHI EA '16, page 512–524, New York, NY, USA. Association for

Computing Machinery.

Vatsyayan, K. (1974). *INDIAN CLASSICAL DANCE*. Publications Division, Ministry of Information and Broadcasting, Government of India.

Villarreal-Narvaez, S., Vanderdonckt, J., Vatavu, R.-D., and Wobbrock, J. O. (2020). *A Systematic Review of Gesture Elicitation Studies: What Can We Learn from 216 Studies?*, page 855–872. Association for Computing Machinery, New York, NY, USA.

Wainwright, S. and Turner, B. (2004). Epiphanies of embodiment: Injury, identity and the balletic body. *Qualitative Research*, 4:311–337.

Walton, E., Caramiaux, B., Fdili Alaoui, S., Bevilacqua, F., and Mackay, W. E. (2021). Reconciling Technology-Driven and Experiential Approaches for Movement-Based Design. In *IHM'20.21 - 32e Conférence Francophone pour l'Interaction Homme-Machine*, Virtual Event, France.

Wang, Y. and Zheng, G. (2020). Application of artificial intelligence in college dance teaching and its performance analysis. *International Journal of Emerging Technologies in Learning (iJET)*, 15:178.

Weisberg, R. (2006). Expertise and reason in creative thinking: Evidence from case studies and the laboratory. *Creativity and Reason in Cognitive Development*, pages 7–42.

Weiss, A., Bernhaupt, R., Dürnberger, D., Altmaninger, M., Buchner, R., and Tscheligi, M. (2010). User experience evaluation with a wizard of oz approach: Technical and methodological considerations. pages 303 – 308.

Wilde, D., Vallgårda, A., and Tomico, O. (2017). Embodied design ideation methods: Analysing the power of estrangement. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, CHI '17, page 5158–5170, New York, NY, USA. Association for Computing Machinery.

Williamson, J. and Murray-Smith, R. (2012). Rewarding the original: Explorations in joint user-sensor motion spaces. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '12, page 1717–1726, New York, NY, USA. Association for Computing Machinery.

Wobbrock, J. O., Aung, H. H., Rothrock, B., and Myers, B. A. (2005). Maximizing the guessability of symbolic input. In *CHI '05 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '05, page 1869–1872, New York, NY, USA. Association for Computing Machinery.

Wobbrock, J. O., Morris, M. R., and Wilson, A. D. (2009). User-defined gestures for surface computing. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '09, page

1083–1092, New York, NY, USA. Association for Computing Machinery.

Wulff, H. (2020). *Ballet across Borders: Career and Culture in the World of Dancers*. Taylor & Francis.

Yan, S., Ding, G., Guan, Z., Sun, N., Li, H., and Zhang, L. (2015). Outsideme: Augmenting dancer's external self-image by using a mixed reality system. In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems*, CHI EA '15, page 965–970, New York, NY, USA. Association for Computing Machinery.

Yang, Y., Leung, H., Yue, L., and Deng, L. (2013). Generating a two-phase lesson for guiding beginners to learn basic dance movements. *Computers and Education*, 61:1–20.

Yu, T. and Johnson, P. (2003). Tour jeté, pirouette: Dance choreographing by computers. In *GECCO*.

Zbikowski, L. (2014). *Dance topics I: music and dance in the ancien régime*, pages 143–163.

Zhou, Q., Chua, C. C., Knibbe, J., Goncalves, J., and Velloso, E. (2021). *Dance and Choreography in HCI: A Two-Decade Retrospective*. Association for Computing Machinery, New York, NY, USA.

Zimmerman, J., Forlizzi, J., and Evenson, S. (2007). Research through design as a method for interaction design research in hci. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '07, page 493–502, New York, NY, USA. Association for Computing Machinery.

université PARIS-SACLAY

ÉCOLE DOCTORALE
Physique et ingénierie : Electrons, Photons, Sciences du vivant (EOBE)

Titre : Transitions de Styles de Danse : de la Pratique des Danseurs à la Technologie Basée sur le Mouvement

Mots clés : interaction basée sur le mouvement, transitions de style de danse, études empiriques, interaction homme-machine

Résumé : Les méthodologies de conception pour l'interaction basée sur le geste et le mouvement proposent d'adopter des visions différentes et mutuellement excluantes : soit en quantifiant le mouvement d'un point de vue externe, soit en soutenant l'exploration et la description des sensations intérieures. Cependant, les professionnels du mouvement, comme les danseurs, définissent les poses et les phrases en utilisant à la fois les descriptions des chorégraphes et les indices corporels personnels. Je soutiens que les transitions entre styles de danse permettent aux chercheurs d'observer l'expérience des danseurs alors qu'ils remettent en question et rééquilibrent les parties externes et internes de leur formation : celles codifiées et celles ne pouvant pas l'être. Après avoir utilisé des méthodes qualitatives, je présente les défis et les stratégies de la transition de style de danse et je discute de la façon dont la structuration de la technologie autour des substrats de mouvement pourrait soutenir le changement de mentalité nécessaire aux danseurs pour accéder à de nouveaux types de mouvements. Je décris ensuite le système ImproviGrid et je discute de l'impact qu'a la modalité de sortie sur l'utilisation des indices par les danseurs pendant l'improvisation, afin de comprendre comment mieux concevoir l'exploration du mouvement, qui est un défi de la transition de style de danse. Je conclus avec une implication plus importante des méthodologies de mouvement conçues par l'utilisateur, en les considérant plus comme des utilisateurs créant des gestes chorégraphiés plutôt que des chercheurs suscitant des gestes.

Title : Dance Style Transitions : From Dancers' Practice to Movement-Based Technology

Keywords : movement-based interaction, dance style transitions, empirical studies, human-computer interaction

Abstract : Design methodologies for gesture- and movement-based interaction take divergent perspectives, either quantifying movement from an external point of view or supporting inner sensation exploration and description. However, professional movers, like dancers, define poses and phrases using both descriptions from choreographers and personal, bodily cues. I argue that dance style transitions offer researchers insights into dancers' experiences questioning and balancing the externally codified and internally not-possible-to-be-codified parts of their training. After employing qualitative methods, I present the challenges and strategies of the dance style transition and discuss how structuring technology around movement substrates could support the mentality change necessary for dancers to access new types of movement. I then describe the ImproviGrid System and discuss how output modality impacts dancer use of cues during improvisation, in order to understand how to design better for movement exploration, a challenge of the dance style transition. I conclude with greater implications of user-designed movement methodologies, reframing them as users creating choreographed gestures rather than researchers eliciting gestures.