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Learning Complex Actions Through Physical vs. Observational Experience: Implications and Applications for Dance and Other Performing Arts

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Introduction

Observing a model is often a first step towards learning a new motor skill. When learning a complex new movement, such as a triple jump in figure skating or a challenging chord progression in a piano piece, an instructor can communicate precise visual, spatial and movement characteristics of an action simply through demonstration. The observer must then memorize this action before converting it into a motor command that can be accurately

performed. Although numerous studies in motor learning have measured how physical performance improves with repeated practice (Lee, Swinnen and Serrien 1994; Wulf and Schmidt 1997; Walker et al. 2002; Savion-Lemieux and Penhune 2005), the precise manner in which physical and observational experience affect action memory is less well understood. Nevertheless, a growing body of literature is beginning to address how the ability to process other peoples's bodies moving in space may contribute to improvements in an observer's ability to understand and subsequently perform a movement.

Performing an exact set of movements as modelled by a choreographer or director can be a crucial aspect of artistic expression in performing arts settings, such as when learning classic Denishawn, Graham or Balanchine choreography.[1] As such, the type of memory processes required to learn sequences of movements in these settings can be considered distinct from other types of skill learning, given that these actions are defined by highly specific characteristics of timing, intention and expression. For instance, crossing a stage from upstage left to downstage right performing a combination of *piqué* and *chaîné* turns requires performance of a sequence of movements defined not just by an end goal (i.e. to cross the stage), but also by the precise movement profiles of the individual turns, as well as the choreographic intent underlying this movement (i.e. the dancer is heading to that part of the stage to joyfully greet a friend in a celebration scene in a particular ballet). In a contrasting example taken from sport, different tennis players may use different approaches to hit a ball that are nevertheless equally effective in scoring points. Similarly, professional basketball players may pass a ball using movements that are different between players, but can be combined during team play to achieve the mutual objective of scoring points. For students of dance and other performing arts, the additional imitative aspects of performance (for instance, emulating the focus of gaze, the tension held in the shoulders and angle of the head) place numerous extra demands on action memory compared to contexts where minute features of movement kinematics are less emphasized and the goal of an action (i.e. passing a ball or scoring a point) matters most. The aim of this chapter is to illustrate how findings from empirical investigation of observational learning may be applied to contexts that require detailed movement memory for action performance.

Body processing in the brain

Fortunately for performers and non-performers alike, the human brain is equipped with sophisticated cognitive machinery that can deal with the demands of translating rich visual information about the postures and movements of another performer's body onto one's own body. When observing actions, the human brain processes these actions using multiple tiers of visual data. Early visual processing areas in the brain, located within the occipital and temporal lobes, decode visual input regarding the angles of body parts and outlines of body shapes that we encounter when we see other people (Downing et al. 2001; Kamitani and Tong 2005; Urgesi et al. 2007). Particular patches within the occipital cortex contain populations of neurons that respond to basic visual properties such as colour, shape and line orientations in the surrounding environment (Murray, Olshausen and Woods 2003; Kamitani and Tong 2005; Parkes et al. 2009). In addition, activity within the *extrastriate body area* (EBA) and *superior temporal sulcus* (STS) appears to be tuned to bodies (Downing et al. 2001) and biological motion (Thompson et al. 2005), respectively.
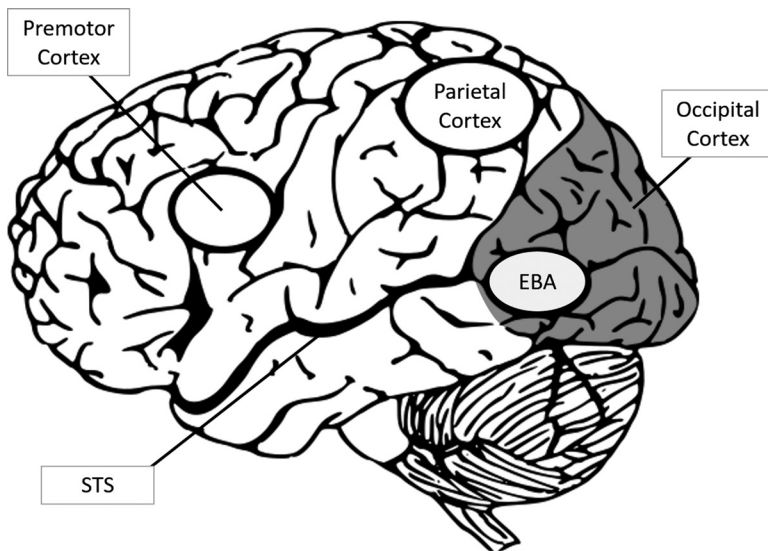

FIGURE 6.1 *Key brain regions involved in body processing.*

Overall, activity within these particular brain regions facilitates the visual processing of others' bodies in rich detail.

Some studies have shown that we are able to understand biological motion even in the absence of visually detailed human figures, as in the case of point-light displays (Pinto and Shiffrar 1999). These displays are often composed of nothing more than a few 'floating' dots positioned on key joints in a moving human figure, which when seen moving together give the viewer a strong impression that they are watching a human body in motion, even though they might only be seeing seven white dots moving on a black background. Despite the fact that the figure itself is completely invisible, the ability to infer motion is so advanced that humans can accurately determine whether a figure shown in a point-light display is happy, sad or fearful (Clarke et al. 2005). Remarkably, even an actor's gender (Mather and Murdoch 1994) and sexual orientation (Blake and Shiffrar 2007) can be deduced at higher rates than chance from such point-light displays of biological motion. These findings demonstrate that complex information regarding identity, emotion, sexual orientation and even mental states can be inferred through human actions depicted using an extremely minimal level of visual detail. The fact that the human brain can pick up such a rich array of movement and social information from a few dots moving on a screen suggests that such minimal displays might also be useful in exploring how memory for movement is encoded.

Point-light display

Speaking further to this point, if detailed visual information about another person's body is not required for the human brain to process human motion, point-light displays themselves may be an effective tool in teaching movement information in a stripped-down context. Currently, studies that have compared point-light displays against other forms of demonstration provide mixed support for using visually reduced stimuli to teach new movements (Rodrigues, Ferracioli and Denardi 2010; Kordi and Ghamary 2014). When comparing point-light displays to naturalistic video demonstrations, Rodrigues, Ferracioli and Denardi (2010) found that dance-naïve participants in the naturalistic video group performed better than
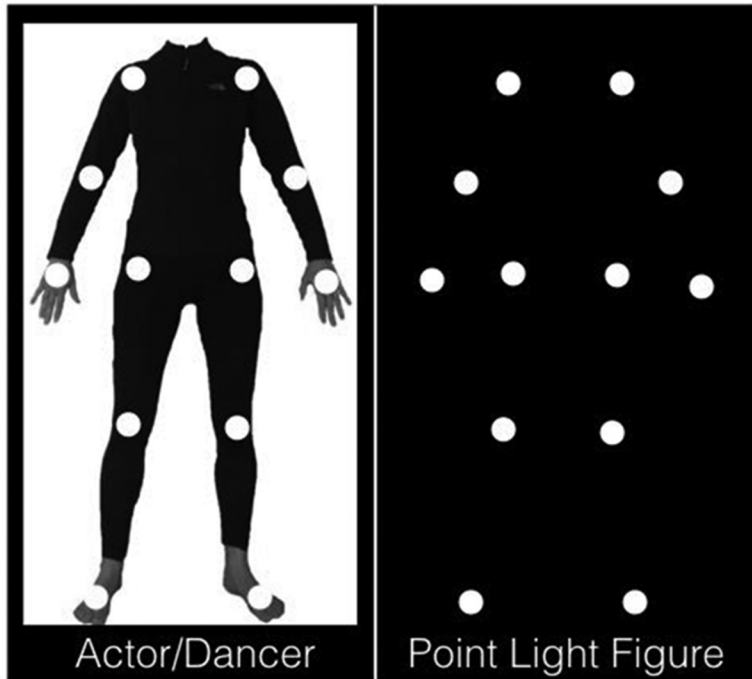
FIGURE 6.2 *Mapping of a human figure onto a point light display.*

participants in the point-light group when performance was assessed by expert ballet dancers. In a separate study involving basketball free-throws, however, participants assigned to a point-light group showed a similar capacity to learn these movements as participants assigned to a naturalistic video group, indicating that skill learning in this particular basketball context was comparable across the two demonstration modes (Kordi and Ghamary 2014). However, these studies only feature point-light displays during initial demonstration and do not explore how the same displays could be adapted to provide online feedback during performance. Using similar motion capture techniques as those required to produce the point-light displays in the first place, instruction and feedback modes could be combined side-by-side so that students seeking to perfect aspects of a particular movement (such as the timing or amplitude of a jump or a kick) can observe the extent to which their own movements deviate from a

model when observed in a simplified point-light format. Whilst this technique might not be as useful for students working on expressive variations, such as muscle intentionality or direction of gaze, what point-light displays do offer are simple interfaces to communicate subtle physical and visual differences between demonstrated and reproduced movements whilst leaving out visual detail that might otherwise distract when focusing on enhancing precise physical reproduction of movement timing, scale and amplitude.

Learning by doing versus learning by seeing

Research findings from social neuroscience could help explain why providing more detailed visual feedback may not necessarily aid action memory and performance in all contexts. Although some common brain regions spanning sensorimotor cortices are engaged when we perceive as well as perform movements (Grèzes and Decety 2001; Caspers et al. 2010), the degree to which these regions are found to be active during observation and performance vary across studies. When expert ballet dancers observe unpractised choreography performed by opposite-gendered performers, activation in key visuomotor processing regions such as the *premotor* and *parietal* cortices (see Figure 6.1) is reduced compared to when they observe movements from their own-gendered repertoire (Calvo-Merino et al. 2006). This profile of neural activity amongst expert dancers suggests that a lack of physical experience with movements that are gender-specific for the opposite gender, despite frequent visual experience, results in more superficial processing of these actions.

In contrast, during action observation amongst dance-naïve participants, Cross and colleagues found similar patterns of brain activation for previously observed and previously performed dance movements, following five days of visual or physical practice (Cross et al. 2009; Kirsch and Cross 2015). Juxtaposing these results with those reported by Calvo-Merino et al. (2006), the participants featured in the study by Calvo-Merino and colleagues may have had more fully developed motor templates for actions they had learnt through years of physical training, which were not engaged when

observing choreography that is extremely visually familiar, but not at all physically familiar. For Cross and her collaborators's dance-naïve participants, it is likely that the recentness of observational and physical training experience, as well as the overall similarity of movements encountered across both types of training, may have evoked similar movement memories. Overall, these studies highlight how individual differences in movement experience as well as task-related differences could affect the degree to which observed actions elicit movement-related activity in the brain.

In certain conditions, observation alone has been shown to improve subsequent motor performance (Kohl and Shea 1992; Black and Wright 2000), highlighting the fact that some improvements in motor performance can be achieved without concurrent sensorimotor feedback. In a study that required participants to trace patterns using a computer mouse, observing another learner's movement errors produced subsequent improvements in the observer's own movement profiles, even when no physical practice was involved (Hayes, Elliot and Bennett 2013). Specifically, participants in the observation group demonstrated improved performance after being yoked to participants in a physical practice condition, indicating that visuomotor information regarding tracing motions could be learnt and retained through observation alone. Similar effects on performance have also been documented immediately following observation without prolonged training. In a study by Mattar and Gribble (2005), participants who observed videos of other individuals learning to manipulate a robotic arm performed better than control subjects who had no experience observing how to move the robot arm. Together, these studies suggest that useful information about how to perform a new action may be learnt and retained for later performance, even within a limited timeframe and even when no concurrent physical movement is performed.

Movement facilitation during action observation

Depending on circumstances, executing an action whilst concurrently observing another person performing the same action has been associated with more fluid performance. For example,

participants in a study by Heyes et al. (2005) experienced facilitation of their own movements when performing hand gestures if they concurrently observed videos that were congruent with their own actions, such as opening and closing the hand. Similarly, movement facilitation has also been demonstrated when participants are instructed to perform finger-lifting movements if these movements match videos that are simultaneously observed (Brass et al. 2000). These studies suggest that observing movements of others can activate similar motor representations in an observer's brain (see Introduction to this volume for more discussion of the human mirror system), which may in turn lead to more fluid movement execution. If this logic applies during complex movement learning, movement facilitation effects may directly contribute to the speed with which movement memories are formed and transformed into self-generated motor commands. In practical settings that involve simultaneous demonstration and performance (particularly when a mirror is present, to provide additional visual feedback on whole-body movements), it would be expected that learning would be superior in these contexts, compared to simply watching or performing without visual feedback. As such, demonstrations are potentially most effective in contexts where an observer is able to perform during observation, like in the context of many dance, mime and physical acting classes.

As alluded to above, facilitation effects during imitation have additional implications in training contexts that incorporate a performer's own reflection. However, little is known about how observing one's own movements during performance from a third-person perspective could lead to motor improvements. If physical action understanding is built purely on the basis of basic visual processing, the human brain should treat a mirror reflection as it would any other human body in space. With that being said, the ability to identify one's own body in a mirror likely has a positive impact on the ability to learn movements compared to observing (only) someone else. In essence, a mirror reflection instantly communicates movement feedback during performance in a way that cannot be matched by demonstrators or verbal feedback alone. Since immediate error-related feedback is known to facilitate learning (Kawato and Gomi 1992; Bijsterbosch et al. 2011), mirrors and other techniques that enable real-time movement feedback, such as humanoid avatars in gaming devices, may prove

to be particularly useful in contexts that require precise movement replication.

However, studies that generate movement facilitation effects tend to involve situations where participants can produce movements without lengthy periods of training (Maeda, Kleiner-Fisman and Pascual-Leone 2002; Hardwick and Edwards 2012). In real-world contexts, it may be the case that these facilitation effects are only preserved if demonstrated movements are either very simple or very similar to movements that a learner can already perform. In contrast, movements that are much more physically complex may require far more varied approaches to demonstration and training. In a virtual environment, a learner may be able to use his or her own body within the same space as an avatar to 'trace' an action as it is being performed. Similar techniques available in racing videogames such as *Forza*, *Dirt* and *Gran Turismo* (available across various gaming platforms) allow players to trace the paths of competitors in order to beat leading race times. The feature is commonly referred to as 'ghosting' due to the transparency of the competitor's vehicle, which allows a player to move one's own car within the competitor's space. If this type of simultaneous action modelling is adapted for other forms of movement learning, such as music and dance, a novice would be able to gain access to movement feedback from an expert's perspective, even if the learner's own performance ability is limited.

Action encoding across different spatial reference frames

An individual's own experience performing specific motor actions may determine the extent to which an observed action is encoded in memory. A movement could be encoded according to an extrinsic reference frame where a movement's features are mapped with respect to the external environment (i.e. I run towards upstage left, turn around and then *piqué* turn towards the tree located downstage right), or an intrinsic reference frame that maps movement with respect to the observer's own body (i.e. I turn around my left shoulder, take two steps backwards and then perform five *chaîné* turns leading with my right foot in a clockwise

direction). Frequently observed actions that are never practised do not benefit from feedback acquired through physical experience, and as such, may be encoded with visual and spatial information relative only to an extrinsic frame of reference. This limitation of visual-only experience has implications for observational learning contexts where an observer has no first-person, intrinsic reference frame for matching an observed action onto his or her own body. In contrast, firsthand physical experience may provide access to both intrinsic as well as extrinsic visuomotor information, which in turn could facilitate long-term memory for frequently practised movements. Evidence from arm-reaching experiments by Brayanov, Press and Smith (2012) demonstrates that intrinsic and extrinsic action encoding is likely fluid in nature. In this experiment, arm movements generated by participants were mapped using intrinsic as well as extrinsic reference frame information, suggesting that an individual's memory of a movement may move flexibly between the two reference frames during learning. The additive impact of both physical and observational experience may facilitate long-term movement retention through cognitive mechanisms that encode actions using coordinate systems not limited to just the observer's own body or just the external environment.

In intervention programs designed to treat developmental coordination disorder (DCD), difficulties with encoding intrinsic and extrinsic aspects of movements by observation can be overcome if an experimenter manually positions a learner's limbs to provide haptic feedback (Niemeijer et al. 2003). When limbs are repositioned, the learner is able to bypass difficulties translating extrinsically encoded movements by gaining access to the motor information within an intrinsic reference frame. For students who exhibit difficulties imitating observed movements during early stages of training, similar forms of instruction could be incorporated to provide intrinsically-framed motor feedback if translating extrinsically encoded movement information proves difficult. For example, if a dance student is finding it difficult to emulate his instructor's *épaulement*, his learning could possibly be accelerated by the instructor placing the student's heads, arms and torso in the appropriate place, so he can experience, firsthand, what his body should feel like in a certain position. Naturally, many dance instructors already make use of this approach, but exploring ways to provide learners with intrinsic motor feedback

during more complex action learning could further accelerate the learning process.

In studies that involve similar feedback principles, haptic sensation has been successfully used to improve motor learning in tasks ranging from juggling (Ankarali et al. 2013) to driving (Marchal-Crespo and Reinkensmeyer 2008). By incorporating haptic feedback into a virtual juggling task, Ankarali et al. (2013) demonstrated that artificial force impulses applied to the hands could be used to minimize movement errors during learning. When virtual juggling motions are accompanied by haptic feedback that the brain can encode within an intrinsic space, the student is able to combine information from both intrinsic as well as extrinsic reference frames to form a more detailed memory of effective juggling motions (Ankarali et al. 2013). Similarly, driving accuracy was improved in simulator conditions where haptic feedback was provided through steering mechanisms that also helped participants to integrate information from intrinsic and extrinsic spatial reference frames (Marchal-Crespo and Reinkensmeyer 2008).

To consider how similar haptic mechanisms could be applied to whole-body learning in a performing arts context, students could wear augmented clothing or accessories that provide degrees of vibrating haptic sensation to specific regions of the body when moving through space. If the student learns that the nature of the haptic sensations is linked to how well or effectively a movement is performed, the student may be able to determine how to adjust that movement in order to maximize its aesthetic value or how clearly it is 'read' by the audience. Variations of such systems could also incorporate auditory feedback that works in tandem with haptic feedback to provide more detailed timing cues. In this manner, virtual environments and multisensory feedback options could be combined to provide an array of extrinsic and intrinsic movement information as students learn to perform complex movement sequences themselves.

Individuals who are better able to distinguish between internal and external reference frames during new action learning may also possess more detailed knowledge of the kinematic and visuospatial properties of newly learnt actions. In turn, detailed action memories could also be associated with an individual's abilty to reproduce these movements from memory. To test this theory, our research team developed a four-day dance training paradigm where novice dancer-participants received physical and/or observational experience with

hip-hop dance sequences using an Xbox Kinect set up and the Dance Central video game (Sumanapala et al. 2017). Following training, participants were asked to identify the learning modality (physical or observational) associated with individual actions depicted via animated body silhouettes. These silhouettes were used to test action memory in conditions stripped of any superficial visual similarity associated with a motor action's original training context, which featured several detailed avatars in visually rich contexts. Although response accuracy in this task did not significantly differ between physically practised and observed actions, accurate categorization of physically practised actions was associated with an increased ability to perform these actions following training. In addition, accurate categorization of observed actions was also associated with an increased ability to perform observed actions following observational training. These results suggest that a participant's ability to learn via motor training was associated with their ability to discriminate between the visual and physical features of actions acquired through physical and observational learning. In contrast, categorization of untrained actions was not associated with increased performance ability for untrained actions, despite the fact that categorization accuracy was highest for untrained actions, potentially due to the fact that the untrained actions might have captured attention as being particularly novel. Nevertheless, categorization rates for actions from all training contexts (physically practised, observed and untrained) were significantly above chance levels, indicating that participants could reliably recall characteristics of their training experience with particular actions. The ability to categorize specific training modalities based on highly simplistic depictions of actions demonstrates a level of intrinsic and extrinsic action encoding that is not dependent on visual familiarity with the original stimuli encountered during training. As such, it is plausible that a learner's ability to generalize intrinsically and extrinsically encoded action information into novel visual contexts could be directly linked to performance proficiency.

Avatars and virtual feedback

Conventional training contexts can often present physical obstacles to incorporating information from multiple reference frames. For

instance, a novice trapeze artist would have difficulty gaining intrinsic movement information from watching an expert perform if he or she has spent very little time hanging upside down on a trapeze. Any bold attempts to follow through with complex trapeze moves could result in serious injury if the novice has little or no experience coordinating and performing highly skilled movements whilst swinging with one's feet above one's head. However, the use of animated avatars to render such movements within an artificial environment could radically transform the type of physical and visual information available to a learner. Specifically, an avatar of a moving agent can be designed to communicate precise aspects of movement information, and nothing more. For instance, a three-dimensional recording of a backflip could be rendered in a virtual environment in such a way that postural information can be studied in isolation at various time points and from various angles – for example, side-on, from below, from above, etc. Although traditional video footage permits frame-by-frame movement analysis, a virtual environment could allow learners to pause movements and examine them from multiple viewing perspectives. Another benefit of using this kind of technology to learn particularly complex movements where the performer's safety relies heavily on getting the timing and amplitude of the movements right would be to juxtapose digital displays (possibly point-light displays) of the learner's movements with an expert's, in order to highlight particular aspects of the movement or stunt that need to be refined. Currently, this type of training or feedback setup has yet to be rigorously tested in empirical settings, but more research in this field may be on the horizon due to the growing availability of accessible three-dimensional motion tracking technology.

To date, complex avatars have already shown promise in feasibility studies as instructional agents in motor learning as well as rehabilitation paradigms (Eaves, Breslin and van Schaik 2011; Roosink et al. 2015). Moreover, the popularization of Microsoft's Kinect motion capture system has led to the development of popular video games that match a player's movement profile to computer avatars (e.g. *Dance Central*, *Just Dance* and *Dance Masters*, available on the Xbox platform). The rudimentary scoring methods featured in these games provide players with a basic index of their ability to move in ways that match the avatar's movement timing, positioning and amplitude. Whilst these technologies are still in their infancy,

great scope exists for developing them further, allowing researchers to quantify the learning process in finer detail. In particular, direct comparisons between movement representations of avatars and players could inform both recreational as well instructional settings.

One study that specifically addressed dance learning through virtual reality demonstrated that limited feedback via an avatar led to better movement performance in participants than feedback via an avatar that provided more detailed information (Eaves, Breslin and van Schaik 2011). In this case, the benefits of using avatar-based feedback may be related to an individual's threshold for retaining visual and spatial aspects of movements during observation. This threshold could be modulated by individual differences such as attention, working memory, visuospatial processing and prior visuomotor experience. Currently, such thresholds and their overall impact on action memory and performance remain ripe for future investigation.

Learning paradigms for the future and concluding thoughts

In this chapter, we aimed to provide an introduction to research in psychology and cognitive neuroscience that is relevant to learning via watching or doing within the performing arts. Although the content reviewed here is by no means an exhaustive overview of all relevant empirical studies within these domains, the examples featured cover an array of paradigms addressing simple movements that require no prior training, to more complex movements that require years of experience to master. These studies have been selected to highlight the diversity of factors that affect performance gains and movement memory through observational experience, as well as associated brain processes. Nevertheless, various other questions regarding the impact of observation on overall motor learning remain unanswered. For example, to our knowledge, no studies have yet conducted detailed comparisons of how observational learning of whole-body actions may differ from observational learning of fine motor skills. Generally, whole-body actions, such as dance choreography, could provide an observer with a greater volume of movement information to be reproduced, compared to fine-motor actions, such as playing a sonata on the

piano. In the former instance, learning to perform a dancer's leap sequence, for example, would involve more effectors (i.e. the head, legs, feet, torso, hips, arms, hands, etc.) than learning to reproduce the intricate finger-motions of a pianist, when viewed from the perspective of a passive observer. However, learning the precise temporal features and a long sequence of the many individual notes involved in playing a piano sonata could be far more demanding than remembering the three individual jumps of the dancer's leap sequence. Such differences in observable and mappable movement information will undoubtedly influence the degree of performance gains acquired through observation in fine-motor compared to whole-body training contexts. In-depth comparisons of action perception in fine-motor versus whole-body training settings could thus be useful for determining when and how observational practice provides conditions that are most beneficial for motor learning.

Returning to examples explored earlier in this chapter, methods such as motion tracking, virtual reality and virtual body representations must be carefully evaluated in terms of how they shape high fidelity action reproduction and learning before they are incorporated into training environments. In the example of the pianist, the placement of the performer's fingers in close proximity to each other may obscure vantage points that are necessary for an observer to map the observed actions onto his or her own hands. However, if the pianist's fingers are mapped in a virtual environment using point-light markers (or similar techniques), then the highly skilled movements required for virtuosic piano performance can be examined in a three-dimensional space that is free from visual obstructions such as the piano itself, or even the anatomical detail of the hand. The scope of these training paradigms could even be extended to visual renderings of musculoskeletal anatomy to show how performed movements might appear beneath a performer's skin. This would provide an observer with novel insights into movement characteristics that are generally impossible to communicate in a traditional learning environment. In order to apply such techniques to training, however, the practicality of these methods must be rigorously investigated to assess whether potential training benefits outweigh the cost of implementation.

If traditional training environments, which typically feature live demonstration and verbal instruction, result in the optimal

rate of performance gains, then investing in virtual technologies to accelerate learning may not be beneficial for learners in the short term. However, to avoid the possibility of confounding cohort effects, newer generations of performers could provide an unbiased base for testing the effectiveness of newer, technology-based techniques in the absence of experience with more traditional methods. New students entering ballet or acrobatics training could be recruited to explore the benefits of virtual training environments in a side-by-side comparison with other students learning via traditional instruction methods. If training of both groups progresses similarly in all respects except for the type of training implemented, any (statistically) significant differences between their learning outcomes could be used to promote either form of instruction, depending on what is found. Drawing on research expertise from backgrounds as diverse as psychology, neuroscience, computer science and engineering – as well as the performing arts themselves – such investigations may inform how technological advances can transform and accellerate the way we learn, remember and perform movement, both onstage and off.

Note

1 We acknowledge that in many contemporary dance and devised theatre settings, choreography and movement scores are first generated through improvisational responses to tasks and then set. Thus, they are frequently *not* modelled by a director or choreographer. Participatory, immersive, environmental, relational, site responsive and improvisational approaches to dance and theatre furthermore include a series of responses in performance that also cannot be predetermined or modelled. In such contemporary praxis, the performers work with rules, material to recycle and a network of possibilities. However, in the context of this present chapter, we are concerned with specific movement vocabularies that require reproduction with fidelity.

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