Interactive Visuals as Metaphors for Dance Movement Qualities

SARAH FDILI ALAOUI, School of Interactive Arts and Technologies, Simon Fraser University
FREDERIC BEVILACQUA, Sciences et Technologies de la Musique et du Son (STMS)
IRCAM - CNRS - UPMC
CHRISTIAN JACQUEMIN, University Paris-Sud and LIMSI-CNRS

The notion of "movement qualities" is central in contemporary dance; it describes the manner in which a movement is executed. Movement qualities convey information revealing movement expressiveness; their use has strong potential for movement-based interaction with applications in arts, entertainment, education, or rehabilitation. The purpose of our research is to design and evaluate interactive reflexive visuals for movement qualities. The theoretical basis for this research is drawn from a collaboration with the members of the international dance company Emio Greco|PC to study their formalization of movement qualities. We designed a pedagogical interactive installation called *Double Skin/Double Mind (DS/DM)* for the analysis and visualization of movement qualities through physical model-based interactive renderings.

In this article, we first evaluate dancers' perception of the visuals as metaphors for movement qualities. This evaluation shows that, depending on the physical model parameterization, the visuals are capable of generating dynamic behaviors that the dancers associate with *DS/DM* movement qualities. Moreover, we evaluate dance students' and professionals' experience of the interactive visuals in the context of a dance pedagogical workshop and a professional dance training. The results of these evaluations show that the dancers consider the interactive visuals to be a reflexive system that encourages them to perform, improves their experience, and contributes to a better understanding of movement qualities. Our findings support research on interactive systems for real-time analysis and visualization of movement qualities, which open new perspectives in movement-based interaction design.

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1. INTRODUCTION

In dance, movement is often described by its qualitative characteristics. Practitioners and theorists of dance refer to "movement qualities" as the qualitative characteristics

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Authors' addresses: S. Fdili Alaoui (corresponding author), School of Interactive Arts and Technologies, Simon Fraser University, Vancouver, Canada; email: sfdilial@sfu.ca; F. Bevilacqua, IRCAM 1, place Igor-Stravinsky, 75004 Paris; email: Frederic.Bevilacqua@ircam.fr; and C. Jacquemin, CNRS-LIMSI & Univ. Paris-Sud 11, BP 133, 91403 Orsay, France; email: Christian.Jacquemin@limsi.fr.

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produced by dynamics and defining the manner in which movement is executed. Since they impact expressiveness and communication, movement qualities are important features of movement that have a strong potential for the design of movement-based interactions with applications in entertainment, education, or rehabilitation.

The overall goal of our research is to design and evaluate interactive systems providing visual feedback that can inform users about their movement qualities. Our interactive system includes two stages. The first stage consists of movement capture and real-time analysis, which include movement feature extraction and movement qualities recognition. The second stage consists of movement qualities visualization based on physical models rendering and control (given the extracted movement qualities).

Our methodology relies on close collaborations with the dance practitioners who have expertise in teaching movement qualities. In particular, we collaborated with the international dance company Emio Greco|PC (EG|PC) because of their emphasis on movement qualities as a basis of their practice, and because of their theoretical work on the formalization of movement qualities. We studied four of their basic dance components encompassing different movement qualities that can serve as a basis for a wide variety of complex and combined movement qualities not only in dance, but also in the domain of movement-based interaction. The work presented in this article builds on our previous works on movement qualities in interactive installations, using the the glossary developed by EG|PC [Fdili Alaoui et al. 2012], and adds significant new contributions.

We modelled EG|PC's movement qualities for whole-body movement (motion capture, feature extraction, and movement qualities recognition) and applied it to an interactive installation called *Double Skin/Double Mind (DS/DM)* [Bermudez et al. 2011]. For *DS/DM*, we developed interactive visuals based on physical models, particularly mass-spring systems installation. These visuals provide feedback that reflects on the user's performance of movement qualities in real time. To do so, we mapped the mass-spring systems' physical parameters with the extracted movement qualities in real time. Our visuals belong to the class of interactive systems defined by Pachet as reflexive, in which users can interact with "agents that have a mimetic capacity and can evolve in an organic fashion" [Pachet 2006]. We hypothesize that users would experience these visuals as empathic and stimulating, rather than evaluative and constraining.

The *DS/DM* installation was designed as an interactive artwork that is used for dance training and education. It has been included in the curriculum of the dance students of the *Amsterdamse Hogeschool voor de Kunsten* (Amsterdam School of the Arts). We have previously reported on a preliminary qualitative evaluation of *DS/DM* [Fdili Alaoui et al. 2013]. In this article, we describe the *DS/DM* installation and report on two different users' studies that evaluate thoroughly dancers' perception of the visuals and their experience of interacting with it.

First, through an online user evaluation, we investigated the question of whether the visuals are able to have a mimetic capacity by generating dynamic behaviors that are perceived by dancers as metaphors of movement qualities. We asked dancers to associate manually tuned dynamic behaviors of mass-spring systems with videos of movement qualities performed by Emio Greco, EG|PC's choreographer. Second, we investigated the exploratory value of the interactive visuals for training dancers to perform EG|PC's movement qualities. We evaluated dancers' experience of interacting with the visuals first in a training context, with expert professional dancers of EG|PC, then, in a pedagogical workshop with dance students from the Amsterdam School of the Arts. In these experiments, we tested, in two groups of different expertise, the hypothesis that *DS/DM* interactive visuals provide a reflexive feedback that encourages dancers to explore and practice the movement qualities. Our findings allow us to articulate the exploratory and pedagogical value of *DS/DM* interactive visuals. More generally, our experiments support the research on interactive systems for real-time analysis and visualization of movement qualities, which open new perspectives in movement-based interaction design.

2. BACKGROUNDS

2.1. Background on Movement Qualities in Dance

Practitioners and theorists of dance name *movement qualities* the qualitative characteristics that define the manner in which a movement is executed. They are defined by Blom and Chaplin [1982] as "*the distinctly observable attributes or characteristics produced by dynamics and made manifest in movement.*" Movement qualities play a fundamental role in the practice of modern and contemporary dance. According to Lockhart and Pease [1982]: "*The preparation for learning to shape movement into motion comes as a result of the student becoming sensitive to the general characteristics of movement quality and the shading of quality through the use of dynamics[. . .].*"

Movement theorist Rudolf Laban considered movement qualities to be a central notion in human motion. He developed the Laban Movement Analysis system, which focuses on experiencing, observing, and describing movement patterns. It provides a rigorous use of language to analyze functional and expressive movement. Laban Movement Analysis describes movement in terms of Body (What is moving?), Effort (How is it moving?), Space (Where is it moving?), and Shape (What relationship with the environment?) [Laban 1994]. It formalizes movement qualities mostly into the Effort and Shape categories. Laban Effort describe movement qualities according to four factors: Space, Time, Weight, and Flow. Each factor has two elements (Space: direct/indirect; Time: sudden/sustained; Weight: light/strong; Flow: bound/free) that can be understood as two ends of a continuum in which the movements can vary and thus reveal different *Effort qualities*.

2.2. Movement Qualities and Interactive Systems

The description of movement qualities through the lens of Laban Movement Analysis is applicable to a wide range of movements. This is precisely why most models that incorporate movement quality analysis and/or synthesis rely on the Effort and Shape categories of Laban Movement Analysis. Some of the earliest work taking movement qualities into account in computer animation comes from Norman Bradler's research group. They developed the EMOTE system to simulate expressive and natural movements of a 3D character using Laban's Effort and Shape qualities [Chi et al. 2000]. They also developed movement segmentation techniques using high-level movement descriptors inspired by the Effort factors [Bouchard and Badler 2007]. Movement qualities features inspired by Laban Movement Analysis are also available on the EyesWeb visual programming platform for analyzing performance-oriented gesture [Volpe 2003; Camurri et al. 2000]. Laban Shape qualities are exploited by Swaminathan et al. [2009] and used to train dynamic Bayesian networks for movement quality recognition.

In Human–Computer Interaction (HCI), Laban Effort qualities inspired a theoretical framework for the design of "graceful" movement-based interactions proposed by Hashim et al. [2009]. Kjolberg [2004] suggests that incorporating such a theory into interaction design leads to the creation of interactions that allow for personal expression. Schiphorst [2009] uses eight Effort actions defined by Laban (Press, Flick, Wring, Dab, Slash, Glide, Punch, Float) that combine different Effort qualities in order to enhance the user's aesthetic appreciation by involving the whole body in interacting with digital media. Schiphorst et al. [2005] also use Laban Effort actions to develop a gestural semantics of "caress" with different qualities of touch. Work by Subyen et al. [2011] explores the aesthetics of visualizing movement by generating color, lines, and graphics to suggest the participant's Effort qualities detected using a single accelerometer system called EffortDetect [Maranan et al. 2013]. More recently, Mentis and Johansson [2013] proposed a study that aims to situate the perception of movement qualities in one's own movement and in another's movements. For this purpose, they built a Kinect-based system for an improvisational dance performance in which audience members' Effort qualities are used to influence the music. Their study showed that seeing movement qualities can vary depending on the experience and background of a viewer. They also found that general audience members do not intuitively define, perceive, or see movement qualities according to the factors defined by Laban in his Effort theory. Their article concluded that using Laban Effort qualities in interactive systems for general nonexpert users to control an output modality is not necessarily natural and intuitive, and requires prior acquisition of such Effort notions.

We acknowledge that Laban's Effort factors capture a broad range of movement qualities and focus on the way the movement is performed rather than the specific form of the movement. However, there are multiple drawbacks in the use of Laban Effort theory in interactive systems, particularly for applications in dance training. First, close reading of the literature on the existing computational models of Efforts show that most are coerced into the Effort theory because of its genericity, but end up offering an overly simplistic modeling of its factors and qualities [Maranan et al. 2013]. Second, although Laban Effort theory has been most commonly approached in HCI, its use in the dance field is far from being unanimous because it requires extensive training and because most of the choreographers and dance techniques develop specific formalisms, jargon, and movement vocabularies that better suit their practice.

Inspired by other theories in dance than Laban Movement Analysis, some remarkable interactive systems exploring movement qualities have emerged in HCI. For example, Moen and Sandsjö [2015] use movement qualities inspired by modern and contemporary dance and formalized by Blom and Chaplin [1982] in order to exploit full-body movement as a modality in the design of pleasurable interactions. Using the Viewpoints framework, Corness and Schiphorst [2013] designed the Ariel system, which provides musical responses for movement improvisation. From our collaboration with EG|PC, we developed in a previous work an artistic interactive installation called *A light touch*, for which participants are invited to explore the movement qualities of their hand gestures in order to control in real-time the behavior of a light spot projected on a screen. Analyzing user experience in this installation allowed us to prove that an interaction modality based on movement qualities tends to promote movement exploration and expressiveness [Fdili Alaoui et al. 2012]. Our approach in this article is in line with our previous work and aims at developing models of movement qualities by drawing on collaboration with the dance company EG|PC.

2.3. Movement Qualities in the Context of the EG|PC Dance Company

EG|PC formalization of movement qualities results from 10 years of research in linguistics, Laban Movement Analysis, dance notation (Labanotation and Benesh), and digital media. Since 2005, the company has initiated an interdisciplinary research project that focuses on the transmission of their physical preparation, called the *Double Skin/Double Mind (DS/DM)* workshop, which encompasses their movement qualities vocabulary. It serves as a daily training for their dancers and as a workshop for external dance students. EG|PC produced a body of work to transmit *DS/DM* through notation techniques, motion capture, interactive DVD-ROMs [Delahunta 2007], documentary film, movement glossary [Bermudez and Fernandes 2010], and a multimodal interactive installation [Bermudez et al. 2011].

The movement quality vocabulary in the *DS/DM* workshop is described in the company's glossary within four main components called *Breathing, Jumping, Expanding, and Reducing* [Bermudez and Fernandes 2010]. This glossary has served as a starting

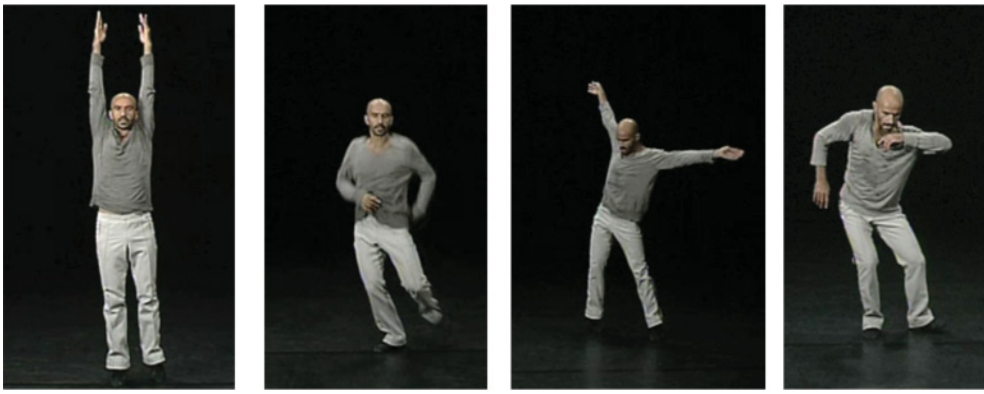

Fig. 1. Emio Greco executing the movement qualities *Breathing* (first image on the left), *Jumping* (second image), *Expanding* (third image), and *Reducing* (fourth image). Images from the DVD of the book [Delahunta 2007].

point for our development of the eponymous interactive installation, *DS/DM*. Although *DS/DM* components seem less generic than Laban Effort because they result from one choreographer's formal approach, they cover a range of movement qualities in dance that is as wide as the Effort continuum. While the components are named after specific kinds of movements (e.g., jumping, expanding), their focus is on the qualities of such movements, that is, how the "extension" or the "rebound" are performed. We chose to study the specific vocabulary of EG|PC rather than the general Effort qualities from the Laban Movement Analysis because we believe that advances in the field require relying on a strong theory and a grounded artistic practice of movement qualities such as that developed by EG|PC. Collaborating with EG|PC offered us an exemplary case study and allowed us to build a system that they use to transmit their vocabulary in real-life pedagogical context.

The following summarizes the four main components. Figure 1 shows Emio Greco performing these four components. Videos of these performances are available online[1].

—*Breathing*: The embodiment of the action of breathing through a gradual vertical extension reaching the maximum length of the whole body, and vertical release to come back to the starting position. The *Breathing* is meant to embody the endless sense of reaching and disappearing inside the self.
—*Jumping*: The dancer drops the weight of the body into the feet, letting it rebound for a long time and creating a repetitive movement. The *Jumping* is meant to embody the metaphor for sensing the soft body.
—*Expanding*: The dancer extends the space within the body, travels through the space by opening the legs, understands the weight shift through the feet. The *Expanding* uses the same pattern as in the *Breathing*, to expand and release, but adds the three-dimensional penetration of the space.
—*Reducing*: The dancer needs to achieve a mental state that allows the body to experience the metaphorical quality of the thick air within and around the movements, and to reduce the length previously created.

3. THE *DOUBLE SKIN / DOUBLE MIND* INTERACTIVE INSTALLATION

The interactive installation *DS/DM* is designed to train dancers on EG|PC movement qualities. As shown in Figure 2, the installation provides various feedback, such as

[1]Videos of Emio Greco performing *DS/DM* 4 components: https://vimeo.com/38974588.

Fig. 2. Picture of a dancer in *DS/DM* installation space. ©Thomas Lenden

explanatory videos and demonstrations, icons, and text instructions as well as interactive visuals and sound feedback. The interactive sound, icons, and text instructions reflect literally on the movement performed by the dancers for pedagogical purposes. The interactive visuals provide more subtle, expressive, and abstract feedback that can help the users relate their own performance with the corresponding *DS/DM* component and encourage them to explore and practice each targeted component. In relationship with previous literature on motor learning, the approach in *DS/DM* could be considered as a "knowledge-of-performance" approach. Indeed, the visuals provide feedback on how the participants execute *DS/DM* components in order to help them explore their complex movement qualities [Kernodle and Carlton 1992]. Unlike the frequent use of video feedback in knowledge-of-performance approaches, the interactive visuals in *DS/DM* are a reflexive feedback with a similarity effect (producing a similar effect to what users themselves are able to produce), agnosticity (ability to reproduce the user's "personality"), scaffolding of complexity (organicity allowing for incremental learning), and seamlessness (producing virtually indistinguishable output from the user's input), which are the characteristics of interactive reflexive systems enhancing individual creativity defined by Pachet [2006]. In this article, we describe the interactive visuals based on mass-spring systems that are mapped to the movement quality analysis (motion capture, feature extraction, and movement qualities recognition; see Figure 3). The elements related to the installation's explanatory videos, demonstrations, icons, text instructions, and sound feedback will not be addressed in this article since they are not the object of our study. We will focus on describing and evaluating the interactive visuals. A full description of the interactive environment of the *DS/DM* installation and a video of a dancer from EG|PC testing *DS/DM* installation are available online[2].

3.1. Movement Qualities Feature Extraction

As shown in Figure 3, our system first captures the user's body movements with a single infrared camera and extracts his silhouette from the video stream. The second layer is the extraction of geometrical features from the silhouette: the body's width, height,

[2]Video of a dancer testing *DS/DM*: http://saralaoui.com/2015/03/double-skin-double-mind/.

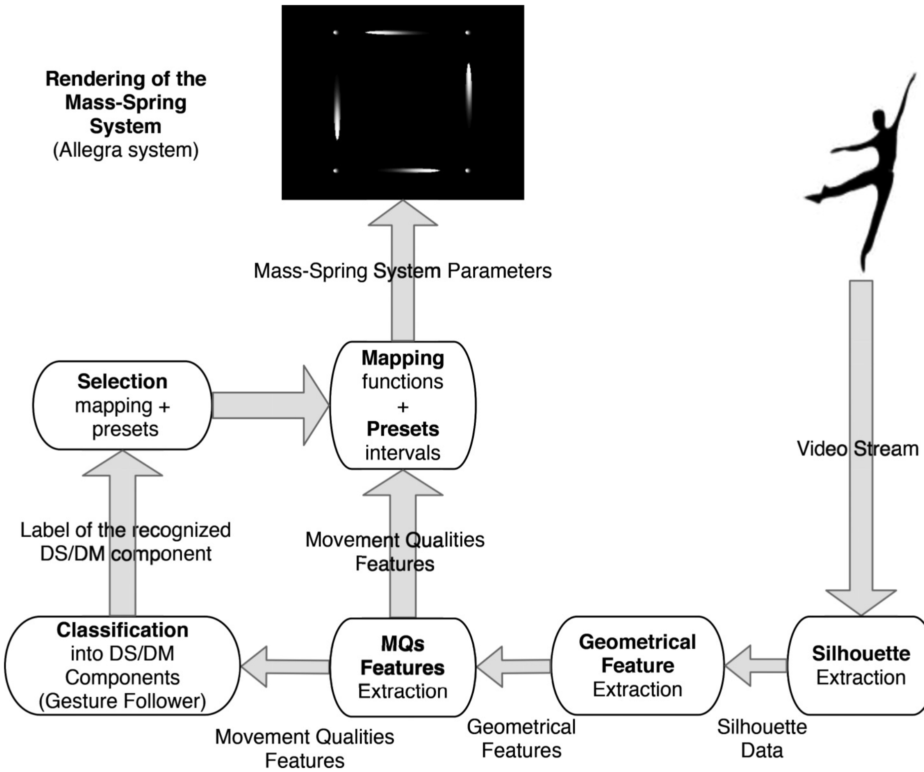

Fig. 3. *Double Skin/Double Mind (DS/DM)* system design.

center of gravity, and bounding box around the silhouette. We divide the bounding box in four quadrants (subbounding boxes), allowing for the assessment of asymmetry in left/right and up/down parts of the silhouette. We then use geometric features to extract movement qualities features that characterize the four components of *DS/DM*. Such movement qualities features are inspired directly by the glossary of movement qualities, and result from participatory design workshops that were held with members of the company. In particular, one former dancer and researcher of EG|PC contributed to all of the steps of the project, from its design to its evaluation. The movement qualities features have been described in Fdili Alaoui et al. [2013]. We summarize them here:

(1) *Verticality:* The ratio of the width by the height of the silhouette. The verticality of the movement characterizes the *Breathing* vertical quality.
(2) *Extension:* The maximum distance between the center of mass and the edges of the limbs.
(3) *Leg opening:* The width between the position of the two feet.
(4) *Shifting of weight:* The distance between the position of the center of mass and the position of the center of the feet. The extension, shifting of weight, and leg opening characterize the *Expanding* extension quality.
(5) *Periodicity:* The mean of the coefficient of autocorrelation on each extremity of the 4 subbounding boxes. The statistical autocorrelation is the correlation between a signal and its values at different points in time. Thus, when a signal is periodic, the autocorrelation value is high. Our periodicity feature characterizes the rhythm

of the rebound in the *Jumping* because each extremity of the bounding boxes has a periodic movement and thus a high autocorrelation value.

(6) *Quantity of Motion:* The variation of the pixel intensity representing the silhouette of the participant during time. It can be seen as the amount of detection of motion in time. The quantity of motion characterizes the energy in the *Reducing* sustained quality.

3.2. Movement Qualities Recognition

As shown in Figure 3, the movement quality features feed a classification engine that classifies in real time the movement into one of the four *DS/DM* components. We used a gesture recognition software called the Gesture Follower (GF) that relies on Hidden Markov Models, a machine-learning technique [Bevilacqua et al. 2007]. The GF trains a Markov Model for each gesture of the vocabulary using only one prerecorded reference of the gesture's feature values. During the test phase, the system recognizes specific sequences of a gesture by estimating in real time similarities between the sequence and the prerecorded references. It provides a temporal modeling of the sequence being performed and outputs continuously the time progression index and the likelihoods. We adapted the GF to be able to classify the dancers' movement qualities into *DS/DM* components. To do so, we fed the GF with the high-level features of movement qualities rather than gestural raw data. The recognition is thus no longer based on gestural patterns, but on the patterns of the movement qualities. We recorded examples of the four components, executed by the dancer from EG|PC, extracted the movement qualities features and used them as input of the GF to train the Markov Models offline. Based on these examples, the GF is able to estimate in real time the similarities between the movement qualities performed by the dancer and those of the prerecorded examples of each component. It classifies the movement qualities in real time into the component that obtains the highest likelihood (e.g., probability). More details on movement quality analysis can be found in Fdili Alaoui et al. [2013].

3.3. Movement Qualities Visualization Based on Mass-Spring Systems

To reflect users' movement qualities, visualizations such as levels, charts, and numerical values are not well suited because of the strong discrepancy between such basic visualization tools and the performed movements. This has pushed us toward using more subtle, abstract, expressive, and empathic visualization that reflects the movement dynamics. Physical models such as fluid dynamics models, mass-spring systems, or particle systems are good candidates for this purpose. They generate what we call "physico-plausible" rendering when their behaviors are perceived as "plausible" without necessarily imitating a realistic phenomenon [Fdili Alaoui et al. 2014]. Because physical models are governed by simplified laws of physics, they can produce physico-plausible behaviors when their parameters receive realistic values. However, they can also produce unpredictable and "nonphysico-realistic" behaviors due to the stepwise computation of the system dynamics, when their parameters receive extreme values.

In this work, we explore mass-spring systems that are often used in Virtual and Augmented Reality through 3D animation software such as Maya, 3DStudio Max, or Blender to animate or simulate deformations of a soft object [Provot 1997; Lee et al. 1995] or to model physical movements [Hsieh and Luciani 2005]. Mass-spring systems have been used to synthesize movement in various applications for the interactive and digital arts. For example, libraries such as PMPD in the PureData development environment offer a set of external objects that allow for relatively simple use and control of mass-spring systems for audiovisual composition [Momeni and Henry 2006]. In *DS/DM*, we explore the possible parallels between the movement qualities of a user and the physico-plausible dynamic behaviors of an abstract visualization based on

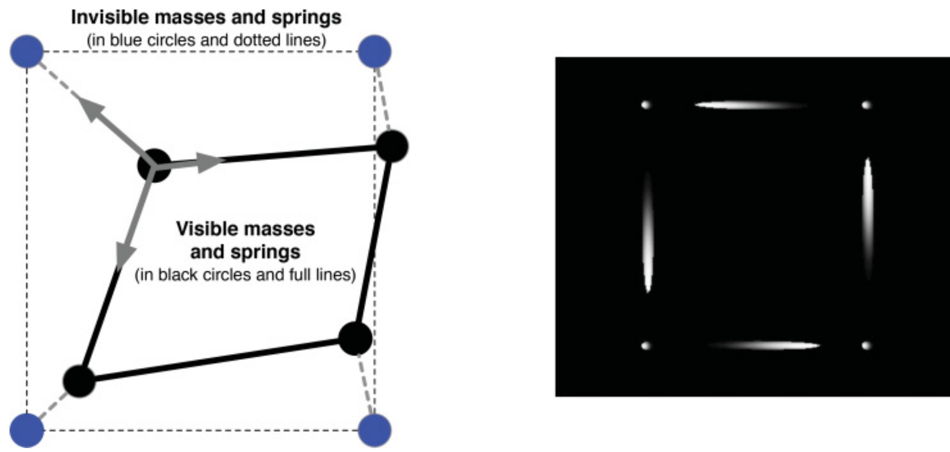

Fig. 4. The figure on the left shows the topology of the mass-spring system in the *DS/DM* installation, including the visible and invisible masses and springs. The figure on the right shows the layout, including the 4 visible masses and springs initially in a square shape.

mass-spring systems. The visual synthesis uses Allegra technology [Jacquemin 2008], which renders complex behaviors through the movement of a mass-spring system calculated on the GPU following the method developed by Georgii and Westermann [2005]. Initially, Allegra designed a mass-spring system to be controlled through a direct mapping between the user's movement and the positions of slave masses [Jacquemin and de Laubier 2006]. For *DS/DM*, the captured movement qualities are mapped to a mass-spring system's parameters of forces rather than the positions of slave masses allowing the mass-spring system dynamics to reflect the user's movement qualities (see Table I). Various parameters of force produce different dynamic behaviors, for example, a mass rebounding quickly or a mass evolving sustainedly in a highly viscous environment. The dynamics of each mass of the mass-spring system are controlled by the sum of the elastic forces of the springs connected to the mass, following Hooke's law [Georgii and Westermann 2005], and by the external forces due to the environment in which the physical mass evolves (gravity, force field, viscosity, obstacles, and so on).

In order to be able to control each mass and each spring individually, our mass-spring system is composed of a small number of elements: four visible masses connected to each other with four visible springs initially in a square shape, as well as four fixed invisible masses linked to the four visible ones with invisible springs (see Figure 4). Whenever the dancer is still, the invisible masses and springs are used to bring back the visible ones to a neutral position, that is, the initial square. Further details on the mass-spring system parameters, structure, and on the control strategies developed for the *DS/DM* installation are given in Fdili Alaoui et al. [2013].

3.4. Visual Metaphors of Movement Qualities

As shown in Figure 3, the classification layer informs the system of which *DS/DM* component is being performed and selects the associated mapping functions and the presets of the mass-spring system parameter intervals. The mappings are linear functions that associate movement qualities feature values with mass-spring system parameter values. We call *mass-spring system presets* the fixed predefined intervals in which the mass-spring system parameters vary according to the mapping functions. Both the presets' intervals and the mapping functions were designed and validated for each component in collaboration with our expert collaborator from the dance company.

Fig. 5. Picture of a dancer interacting with the visuals by performing the four components of *Breathing* (first image on the left), *Jumping* (second image), *Expanding* (third image), and *Reducing* (fourth image).

Table I. Mapping between the Movement Qualities Features and the Mass-Spring System Parameters for Each Component of *Double Skin/Double Mind* Workshop

DS/DM components	Movement qualities features	Mass-spring system preset parameters
Breathing	Verticality	Vertical springs' rest length and stiffness
	Quantity of motion	Viscosity
Jumping	Periodicity	Vertical springs' stiffness
	Quantity of motion	Vertical springs' rest length and viscosity
Expanding	Extension	Springs' stiffness
	Leg opening	Springs' rest length
	Quantity of motion	Viscosity
Reducing	Quantity of motion	Springs' rest length
	Shifting of weight	Viscosity

They produce specific dynamic behaviors that are a metaphorical visualization of the movement qualities encompassing the corresponding *DS/DM* components. According to our expert collaborator, their behaviors best evoke the corresponding *DS/DM* components for a viewer (whether expert or not). We present hereafter all the behaviors of the four mass-spring system presets. Figure 5 shows pictures of a dancer interacting with each of these behaviors.

(1) The metaphor of *Breathing* is a symmetrical vertical expansion of the mass-spring system reaching progressively and slowly a certain maximum length, then releasing to a minimum length, suggesting the pattern of vertical breathing in and out.
(2) The metaphor of *Jumping* is a symmetrical quick vertical rebound of the mass-spring system, suggesting the pattern of the repetitive drop and release in the rebound of the movement.
(3) The metaphor of *Expanding* is a quick three-dimensional extension of the mass-spring system, suggesting the spatial extension of the movement.
(4) The metaphor of *Reducing* is a slow, symmetrical shrinking of the masses into a point at the center of the screen where they merge, suggesting the thick air around the body and the length reduction.

Although the preset's intervals are fixed, the linear functions of the mappings make the association between the movement qualities and the mass-spring system parameters dynamic. For example, if a dancer is performing a *Jumping*, the system recognizes the component being performed and selects the corresponding mapping. As explained in Table I, the system maps the quantity of motion of the dancer with the viscosity and the vertical springs' rest length, and maps the periodicity of the movement with the vertical springs' stiffness. This mapping is designed so that the higher the frequency of the dancer's rebound, the stiffer the vertical springs (thus the frequency of the mass-spring system's vertical rebound). Moreover, the higher the quantity of motion of the dancer, the lower the viscosity and the higher the springs' rest length, implying a larger and more energetic rebound of the mass-spring system. In other words, when the system classifies the movement as a *Jumping*, and if the "jumpiness" is exaggerated, then the mass-spring system responds in the same way.

4. USER STUDY 1: MOVEMENT QUALITIES VISUALIZATION EVALUATION

The general purpose of this first study is to investigate the capacity of the mass-spring system to reflect on and evoke movement qualities. We run a user-based, online experiment in which mass-spring system behaviors are compared with videos of Emio Greco, the choreographer of EG|PC, performing *DS/DM* components. In this experiment, we evaluate:

(1) The ability of the set of behaviors resulting from the same mass-spring system preset, to generate clear and unambiguous metaphorical representation of the analogous *DS/DM* component.
(2) The influence of variations applied to presets' intervals, on the classification of the resulting behaviors into *DS/DM* component. We hypothesize that behaviors resulting from parameters outside the predefined intervals are weakly associated with the analogous *DS/DM* component.

We will call our four mass-spring system presets B-set, J-set, E-set, and R-set, which correspond to *Breathing*, *Jumping*, *Expanding*, and *Reducing* components, respectively. These presets are defined by specific combinations of intervals in which parameters of stiffness and rest length of each spring, and viscosity, vary. Based on these four mass-spring system presets, we generated 35 behaviors from a combination of values inside, at the boundaries, and outside of each preset's intervals.

4.1. Participants

We chose to use a controlled online evaluation because our first goal was that dancers with previous knowledge of the *DS/DM* movement qualities who lived abroad could participate. We were able to recruit 26 participants, 14 women and 12 men, with a mean (SD) age of 27(5.5) years.

4.2. Experimental Procedure

The experiment follows a within-participant design, and the stimuli were counterbalanced. Each participant evaluated 10 behaviors of the mass-spring system selected randomly among the 35 generated behaviors and appearing in a random order.

The participants watched four videos of Emio Greco performing and explaining with his own words the movement qualities of the four components of *DS/DM* before they started the classification test. Thereafter, the participants were required to watch videos of the mass-spring system behaviors and classify them into *DS/DM* components through a questionnaire. For each behavior, the participants could watch the video as many times as they wished before answering the questionnaire. Each behavior was presented in a 20s video. Figure 6 shows a screenshot of one of the phases of the evaluation. Excerpts of the videos of the mass-spring system behaviors as well as the online questionnaire are available online[3].

We developed a set of controls for the online evaluation:

(1) The participants were not able to start the evaluation without watching all of the videos in which Emio Greco explains and executes the four components of *DS/DM*.

[3]http://recherche.ircam.fr/equipes/temps-reel/egpc/pmwiki/uploads/experiments.php.

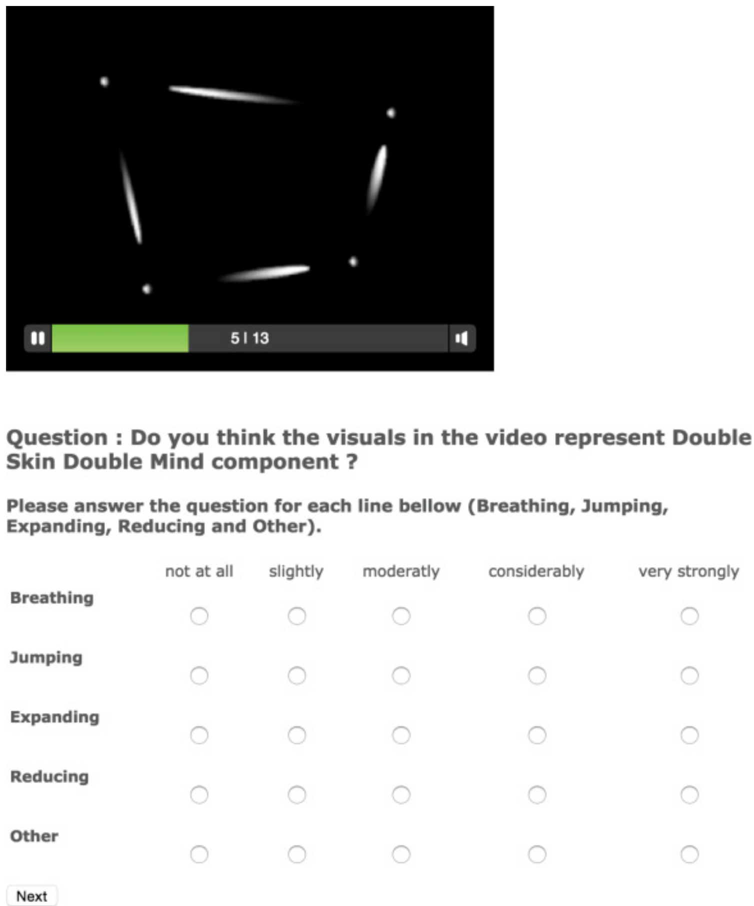

Fig. 6. Screenshot showing a page of the online experiment.

(2) At each stage of the evaluation, it was not possible to go back to the previous stage or to answer the questionnaire without previously watching the video of the behavior. It was also not possible to move to the next step without answering the question for each of the 5 items of the questionnaire (four components of DS/DM and the item *Other*).
(3) For each item of the questionnaire, it was only possible to check one of the buttons of the linear scale ranging from “not at all” to “very strongly”.

4.3. Questionnaire

The questionnaire shown in Figure 6 consists of a single question asked for each behavior: *Do you think the visuals in the video represent Double Skin/Double Mind component?* The participants had to answer the question by classifying each behavior into one of the four components of DS/DM on a linear scale from 1 to 5, where 5 is “very strongly” and 1 is “not at all.” The item *Other* was added to the questionnaire in case the participants chose not to classify a behavior of the mass-spring system into any component of DS/DM.

4.4. Data Analysis

We collected $10 \times 5 \times 26$ scores of the classification of 10 behaviors into the 5 questionnaire items by 26 participants.

First, we analyzed how each group of behaviors resulting from the same preset are classified into *DS/DM* components. We performed an analysis of variance (ANOVA) with one factor, the preset, and 4 levels, (B-set, J-set, E-set and R-set). The ANOVAs are performed on the scores of classification of groups of behaviors, into the questionnaire's five items. Subsequently, we performed post-hoc analysis that compared the presets in pairs in terms of the perceived movement qualities. In addition, for each result, we obtained the average and standard deviation of the classification scores.

Second, we examined how each behavior resulting from parameters inside/boundary/outside of the presets' intervals taken individually is classified into *DS/DM* movement qualities. For that purpose, we performed an ANOVA with one factor, the interval condition, on the classification score of each individual behavior. Subsequently, we performed a post-hoc test to compare the behaviors in pairs, depending on their classification into *DS/DM* components. Moreover, for each behavior, we obtained the mean and standard deviation of the classification scores.

We performed the statistical analyses for the dependent variables using Statistica. For all the statistical tests, we used an alpha level of 0.05. The results are explicitly referred to as "significant" if $p < 0.05$ and as a "trend" if $0.05 < p < 0.1$.

4.5. Results of the Evaluation of the Similarities Between Movement Qualities and Mass-Spring System Behaviors

4.5.1. Influence of the Presets on the Perception of the Movement Qualities. We report in Figure 7 on the results of the ANOVA on the scores of the classification of each group of behaviors resulting from each preset into the analogous *DS/DM* component. Figure 7 shows that the preset has a significant influence for the classification into each component of *DS/DM* [*Breathing*: $F(3.249) = 38.2$, $p < 0.05$; *Jumping*: $F(3.249) = 22.5$, $p < 0.05$; *Expanding*: $F(3.249) = 2.9$, $p < 0.05$; *Reducing*: $F(3.249) = 5.8$, $p < 0.05$; and *Other*: $F(3.247) = 3.7$, $p < 0.05$]. The post-hoc analysis shows that all the behaviors generated from B-set, J-set, and R-set were significantly more classified as the corresponding components of *Breathing*, *Jumping*, and *Reducing* ($p < 0.05$).

For the classification as *Expanding*, the results of the post hoc analysis show that the groups of behaviors from B-set and E-set are significantly more classified as *Expanding* than the behaviors from R-set. However, the participants ambiguously classified behaviors from B-set and E-set as *Expanding*. The ambiguity can be explained by the difficulty inherent to distinguishing the *Expanding* from the *Breathing* component. This difficulty has been confirmed by the dance students and will be discussed further in the second user study described in this article.

Finally, the result of the classification as *Other* reveals that the participants have, on average, classified significantly fewer B-set behaviors as *Other* than other behaviors. However, the average of the classification scores into *Other* is fairly low for all the behaviors because, in most cases, the participants were able to assimilate the movement qualities of *DS/DM* to the behaviors shown in the videos.

4.5.2. Influence of the Presets' Intervals on the Perception of DS/DM Movement Qualities. We report on the results of the ANOVAs on the scores of classification of each individual behavior generated from parameters' values in/out/on the border of the preset intervals into *DS/DM* components. The results show that the interval conditions have a significant influence on behavior classification [*Breathing*: $F(7.52) = 2.2$, $p < 0.05$; *Jumping*: ($F(9.69) = 17.4$, $p < 0.05$; *Expanding*: $F(8.48) = 7.9$, $p < 0.05$; and *Reducing:* $F(8.47) = 11.9$, $p < 0.05$)). The results of the post hoc test show that, for each component, the

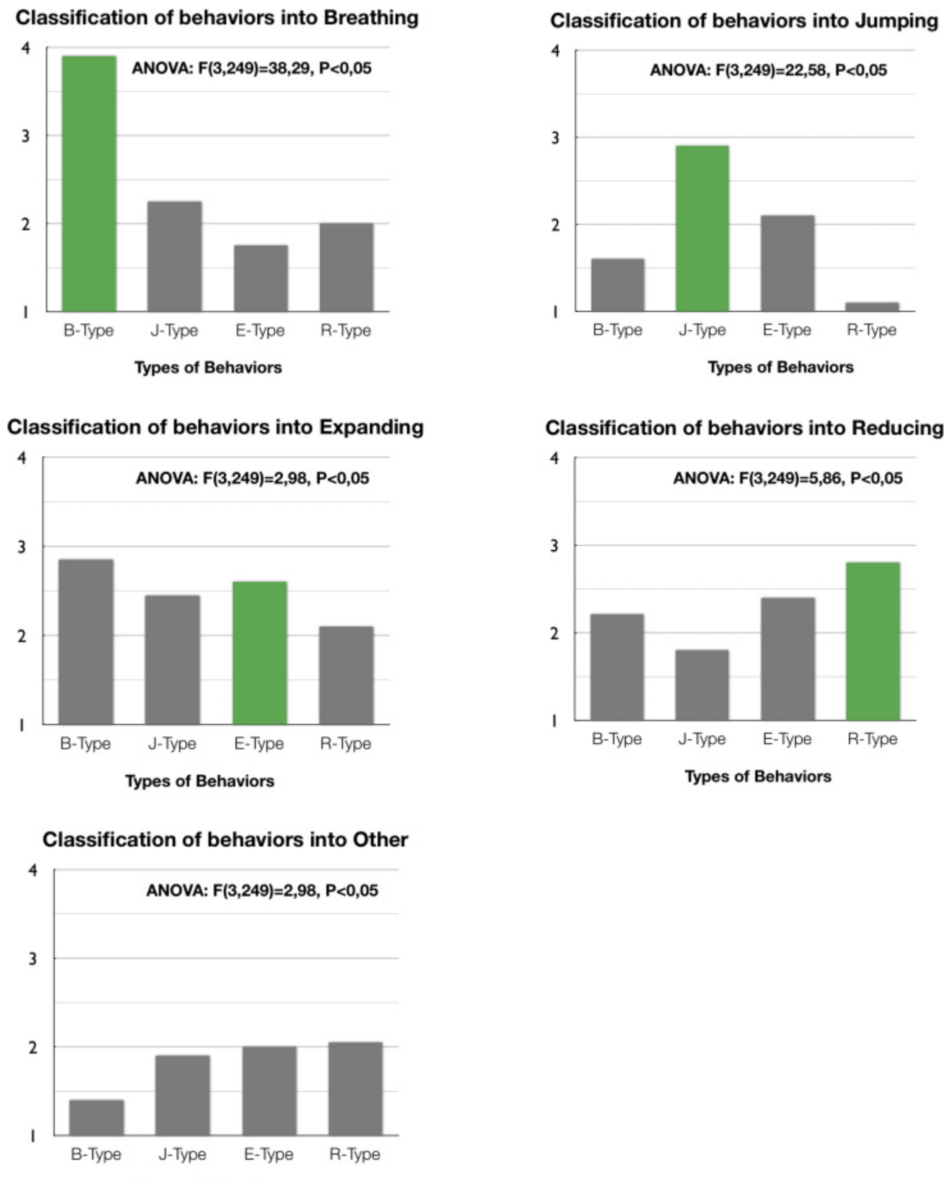

Fig. 7. Results of the ANOVA on the classification scores of behaviors grouped by presets into *Breathing* (top left), *Jumping* (top right), *Expanding* (bottom left) and *Reducing* (bottom right).

behaviors resulting from parameters outside of the preset intervals are weakly classified as the corresponding component. We summarize these results here:

(1) A B-set behavior is weakly classified as a *Breathing* if it displays an extension of the mass-spring system in all directions and not only the vertical one.
(2) A J-set behavior is weakly classified as a *Jumping* if it induces a slow oscillation, a slow extension, or a still motion. However, the perception of the *Jumping* is not altered if the behavior is a rebound in all directions, thus the verticality of the

mass-spring system motion is not a sine qua none condition to generate a suitable metaphor for the *Jumping*.

(3) An E-set behavior is weakly classified as an *Expanding* if it implies a slow reduction of the masses toward the center rather than their extension, or an overly elastic extension of the masses.

(4) An R-set behavior is weakly classified as a *Reducing* if it induces an extension rather than a reduction of the mass-spring system, or a still motion.

4.6. Discussion on the Evaluation of Movement Qualities Visualization

The experiment described in this section showed the ability of a simple mass-spring system tuned with the presets defined in collaboration with the expert dancer of the company, to create metaphors of the movement qualities in *DS/DM*.

Nevertheless, the classification as *Expanding* was ambiguously associated with behaviors generated from the presets B-set and E-set. The ambiguity can be explained by the fact that the *Expanding* and *Breathing* can be confounded because they are both based on extensions on the rhythms of breathing in and out. Such ambiguity has been confirmed by dance students and will be discussed in the following user study. Therefore, the low contrast that we obtained is also due to a lack of contrast in human perception between the *Expanding* and the *Breathing* movement qualities.

In addition to validating the capabilities of a mass-spring system to evoke the *DS/DM* components, our experiment also evaluated the importance of the interval values of the mass-spring system parameters. It showed that the behaviors resulting from parameters inside of the chosen intervals are perceived as visual metaphors of the analogous *DS/DM* movement qualities.

Our experiment allowed us to validate the parametrization of our mass-spring system to obtain a visual metaphor of *DS/DM* movement qualities. We believe that mass-spring systems have the potential to metaphorically generate various ranges of qualities from other movement theories, such as Laban Effort, by adapting the findings of our study to the specificities of their qualities.

5. USER STUDY 2: EXPERIENCE OF THE INTERACTIVE SYSTEM OF DANCE STUDENTS AND PROFESSIONALS

We report in this section on a user study that investigates the user experience of *DS/DM* interactive visuals in terms of promoting exploration, expression, and practice of the movement qualities. Our study took place in a dance workshop with dance students and in a dance training context with professional dancers; it involved a free-expression task.

5.1. Participants

In this study, we had two sets of users with two different profiles of expertise.

(1) Expert users, that is, the professional dancers of EG|PC company that are very familiar with *DS/DM* because they use it in their daily training. We recruited the 10 dancers of the company, 3 men and 7 women.

(2) Nonexperts during a one-week workshop organized along with EG|PC for the students of the Amsterdam School of the Arts to teach them the principles of *DS/DM*. We recruited 16 students in the second year of the contemporary dance curriculum, 6 men and 10 women.

5.2. Experimental Procedure

Before experimenting with the installation, the nonexperts (i.e., the students) attended an introduction lecture about the principles of *DS/DM*. This lecture was given by a

Fig. 8. Initiation of a group of students to the installation *DS/DM* through videos in which Emio Greco explains and executes components of *DS/DM*.

researcher, dancer, and teacher from the company. In addition, as shown in Figure 8, the students practiced the four components of *DS/DM* following the video instructions of Emio Greco explaining and executing these components. This initial practice allowed the students to acquire a basic practice of *DS/DM* before experimenting with the visual interaction.

To evaluate the users' experience of the interaction with the mass-spring system and articulate its exploratory and pedagogical value, we compared two modes of interaction:

(1) *Random mode*, in which the behaviors of the visuals are not interactive and are randomly triggered without corresponding to those performed by the dancers. Specifically, the output of the movement qualities recognition system is replaced by a random process. Therefore, the participant might be performing a *Jumping* and the system responding with a behavior that is related to a *Breathing* component. The parameter values vary randomly inside the mass-spring system presets interval values.
(2) *Interactive mode*, in which the behaviors of the mass-spring system are interactive and respond to the dancers' performance of *DS/DM* components.

All dancers were invited to experience the two modes individually. The experiment was designed in within-participant design. The order of experimental conditions was random, meaning that we counterbalanced the use of the random versus interactive mode. While the participants were dancing, the interactive visuals were projected on the screen in front of them. The experiment was made in silence (no music or verbal interaction with the participants). The dancers could stay in the installation space as long as they wished for practicing a free-expression task. They were asked to improvise when dancing by using the movement qualities of *DS/DM* and to pay attention to the visuals displayed. We did not give the dancers any explanation on the visuals before the beginning the experiment.

5.3. Interviews and Questionnaires

In order to analyze the dancers' experience of the visuals, we combined a quantitative methodology using a questionnaire for dance students and professionals with a qualitative methodology using semi-structured interviews that we conducted with 4 volunteers (2 women and 2 men) among the 16 students denoted E0, E1, E2, and E3. Our interviews play the role of a pre- and post-evaluation of dance students' knowledge gain about *DS/DM* components. Students were interviewed before and after the random mode and then before and after the interactive mode. We chose to run our interviews on a limited subset of students because only 4 agreed to go through the interviewing process that required them to commit for a full-day experiment. Indeed, it is difficult to mobilize a large number of students for such a laborious experiment. Instead, we chose a qualitative methodology, semi-structured interviews, that is suitable for a thorough analysis of the feedback of a few participants rather than a large set of participants. We believe that such an in-depth qualitative methodology applied to a few participants before and after experiencing each mode of interaction allows comparison of students' knowledge gain from one mode of interaction to another. We would like to emphasize that because our interviews were carried out on a limited subset of students, they should be considered as exploratory. The results of the qualitative analysis should be seen as supporting the results of the quantitative analysis in order to assess whether the interactive visuals are a promising exploratory and educational tool that consolidate dance knowledge.

The four students interviewed were asked, before starting the experiment, to give their definition of each *DS/DM* component and to imagine interaction scenarios with the visuals that we showed them on a picture. Specifically, we asked them the following question: "What would you envision the visuals to do when you perform *DS/DM*?" After experimenting with the random and then the interactive mode, the four students were interviewed about each of the themes described earlier. We asked them to describe their perception of the visual feedback and report on their experience of interacting with them. They were asked to report on how the visuals had influenced their performative exploration and practice of *DS/DM*. Note that our semi-structured interviews were flexible and allowed the interviewed students to freely suggest new questions or make comments.

We will report in this article on the results of the questionnaires related to:

(1) *The interaction:* Professional dancers' experiences of the visuals as a response to their movement.
(2) *The influence on the performance:* Dance students' experiences of the visuals' influence on their performance.
(3) *The exploratory value:* Dance students' experiences of the visuals as promoting the exploration and improving the understanding of the components of *DS/DM*.

Dancers responded to each set of assertions after experiencing each mode of interaction. The participants were asked to evaluate the assertions on a linear scale ranging from 0 to 4, where 4 corresponds to "strongly agree" and 0 "strongly disagree." We obtained for this questionnaire an alpha coefficient greater than 0.8 Cronbach (the threshold of acceptability of the American Psychological Association is 0.7).

In addition to the questionnaire, we measured objective data on dancers' interactions with the visuals. First, we measured the movement qualities recognition rate of the system for the professional dancers. This rate is computed as the proportion of the frames in which the system identifies the motion as one component of *DS/DM* to the total number of frames of the performance. Second, we measured the time that the dance students spent in the installation in order to assess which interaction mode engages the participants longer in an exploration of the dance components.

Our user study was carried out on different sets of participants. We investigated the interaction with professional dancers because they have an in-depth knowledge of *DS*/*DM* components that allows them to articulate the capacity of the visuals to provide an interactive response to their movement qualities. We investigated the exploratory value of the visuals and their influence on the performance of dance students because we aim to assess these values within the discovery and learning process of participants with no previous knowledge of *DS*/*DM*.

5.4. Data Analysis

We collected the responses of the four students to our semi-structured interviews and the answers to the questionnaires completed by the dance professionals and students following the experience of each of the two modes of interaction.

We analyzed the questionnaire data with a Student's t-test on the scores of each assertion of the questionnaire. The results given in the following tables present the test value t, representing the fit test to the Fisher law. The value of dl represents the degree of freedom and the value of P indicates whether there is a significant difference (respectively, a trend) between experimental conditions when $P < 0.05$ (respectively, $P < 0.1$).

5.5. Results of the Evaluation of User Experience

In this section, we first report on the definition of *DS*/*DM* components given by the four students interviewed and the imagined interaction scenarios with the visuals. We then report on the results of the evaluations of the visuals' interaction response and their influence in promoting the dancers' exploration of *DS*/*DM* components.

5.5.1. Defining DS/DM Components in the Interviews. The interviews that took place before the dancers experienced the two modes of interaction revealed a good understanding and definition of the *Breathing*, *Jumping*, and *Reducing*qualities. All 4 students homogeneously defined the qualities of *Breathing* as a vertical extension from the bottom to the top ends of the body, due to respiration pattern. Moreover, they all defined the *Jumping* as a release of the body that produced a bounce to the edges of the body. The *Reducing* was defined using personal metaphors. E1 mentioned the metaphor of *honey*. E2 compared the air around him with a *fog*. E3 stated that the *Reducing* creates a resistance area that conquers him. Finally, E0 described the *Reducing* as a smaller controlled movement but not any less important. When asked about the *Expanding*, the students assimilated it to the *Breathing*. To help clarify the *Expanding*, we asked them to think about the differences in terms of space and use of legs. E0, E1, and E2 indicated that—contrary to the *Breathing,* which is solely vertical—the *Expanding* travels through space in different directions. For E1 and E2, the *Expanding* can reach more extreme extensions, allowing movement in spirals and twists, as well as causing loss of balance. E3 considered that the *"Expanding is in fact different [from the Breathing] because it is in space rather than inner. But from the outside, they look similar*." In addition, all students considered that the *Expanding* requires a greater transfer of weight.

5.5.2. Behavior Imagined by Students. The interaction scenarios and visual behaviors envisioned by the four students when we interviewed them before experiencing the visuals were found to be fairly similar to the behaviors provided by *DS*/*DM*. For a metaphor of a *Breathing*, all students imagined visuals growing and shrinking in four directions (except for E3, who mentioned only the vertical direction). For a metaphor of a *Jumping*, all students imagined visuals bouncing up and down. E1 mentioned a

Table II. Dance Professionals' Responses to the Assertion "Movements of the Visuals are a Response to my Movement Qualities"

	Mean (SD)	t	dl	P
Interactive Mode	1.9 (1.1)	1.86	9	0.09
Random Mode	1.0 (1.4)			

Table III. Dance Professionals' Responses to the Assertion "The Visuals are Alive"

	Mean (SD)	t	dl	P
Interactive Mode	3.0 (0.9)	1.96	9	0.08
Random Mode	2.4 (1.1)			

soft bounce. E0 imagined that the visuals resonate with a rebound that remained after she stopped her movement and that gradually reduced.

For a metaphor of the *Expanding*, all students envisioned a visual extension of the masses in all directions growing and shrinking. E0 compared the behavior of the visuals to *a tree or a plant, something that develops*. E2 evoked the metaphor of *"an object that yawns when he reaches his end."* He imagined that the object goes further and continues to grow. E1 and E3 imagined a spiral rotation movement.

For a metaphor of the *Reducing*, E0 uses the image of the syrup: *"The rest of the components are like the drink, and if you concentrate you get the syrup. The Reducing is also strong, but it is smaller."* E0 and E3 suggest giving color to visually express the *Reducing*. According to E0, *"if the object had a light blue color, while reducing, I would not mind it becoming darker and smaller."* For E2, the visuals should express the resistance: *"They could tremble as if they tried to move, but do not move*." E3 suggested to visualize the *"power outside that shrinks the object."* E1 imagined a slow dynamics, without rhythm.

5.5.3. Professional Dancers' Experience of the Visuals as a Response to their Movement. From the questionnaire, professional dancers perceive a clearer visual interactive response to their movement qualities in the interactive mode than in the random mode ($P = 0.09$) (see Table II). This is consistent with our objective measure of the rate of classification. We measured that, in the interactive mode, 88% of the time the system was able to identify the movement quality performed by the dancer and to respond to it with the analogous visual behaviors. More precisely, the system classified in mean 9748 frames on a total of 11 065 frames of the dancers' movements, as one of the four components of DS/DM.

The dancers' feedback on visuals' response to their movement qualities is fairly low (in the interactive mode the mean is 1.9). This is due to the characteristics of physical models, being reflexive without mimicking the users' exact motion. Dancers tend to perceive the visuals as organic and alive rather than a direct mirror to their movement. This characteristic is discussed both in the work of Pachet [2006] and in the state of the art on physical models in digital arts by Fdili Alaoui et al. [2014]. The responses to the assertion "The visuals are alive" reported in Table III confirm this tendency. Indeed, the dancers perceived the visuals as more alive in the interactive mode than in the random mode ($P = 0.08$), with a mean of 3.0.

The four dance students interviewed perceived more clearly the visual response to their movement qualities in the interactive mode than in the random mode. In the interactive mode, all 4 interviewed students have perceived consistently the response of the visual behaviors. They saw that the visuals grew and shrank vertically in response to the *Breathing* and that the visuals bounced vertically in response to the *Jumping*. They all perceived that the visuals grew in different directions in space in response to the *Expanding*. Finally, they all perceived that the visual narrowed slowly in response

Table IV. Students' Responses Regarding the Influence of the Visuals on their Performance

	Mean (SD)	t	dl	P
Interactive Mode	3.0 (1.0)	−2.3	9	0.04
Random Mode	3.8 (0.4)			

to the *Reducing*. E2 defined the interactive mode as *"a picture of a human way of moving [. . .] creating shapes and movement qualities*."

5.5.4. Dance Students' Experience of the Visuals' Influence on their Performance. From the questionnaire, dance students perceived the visuals as having significantly more influence on their performance when the mass-spring system behaviors are randomly generated ($P = 0.04$) (see Table IV).

This influence is perceived more in the random mode: the students tend to appreciate the random mode because it encourages then to imitate its behaviors, whereas in the interactive mode, they tend to focus on controlling the visual behavior. This has been confirmed by the interviews. For example, E3 stated that he was influenced by the visuals in the random mode by trying to follow their energy and qualities. For him, it was quite easy to follow them as *"they proposed very clear dynamic qualities*." He defined the relationship between his movement and the visual behaviors as *"an attempt to stay together or to inspire one another. To me, they were a sort of inspiration."* On the other hand, in the interactive mode, E3 found it more inspiring to let the visuals follow her. Finally, in interactive mode, E0 was asked about the influence of the model: *"It [the visuals] reacts to me, but I do not know how to react to it."*

5.5.5. The Exploratory Value: Dance Students' Experience of the Visuals as Promoting Exploration and Improving the Understanding of DS/DM Components. The interactive mode can be considered as a "knowledge-of-performance" approach. It provides the students with visual feedback on their performance of the movement qualities. By doing so, the interactive mode seemed to better encourage movement exploration and improvisation. After experiencing both modes, E0 considered that the random mode did not help her and did not encourage her to improvise: *"The visuals were sometimes very slow and did not understand what I was doing*." Moreover, E2 reported about the random mode: *"I tried to move like crazy and they did not follow me [. . .] there was no relationship with me. This led me to wonder if I was not performing the same quality but obviously this is wrong*." Finally, E3 stated that the interactive mode compared with the random mode enabled him to understand *"the connection between the qualities and the forms of the body and have more contact with the outside*."

All 4 interviewed students reported on a better experience of the *DS/DM* installation when the visuals were interactive. E0 and E2 students expressed their disappointment during the experience of the random mode. E2 reported that he preferred the interactive mode because the visuals followed him. After experiencing the random mode, E2 reported that he believed that the model did not follow him, thus he decided to be more clear in his movements so that the system would respond clearly. He eventually expressed being *"very happy"* in the interactive mode when he understood the visual response that he described as *"active*." He found that "*it was very motivating and that it was good."* E3 reported that in the interactive mode, the visuals were "*fun*." For E3, it was more pleasant to experience the installation than working in the studio. According to E3, this preference is due to the fact that the visuals allowed her to *"play with something more literal*."

In the questionnaire, the answers to the assertion "The experience improves my understanding of the *DS/DM* components" show no significant differences between the random mode and the interactive mode. For both modes, the mean of the answer is

Table V. Results Related to the Assertion "The Experience Improves my Understanding of the Components of *DS/DM*"

	Mean (SD)	t	dl	P
Interactive mode	2.6 (0.8)	−2.3	9	>0.1
Random mode	2.5 (0.9)			

Table VI. Mean of the Total Time Frames Spent in each Interaction Mode

	Mean (SD)	t	dl	P
Interactive mode	11065 (2901)	1,40	9	0,19
Random mode	7352 (6579)			

fairly high, around 2.5 (see Table V). Although the interactive mode seemed to better encourage movement exploration, both modes contribute in ameliorating the understanding of the movement qualities differently. The random mode generates visual behaviors that are not related to the movement performed by the participants. Therefore, participants tend to mimic these random behaviors. Such a demonstrative role also affords building an understanding through practice of DS/DM components.

Table VI shows that the mean of the total number of frames spent in both interactive modes is significantly different. Dancers seem to spend 50% more time in the interactive mode compared to the random mode. This result suggests that the interaction promotes the exploration of DS/DM movement qualities and encourages the dancers to pursue the performance of each component longer.

5.6. Discussion of User Experiment Results

The interactive visuals appeared to the student as a reflexive tool, helping them to build an understanding of DS/DM components. They have a pedagogical value related to a "knowledge-of-performance" approach because they provide the students with "augmented feedback" on how they execute the movement qualities. The results of the user experiments show that the students considered that the interactive visuals encouraged them to perform, explore, and practice DS/DM components.

The user experiment also showed that the dancers of the company EG|PC tend to perceive a better visual response to their movement qualities and to perceive the visual behavior as more alive in the interactive mode than in the random mode. These results are consistent with the much longer time spent in the interactive mode compared to the random mode (50% more).

Yet another type of understanding of the components of DS/DM seems to come from the random mode, which generates behaviors that evoke DS/DM components even if they are not related to those performed by the participants. These results correlate the findings of Pachet [2006]. In their discussion on reflexive systems, they found that a virtual system, that does not mimic the user's behavior, but that responds with related "style" combined with a random effect, can have a positive effect on users. Here, the random behaviors have a positive influence on the participants' performance by inviting the users to imitate them. On the other hand, the interactive mode plays a reflexive role that encourages users to explore and improvise using movement qualities, which can result in a better understanding of DS/DM components through their practice. In summary, there seems to be two general trends in the dancers' behaviors: in the interactive mode, the dancers understand that their movements control the visuals and do not intentionally feel constrained to imitate them; in the random mode, they intentionally mimick the visual behaviors to create the missing correlation with their movement.

6. CONCLUSION

In this article, we have presented an interactive installation designed for training dancers on movement qualities. It provides interactive visuals based on mass-spring systems that respond to the dancers' movement qualities. We have evaluated the ability of the visuals to evoke the dancers' movement qualities as well as the dancers' experience of the interactive visuals in the context of a dance workshop and training. Our system has been successfully implemented in the interactive installation *DS/DM* in collaboration with the contemporary dance company EG|PC.

Our first online user evaluation was carried out to assess whether a mass-spring system can generate dynamic behaviors that are assimilated to the movement qualities found in analogous dance videos of the EG|PC dance company. Our evaluation showed that an MSS can generate dynamic behaviors that were perceived by the dancers as metaphors evoking the movement qualities of EG|PC.

We have also reported on our second user evaluation of the system, in which we investigated dance students' and professionals' experience of the interaction with the visual feedback. Our goal was to articulate the value of the interactive visuals for dance students from the Amsterdam School of the Arts in an educational context and dance professionals composed exclusively of the company's dancers who have a previous knowledge of *DS/DM* in a training context. The results of these evaluations showed that the dancers were able to engage with the interactive visuals. They stated that the interactive visuals provided feedback on how they execute *DS/DM* components and helped them explore, perform, and practice their complex movement qualities. The interactive visuals helped the dancers to explore novel movement qualities material and fostered their creativity on generating improvisations with digital media, offering them a digital partner relationship. This type of relationship can be adapted to the context of performance in addition to the educational context.

Beyond applications in dance, we believe that our approach could be adapted to a range of different interactions and constitute a rich source for the design of innovative HCIs for the performing arts. We emphasize that although we studied four dance components of the EG|PC company encompassing basic movement qualities, we believe that our overall approach could be applied to a large range of movement qualities. For example, the four movement qualities that we studied cover a wide range of dynamics that can be considered to visualize different movement qualities.

Thus, the results of our user studies are a significant contribution to the design of movement-based interaction exploiting movement qualities, which, we believe, has strong potential applications in arts, entertainment, education, and rehabilitation. For example, movement quality–based interactive systems can be used in rehabilitation, drawing on methodologies used in movement and dance therapy. These methodologies utilize movement qualities or Laban Efforts in order to engage the patient in a mobility process that allows the body to make adjustments and weight shifts as opposed to the emphasis on static positioning or muscular strength in physical therapy [Hackney 2003]. With an appropriate movement quality vocabulary, the interactive technology can support the patient in making expressive statements through movement qualities as a way to engage in the mobility process fully and progress in achieving full-body integrated movement capacities.

Finally, the user evaluations conducted have shown that our system presents promising features for new approaches to teaching dance in which new media support learning through practice process of the dancers. For this reason, the installation *DS/DM* has been welcomed by professional dance educators. Specifically, it is currently integrated as a teaching tool in the dance curriculum of the Amsterdam School of the Arts.

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REFERENCES

B. Bermudez, S. Delahunta, M. Hoogenboom, C. Ziegler, F. Bevilacqua, S. Fdili Alaoui, and B. Meneses Gutierrez. 2011. The double skin/double mind interactive installation. *Journal for Artistic Research (JAR)*.

B. Bermudez and C. Fernandes. 2010. Inventing the interactive glossary: An approach to documenting contemporary dance. *Arti Journal* 2, 2, 29–31.

F. Bevilacqua, F. Guedy, N. Schnell, E. Flety, and N. Leroy. 2007. Wireless sensor interface and gesture-follower for music pedagogy. In *Proceedings of the 7th International Conference on New Interfaces for Musical Expression*. 124–129.

L. A. Blom and L. T. Chaplin. 1982. *The Intimate Act of Choreography*. University of Pittsburgh Press, Pittsburgh, PA.

D. Bouchard and N. Badler. 2007. Semantic segmentation of motion capture using Laban Movement Analysis. In *Proceedings of the International Conference on Intelligent Virtual Agents*. Springer, Paris, France, 37–44.

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

D. Chi, M. Costa, L. Zhao, and N. Badler. 2000. The EMOTE model for effort and shape. In *Proceedings of the Conference on Computer Graphics and Interactive Techniques (SIGGRAPH)*. ACM, New York, NY, 173–182.

G. Corness and T. Schiphorst. 2013. Performing with a system's intention: Embodied cues in performer-system interaction. In *Proceedings of the 9th ACM Conference on Creativity and Cognition*. ACM, New York, NY, 156–164.

S. Delahunta. 2007. *Capturing Intention: Documentation, Analysis and Notation Research Based on the Work of Emio Greco | PC.* Emio Greco | PC and Amsterdam School of the Arts.

S. Fdili Alaoui, F. Bevilacqua, B. Bermudez, and C. Jacquemin. 2013. Dance interaction with physical model visualization based on movement qualities. *International Journal of Arts and Technology (IJART)* 6, 4, 357–387.

S. Fdili Alaoui, B. Caramiaux, M. Serrano, and F. Bevilacqua. 2012. Dance movement qualities as interaction modality. In *Proceedings of the ACM Conference on Designing Interactive Systems (DIS)*. ACM, New York, NY, 761–769.

S. Fdili Alaoui, C. Henry, and C. Jacquemin. 2014. Physical modeling for interactive installations and the performing arts. *International Journal of Performing Arts and Digital Media (IJPADM)* 10, 2, 159–178.

J. Georgii and R. Westermann. 2005. Mass-spring systems on the GPU. *Simulation Modelling Practice and Theory* 13, 8, 693–702.

P. Hackney. 2003. *Making Connections: Total Body Integration through Bartenieff Fundamentals*. Routledge, New York, NY.

W. N. W. Hashim, N. L. M. Noor, and W. A. W. Adnan. 2009. The design of aesthetic interaction: Towards a graceful interaction framework. In *Proceedings of the 2nd International Conference on Interaction Sciences: Information Technology, Culture and Human*. ACM, New York, NY, 69–75.

C. Hsieh and C. Luciani. 2005. Generating dance verbs and assisting computer choreography. In *Proceedings of the ACM International Conference on Multimedia (SIGMM)*. ACM, New York, NY, 774–782.

C Jacquemin. 2008. Allegra: A new instrument for bringing interactive graphics to life. In *Proceedings of the ACM International Conference on Multimedia (SIGMM)*. ACM, New York, NY, 961–964.

C. Jacquemin and S. de Laubier. 2006. Transmodal feedback as a new perspective for audio-visual effects. In *Proceedings of the 2006 Conference on New Interfaces for Musical Expression*. 156–161.

M. W. Kernodle and L. G. Carlton. 1992. Information feedback and the learning multiple-degree-of-freedom activities. *Journal of Motor Behavior.* 24, 2, 187–196.

J. Kjolberg. 2004. Designing full body movement interaction using modern dance as a starting point. In *Proceedings of the ACM Conference on Designing Interactive Systems (DIS)*. ACM, New York, NY, 353–356.

R. Laban. 1994. *La Maîtrise du Mouvement*. Actes Sud, Arles, France.

Y. Lee, D. Terzopoulos, and K. Waters. 1995. Realistic modeling for facial animation. In *Proceedings of the Conference on Computer Graphics and Interactive Techniques (SIGGRAPH)*. ACM, New York, NY, 55–62.

A. Lockhart and E. Pease. 1982. *Modern Dance: Building and Teaching Lessons* (6th ed.). William C. Brown, New York, NY.

D. S. Maranan, S. Fdili Alaoui, T. Schiphorst, P. Pasquier, and L. Bartram. 2013. Designing for movement: Evaluating computational models using LMA effort qualities. In *Proceedings of the ACM International Conference on Human Factors in Computing Systems (SIGCHI)*. ACM, New York, NY, 991–1000.

H. Mentis and C. Johansson. 2013. Seeing movement qualities. In *Proceedings of the International Conference on Human Factors in Computing Systems (SIGCHI)*. ACM, New York, NY, 3375–3384.

J. Moen and J. Sandsjo. 2005. BodyBug-design of KinAesthetic interaction. In *Digital Proceedings of NORDES In the Making*.

A. Momeni and C Henry. 2006. Dynamic independent mapping layers for concurrent control of audio and video synthesis. *Computer Music Journal* 30, 1, 49–66.

F. Pachet. 2006. Enhancing individual creativity with interactive musical reflective systems. I. Deliège, and G. Wiggins (Eds.), *Musical Creativity: Multidisciplinary Research in Theory And Practice.* Psychology Press, New York, NY.

X. Provot. 1997. Collision and self-collision detection handling in cloth model dedicated to design garment. In *Proceedings of Graphics Interface*. 177–189.

T. Schiphorst. 2009. soft (n): Toward a somaesthetics of touch. In *Proceedings of the International Conference on Human Factors in Computing Systems (SIGCHI)*. ACM, New York, NY, 2427–2438.

T. Schiphorst, N. Jaffe, and R. Lovell. 2005. Threads of recognition: Using touch as input with directionally conductive fabric. In *Proceedings of the International Conference on Human Factors in Computing Systems (SIGCHI)*. ACM, New York, NY, 2–7.

P. Subyen, D. S. Maranan, K. Carlson, T. Schiphorst, and P. Pasquier. 2011. Flow: Expressing movement quality. In *Learning, The User in Flux Workshop at the ACM International Conference on Human Factors in Computing Systems (SIGCHI)*. Vancouver, Canada.

D. Swaminathan, H. Thornburg, J. Mumford, S. Rajko, J. James, T. Ingalls, E. Campana, G. Qian, P. Sampath, and B. Peng. 2009. A dynamic Bayesian approach to computational Laban shape quality analysis. *Advances in Human–Computer Interaction* 2009, 1–17.

G. Volpe. 2003. *Computational Models of Expressive Gesture in multimedia systems*. Ph.D. Dissertation. InfoMus Lab, Genova.

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