

New Partnerships Between Dance and Neuroscience: Embedding the Arts for Neurorecovery

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Neurorehabilitation applies neuroscience and motor control principles for a pragmatic purpose: to affect the recovery of individuals who have experienced a central nervous system injury. The success or failure of these principles and their application hold life-changing consequences for individuals with neural injury. While art, music and dance therapy are sometimes offered to patients as adjunctive therapy, few attempts have been made to embed the arts within traditional rehabilitation programmes despite preliminary evidence that such implementation improves clinical outcomes. This paper presents the rationale for embedding specific dance-based training techniques within standard rehabilitation protocols.

The Embedded Arts project for acute care of brain and spinal cord injury at Dodd Rehabilitation Hospital uses motion capture technology to highlight the personal nature of prescribed rehabilitative movement and to document the recovery process. Lightweight sensors detect patient movement and custom programmes enable the translation of rehabilitative movement performed in the clinic into artistically-enhanced feedback and digital documentation. Patients perform standard physical medicine exercise prescriptions while using Embedded Arts technology; however, we seek to highlight the patient's performance of those exercises as a personal, creative movement practice that is as akin to dance practice as it is to the traditional rehabilitation experience. The relationship to dance goes beyond empowering the patient to make standard exercises into a personal performance experience, however, because it also concerns the way movement exercises are taught and learned. Using learning through imagery (also known as analogy learning) and creative movement generative practices often employed by dance educators, we seek to translate exercises that are generally taught with explicit instructional methods into

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implicit training exercises. Finally, our approach fosters creativity and play through use of interactive arts technology, to link movement (even in very restricted form) with the production of visual images.

There are at least four ways in which embedding the arts in existing rehabilitation protocols may aid the recovery of people who have experienced central nervous system injury. First, embedding the arts and gaming within standard therapy may improve patient engagement and improve adherence to exercise prescriptions. Second, infusing rehabilitation exercises with creative process practices has the potential to tap into implicit process, which has consequences for inducing neural plasticity. Third, patient and clinical treatment teams can track progress of recovery via the created images (e.g. duration of task performance, smoothness, range and speed of motion). Fourth, exploring the creative nature of personal movement in a rehabilitation setting can potentially shift attentional focus in positive ways for people coping with recent, life-changing injuries.

This paper serves to introduce key concepts from dance and neurorehabilitation, and information about our specific, project-based process, with the aim of facilitating other such partnerships between the disciplines. For dance and for rehabilitation medicine, movement is both method and result. In the rehabilitation paradigm, movement is medicine. In the dance paradigm, movement is art. Often, a single movement can be both. Perhaps, through this phenomenon of movement, the arts and medicine are more interdependent than we previously imagined. More study is needed to explore the impact of creative process and dance movement training techniques on stimulating neuromotor plasticity and improving rehabilitation outcomes.

INTRODUCTION

‘This [Embedded Arts] program enhances our ability to bring activity based therapy to patients in a manner that is unique and more engaging for patients while facilitating plasticity and recovery. . . . To medical faculty, each image created by a patient during rehab represents a quantified data series documenting rehabilitation work throughout the time that the patient is in our care, thus opening up previously elusive avenues for outcomes tracking and research within our hands-on and tele-rehabilitation work.’

Dr. W. Jerry Mysiw, Physical Medicine and Rehabilitation, The Ohio State University, 2010

Within the numerous dance practices that are possible for study, this paper explores physical learning methods used in dance teaching that may serve the goals of physical medicine. Specifically, dance employs both learning by analogue or metaphor and learning through generative process. Dance instructors often ask the student to imagine a visual image that they have seen, or ‘experienced’ within their imagination, in order to convey how a novel movement should feel; for instance to achieve a stable balance, dancers may be instructed to imagine their legs as trees with roots growing from the feet into the ground. And dance teachers often guide their students to new physical knowledge by asking them to generate their own movement solutions within defined limits (e.g. you must remain in contact with a partner; you can only move quickly or slowly – *allegro* or *adagio*). For this work, I explore analogy learning and creative process as potentially valuable training techniques within physical rehabilitation.

This paper outlines the potential relevance of dance-based physical learning techniques to the recovery of movement post-central nervous system injury and describes our work to implement such techniques within acute care hospital clinics at The Ohio State University Medical Center.

Neurorehabilitation is a speciality within physical medicine and rehabilitation dedicated to helping people recover after surviving a central nervous system (CNS) injury. Neurorehabilitation doctors are sometimes called physiatrists or rehabilitationists. Physical medicine clinical staff may include therapists (physical, occupational, recreation, and, sometimes, arts) and therapy aides. Patients may have experienced stroke, traumatic brain injury, spinal cord injury, Parkinson disease, Multiple Sclerosis (MS), cerebral palsy, or any number of other acquired or genetic conditions. Challenges involved with these injuries tend to be complex, yet common, across pathologies. For instance, stroke and spinal cord injury involve paralysis due to either flaccidity (de-innervation) or spasticity (excessive activation). Elements of neuromotor processing are compromised in almost all CNS disorders. Cognitive deficits have the potential to compound neuromotor deficits for all CNS conditions with the exception of spinal cord injury. Some conditions, such as cerebral palsy among new born children or spinal cord injury and sports-related traumatic brain injury among teens, extend through the lifespan. The end goal of any physical medicine intervention is recovery of quality of function, accomplished through a combination of healing and adapting. Ideally, any rehabilitation endeavor is managed with a holistic, comprehensive and transdisciplinary approach and social contexts are addressed (Zorowitz, 2006) such that the individual may re-integrate successfully within his or her community.

While art, music and dance therapy are sometimes offered to rehabilitation patients as adjunctive therapy, few attempts have been made to embed arts paradigms within standard physical rehabilitation programmes despite preliminary evidence that such implementation improves clinical outcomes (Earhart, 2009; Thaut et al., 1996; Whittall et al., 2000). Therapy protocols employing creative process, imagery analogies and gaming paradigms have the potential to deliver knowledge implicitly, meaning that the learner is guided to learn for him or herself without following explicit directions from another person (Berry and Dienes, 1993). For movement recovery among people living with neurologic injury—such as people who live with stroke, traumatic brain injury or Parkinson's Disease—implicit training models sometimes result in greater learning effects than explicit learning models (Boyd et al., 2007; Patton and Mussa-Ivaldi, 2004) and appear to be vitally important in particular for training of movement skill (Gentile, 1998). Real-world gaming paradigms have been investigated as a way to improve rehabilitation (see McGonigal (2011) for review). These could include any example of a game—including but not limited to a video-, card-, board- or multi-player social networking game—that is programmed to allow the user to attain real-world gains through play. In addition, tango dance classes have been proven effective for balance and locomotor rehabilitation of patients with Parkinson's Disease (Earhart 2009).

However, very promising dance learning techniques involving analogy learning and creative process have received scant attention as methods for motor skill rehabilitation among people with central nervous system injury.

The process of moving requires physical attention to neuromotor feedback loops – sensing force within the body, generating force from the muscles while taking gravity into account, then sensing again and so on. These feedback loops enable us to perform any movement such as balancing, walking, turning our bodies, but they occur too quickly for conscious control normally to have much say other than dictating when to start or stop. Dance trainings of all kinds teach us to tune in to these feedback loops and exert conscious control in key ways in order to affect physical performance. In fact, Professor Susan Petry, Chair of the Department of Dance at The Ohio State University, has asserted in conversation and in the classroom that sophistication of force modulation is the essence of great performance. Those who have taken a dance class may have noticed the use of analogy, usually in the form of imagery, to accomplish this neuromotor influence. You may have been instructed to imagine something like: two barbershop poles rotating in opposition in order to perform the correct spiraling of turned out lower limbs; a boat steering through the ocean to perform the correct energy of a tango stride; a string pulling your abdominal wall backward through your spine in order to perform a Graham contraction. These visual images have the power to evoke a visceral experience of how to perform a movement, even within a body that has never performed the movement successfully before. Put another way, abstracting complex coordination patterns in the ways we do in dance class seems to enable individuals to self-generate novel coordination patterns. As a dancer, I understand that using imagery and other creative processes enables me to internalize the desired movement; as a scientist I understand that the abstraction enables me to bypass explicit control and tap into implicit processes. More on this topic will be discussed later in this paper.

This multi-disciplinary work spans fields including, but not limited to, dance, neuroscience, interactive digital media, kinesiology/biomechanics, biomechanical engineering, motor control, experimental psychology, rehabilitation science, computer science and physical medicine. In addition, the work also taps into the power of music as neural mediator, though this paper will focus on visual elements of our Embedded Arts work. Embedding the arts in rehabilitation is made possible by advances in technology, namely, motion sensors and associated programming environments developed for digital interactive media artwork. These sensors and their programming platforms (Max/MSP/Jitter, Pd) enable what some might call biofeedback, others might call data collection, and yet others might call interactive art. Such motion sensors and control programmes enable the **quantification** of movement while simultaneously providing real-time feedback in a format that may be **qualitatively** evaluated by patients and clinicians. In other words, as the patient moves he or she can see a drawing appear on screen; that drawing responds to their movement in real-time and he or she can exert control over the course of ‘painting’. Patients fitted with sensors create their own personal abstract images

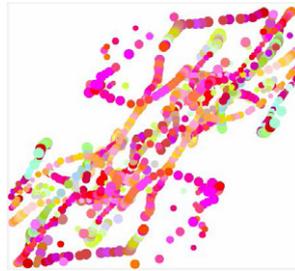


Fig. 1. Image created by a person rehabilitating from central nervous system injury. See other sections for more images.

in real time through the body movement required for their prescribed exercises (Figure 1) and thus create a visual record, or ‘canvas’, of exercise performance. By networking between the disciplines of art, neuroscience and medicine, we hope to provide a platform that can be used in hospital clinics to increase patient engagement, to track movement recovery progress, and ultimately to convert a difficult process requiring repetition and perseverance into implicit, patient-driven recovery.

Real-time feedback allows the patient to observe elements of his or her movement performance as the movement performance is unfolding. In addition, in the case of *Embedded Arts*, abstracting the representation of movement into something aesthetically interesting to the patient may enable him or her to modulate their intentional focus on the performance task. Experiencing structured, aesthetic control over the unfolding, onscreen image composition may shift the patient’s focus – testimonies from patients presented later in this paper attest to a renewed sense of agency from this creative exploration of their new movement state. Finally, recording patient movement with interactive sensors provides a novel option for reviewing performance ‘compositions’ after a therapy session is done, in order to study the patient’s performance of a motor task. In this way, we explore the personalized, creative nature of movement in a rehabilitation setting while also providing the users, both therapists and patients, with a platform for communicating about movement performance. The resulting compositions generated by patients are a physical artifact of the recovery process.

To illustrate these artifacts, visual works produced by patients who participated in the design study are shown in the headings of each section of this paper (e.g. Figure 1). Participants created each image during performance of prescribed rehabilitation exercises. The *Embedded Arts* prototype programme prints circles of randomized size and color onscreen and the center positions of these circles are determined by user motion recorded from the sensor – in the case of the prototype programme this sensor was a gyroscopic mouse. By moving his or her body, the user controls the drawing output, drawing circles at regular intervals onscreen in positions that follow their body motions. This link points to a video of three participants using *Embedded*



Fig. 2. *Embedded Arts* users Brad Burns and Aaron Wolfe (top to bottom).

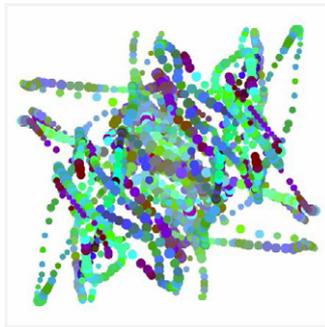
Arts to record their movements while performing rehabilitation exercises (<http://www.youtube.com/watch?v=MABD7sYplkk>). The footage in this video and in Figure 2 serves to demonstrate the movements being performed, the wireless user interface and the way each person responded to working improvisationally with real-time feedback. The final 15 seconds of the video show resulting artwork printed on fabric and exhibited at the Urban Arts Space Gallery in downtown Columbus, OH in March, 2010.

There are at least four ways in which embedding the arts in existing rehabilitation protocols may aid the recovery of people who have experienced central nervous system injury. First, embedding the arts and gaming within standard therapy may improve patient engagement and improve adherence to exercise prescriptions. Second, integrating rehabilitation exercises with the creative process has the potential to tap into implicit process, which has consequences for inducing neural plasticity and improving outcomes. Third, patient and clinical treatment teams can actually track progress of recovery via

the created images (e.g. duration of task performance, smoothness of movement, range and speed of motion). Fourth, exploring the creative nature of personal movement in a rehabilitation setting can potentially shift attentional focus in positive ways for people coping with recent, life-changing injuries.

Neurorehabilitation

'It has become clear that in both humans and in experimental animal models, the injured brain compensates in a variety of ways that contribute to the spontaneous return of function, and that behavioral interventions are perhaps the most powerful modulators of post-injury plasticity.' Nudo & Dancause, in *Brain Injury Medicine: Principles and Practices* (2007) p. 913



Neurorehabilitation seeks to induce neural plasticity and recovery as well as to develop compensatory strategies following central nervous system injury (Brewer, McDowell, and Worthen-Chaudhari, 2007). Cortical remodeling and neural plasticity are two terms used to describe the central nervous system's capacity to rewire given specific stimuli. Like a river's meander in response to erosion or a blockage, the messages traveling through the human nervous system can shift their pathways. Put another way, when an action potential, the unit of neural conduction, encounters damaged tracts internally, there is some capacity to forge a new route using 'spared' pathways. The human neural system is redundant, with more neurons than are needed; sometimes when neurons are injured, the human system can switch to engage alternate neurons that were spared during the injurious event. These action potentials can reroute in response to external stimuli like the kind given in therapy sessions and dance classes, and metaphorically similar to the way that a river can be diverted by external forces. This ability of our neural wiring to reroute when given the right stimuli can be a powerful agent for recovery and has, since the 1980s, emerged as the most promising phenomenon for facilitating neurorehabilitation (Nuno and Dancause, 2007). We have much to learn still, however, about what the right stimuli are. Rehabilitation scientists seek to uncover the physical laws that govern the meandering and diverting of these neural pathways with a goal of optimizing human recovery.

Mechanisms of improvement include physical reconditioning, learning and facilitation of neural plasticity. These mechanisms are based on three

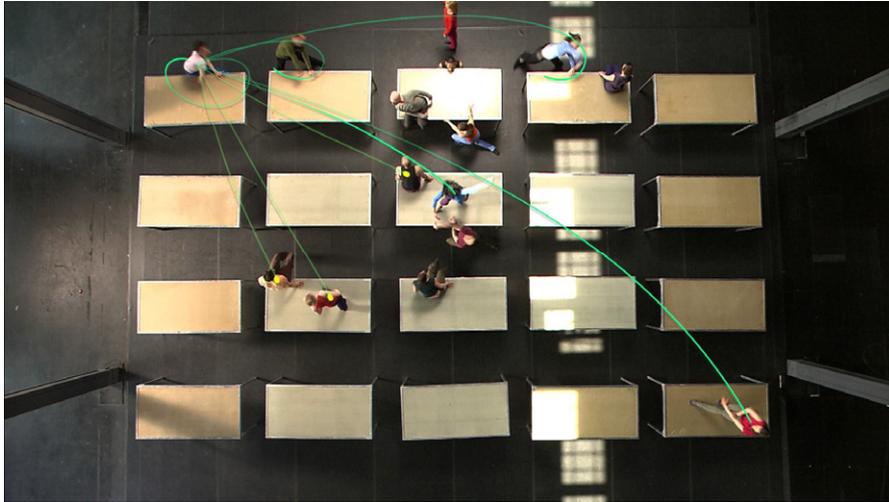


Fig. 3. Individuals depend on each other to perform dance choreography by William Forsythe. Still from annotated video illustrating the complex system of cueing in *One Flat Thing*, reproduced. Credit: Synchronous Objects Project, The Ohio State University and The Forsythe Company.

theories of recovery: diaschisis (recovery of function in tissue adjacent to injured tissue), compensation and adaptive remodeling (Nuno and Dancause, 2007). The theories and practices of neurorehabilitation, however, are evolving. As we grow to understand more about the interdependence of systems previously separated as neural and mechanical, such as the interassociation of mind and body, these distinctions between what is neural and what is mechanical in nature grow complicated. The neural and mechanical systems are coupled. The tissues that make up each are identifiable and distinct, but their structures are functionally coupled through their impact on each other. For instance, Nuno and Dancause (2007) state that the motor cortex ‘cannot be considered strictly as a motor structure, but instead, is a site of somatosensory-motor integration, with a primary motor output function . . .’. The relationships between somatosensory and motor processes are interdependent and thus complicate diagnostic and treatment processes. Performance in each domain is related to performance in the other. One image metaphorically evocative of such an interdependent, relational network is that of group dance choreography in which individual dancers perform their choreographed actions in a seemingly autonomous manner, yet integrity of the work relies so firmly on cueing between individual dancers that, for the purpose of the work, the dancers become interdependent (Figure 3). Within the human body, examples of such interdependency abound; for instance, sensory feedback informs motor planning, perception and cognitive while endocrine outputs impact neural responses and tissue degradation. Further insight from dynamic systems research indicates that embodied experience drives cognitive and sensory-motor development in children and through the life span

(Thelen et al., 2001; Thelen, 2002). In fact, evidence is growing that cognition is fundamentally embodied at all age levels and stages of development (for reviews see (Clark, 1997; Johnson, 2007; Varela, Thompson, and Rosch, 1999). As understanding of the human system evolves, so do the theories and practices of neurorehabilitation.

Patients enter a neurorehabilitation programme because they have experienced a neural system insult: a stroke, traumatic brain injury, spinal cord injury, Parkinson disease, Multiple Sclerosis (MS), cerebral palsy, to name just a few of the possibilities. Deficits associated with these diagnoses and experienced by the patient might include problems with paralysis, spasticity, postural control, visual field recognition, language execution or processing, sensory perception or integration, motor planning, self regulation behaviors such as impulse control, or cognitive processes such as attention or decision-making. Listing these deficits makes each sound as if it can be addressed in isolation, but often these deficits compound as in the case of someone with cognitive deficits that impact impulse-control, decision-making, and motor planning. To add pressure to complexity, strategies for functional recovery depend heavily on time since injury. Elapsed time since injury is important for two reasons: (1) the post-injury period contains windows of vulnerability to maladaptive effects; and (2) learned nonuse sets in after the injury, meaning that the injured neural system avoids using the injured areas, thus creating a cycle of nonuse that reinforces the dysfunction. Though it is traditional to categorize deficits and prescribed therapies by therapeutic specialty, such as speech, motor, cognitive, or behavioral, the goal of any rehabilitation plan, regardless of specialty focus, is to integrate care delivered from these various sub-specialties to help patients relearn 'to carry out their needs successfully' (Carr and Shepherd, 1987; Krakauer, 2006).

Ultimately, each person wants to regain functional movement, cognitive ability, and social behaviors. People want to resume their previous roles within their families and society. A reasonable sophistication of performance is desired. Consider these three examples of people performing a function but not as well as they would like: a person with hemiparesis following stroke may be able to reach for a cup and bring it to their mouth, but only haltingly such that the contents of the cup are spilled before they are able to drink; a person with incomplete spinal cord injury may recover walking function but drag their feet, producing a slow and energy-consuming gait pattern with a high likelihood of tripping; a prosthetic limb may enable a person to locomote, but with pain. The goal for neurorecovery is more than to regain operational function; it is to recover quality of life. Ideally, we want to improve parameters that mediate quality of life such as liveliness, agility and interaction skills (Banerjee, 2008).

But knowledge acquisition is complex. To speak of knowledge is to invoke at least four aspects: acquiring, retaining, accessing, performing. These aspects are inseparable in that they are interdependent. How can one acquire skill knowledge without performing relevant actions? Or access knowledge without acquiring and retaining it first? Despite this interdependence, each aspect of knowledge must be addressed by the successful rehabilitation plan.

Although acquired brain injury and spinal cord injury affect multiple domains of knowledge acquisition that are entangled, for the purpose of this paper I focus on recovery of movement planning and execution such as: reaching movement that can be executed smoothly; locomotion fast enough to cross the street before the light changes; wheelchair use sophisticated enough for community-area transport or for recreational activities like rugby and dance. These gains in motor skill and somatosensory-motor integration are accomplished through regaining the ‘ability to make and correct movement in the proper context’ (Krakauer, 2006), including but not limited to retraining in skill acquisition, motor planning, motor adaptation and real-time force modulation. The need to incorporate motor learning principles into rehabilitation protocol design seems self-evident but there remains much to discover about optimizing motor learning following central nervous system injury and what is known does not always make its way into practice (Brewer, McDowell, and Worthen-Chaudhari, 2007; Nuno and Dancause, 2007). Most existing rehabilitation protocols use a massed practice approach (meaning blocks of repetition of task performance with minimal rest between repetitions) and an explicit learning paradigm. This lack of connection to the motor control literature and lack of design diversity has been criticized (Krakauer, 2006). Given the potential of the neural remodeling phenomenon, it is unfortunate that we do not know a whole lot about how to harness it.

IMPLICIT LEARNING

‘What these situations have in common is that a person typically learns about the structure of a fairly complex stimulus environment, without necessarily intending to do so, and in such a way that the resulting knowledge is difficult to express. This is what we mean by implicit learning.’

- Berry and Dienes, 1993, in Implicit Learning: theoretical and empirical issues, p.2.



Some fundamental processes of motor learning and action performance rely on neural pathways that can excite/inhibit muscle activity more quickly than conscious thought allows. These super fast, hyper-responsive neural processes are most often referred to as ‘implicit processes’. Consider these examples – learning to: ride a bike, speak one’s native language, perform a dance combination, shoot

a basketball, drink from a cup, or learning any concept through example or analogy (like right now). In all cases, the learner/performer has mastered a complex skill or concept by literally feeling his or her way through the process in an incidental, as opposed to an intentional, way. Generally, explicit verbal instruction will distract the learner/performer during this type of skill acquisition and, once learned, it is difficult to verbally explain to someone else how the task is accomplished. Cleeremans describes implicit process as expertise involving 'intuitive knowledge that one seems to have little introspective access to' and gives the examples of medical diagnosis, chess, grammatical rules, and social and aesthetic judgments (Cleeremans, 2002). Implicit knowledge is contrasted with explicit in which rules and knowledge are expressly articulated.

I start this discussion of motor learning strategies by acknowledging current controversies in the related literature. Within the field of cognitive psychology, some have worked to identify where, within the brain, the neurons associated with implicit and explicit processes reside (Reber et al., 2003). A rebuttal has been launched by others with a cognitive specialty focus who challenge attempts to localize such neural processes and also challenge the pre-eminence of the implicit/explicit framework, proposing that encoding and processing are more relevant for cognitive task mastery (Gureckis, James, and Nosofsky, 2010). This paper uses the implicit/explicit framework, without reviewing the neural localization debate because, regardless of where these functions reside and the permanence, or lack thereof, of that location, the implicit/explicit distinction is important for research into human force modulation – a fundamental factor in movement skill retraining. This framework has been adopted by motor control, rehabilitation and sport science researchers studying motor learning including, but not limited to, RSW Masters and J Poolton from The Institute of Human Performance at The Hong Kong University; L Boyd, the Canadian Research Chair in Neurobiology of Motor Learning from The University of British Columbia; and the pioneering AM Gentile of Teacher's College at Columbia University.

Dr. Gentile states that force generation can be mediated only by implicit processes (Gentile, 1998). The regulation of force production during activities such as balancing on two feet, walking, dancing, playing lacrosse, and more, happens too quickly to be managed by conscious process. The lightning-quick turnaround of information within the force feedback loop relies on neural pathways that can excite/inhibit muscle activity more quickly than conscious thought (or 'executive control') allows and are described in the rehabilitation science literature by the term 'implicit'. The concept elucidated by Gentile – force can only be managed by implicit processes – conveys powerful implications for the design of motor learning protocols. Coupled with evidence from the dynamic systems literature that force experiences drive cognitive development in infants (Thelen and Smith, 1994), this insight yields profound implications for human action and cognition in general. If implicit processes are key to modulating force, and force modulation provides key stimulus for cognitive development, then therapists and educators may produce greater

gains in learning by designing interventions that stimulate force learning paradigms.

Force generation is a psychomotor phenomenon that engages body structures traditionally separated into central, peripheral, neural, and mechanical categories. The sensing/generating feedback loops regulating the body's ability to apply force require integration of information from all corners of the human body. Current understanding regarding psychomotor control is furthered as imaging and motion capture technology evolves. Surveying the relevant imaging literature is beyond the scope of this paper, but it is possible to summarize that motor learning is an embodied phenomenon.

To move normally we must engage both implicit and explicit processes in parallel (Gentile, 1998). However, some central nervous system injuries are associated with injury to structures supporting explicit or implicit learning, thus making the person more dependent, post-injury, on the alternate learning mode. It has been reported that incidental learning is preserved among individuals living with stroke (Boyd and Winstein, 2004; Hanlon, 1996; Krebs, Volpe, and Hogan, 2009; Orrell, Eves, and Masters, 2006; Platz et al., 1994; Pohl et al., 2001; Pohl et al., 2006), Parkinson Disease (Masters, MacMahon, and Pall, 2004), Alzheimer's Disease (Zanetti et al., 2001), and amnesia (Baddeley, 1993; Baddeley and Wilson, 1994; Evans et al., 2000; Glisky and Delaney, 1996; Kessels and Haan, 2003) and the efficacy of implicit interventions have been found to interact with patient age (Krebs et al., 2001). Because of the variety of effects that neural injuries can have on motor learning processes, it is important to tailor rehabilitation protocols in order to maximize whatever processes are retained, yet standard rehabilitation approaches have been criticized for overemphasizing explicit learning techniques rather than tailoring appropriately from a diverse menu of options (Krakauer, 2006). Type and intensity of training set the stage for all recovery efforts, but we may be limiting recovery potential by employing learning strategies and instructional methods that do not optimally leverage access to spared neural structures.

Much of the research into implicit learning processes has been performed within the cognitive psychology discipline; some examples of cognitive tasks evaluated include artificial grammar learning, visual categorization tasks (Gureckis, James, and Nosofsky, 2010; Reber et al., 2003), and sequence learning (Cleeremans 2002). Of most relevance to the project of this paper is motor control, sport and rehabilitation science literature that examines implicit as opposed to explicit processes in motor skill acquisition. Examples of implicit strategies that have been proposed to facilitate motor skill acquisition include: analogy learning (Orrell, Eves, and Masters, 2006; Poolton, Masters, and Maxwell, 2006), errorless learning (Maxwell et al., 2001; Poolton, Masters, and Maxwell, 2005), and error-accentuating learning strategies (Patton and Mussa-Ivaldi, 2004; Patton et al., 2006; Reisman, McLean, and Bastian, 2010).

As stated, analogy learning is ubiquitous within dance practices and is one possible means partially to explain skill acquisition facilitated by dance practice. Analogy learning methods have been reported by Poolton et al. (2006) and

Orrell et al. (2006) to be powerful implicit learning strategies for movement recovery among stroke patients, adding to the argument that analogy learning might be an important motor training technique for neurorehabilitation. In addition, motor skills learned by analogy have been found to be more easily recalled under pressure conditions, as in a competitive sports event, than if those skills were learned by explicit verbal instruction (Steenbergen et al., 2010). So, for neurorehabilitation patients who expect to feel pressure – for instance to get across the street before the traffic light changes – analogy learning might be an important training modality.

Results reported among studies evaluating errorless and error-accentuating learning strategies, unfortunately, seem contradictory. In some cases, the take-home message is to allow no error (errorless) on the part of the patient performing a repetitive task; in this scenario force fields assist subjects to maintain desired trajectories in order to preclude conscious generation of movement strategy. However, in studies by Patton and Mussa-Ivaldi, subjects who had had a stroke held onto a robotic handle that sensed movement along a path and accentuated deviations from the path. When a patient strayed from the desired straight path between two points, forces were applied to amplify the movement errors such that a small deviation was rapidly accentuated, instead of corrected as in the error eliminating studies. For instance, if a subject were trying to move the robotic handle from the close left to the far right corner of the research apparatus, but actually moved more in an arc than a straight line, the motorized handle would push the hand further in the direction of error and away from the desired diagonal course. Error-accentuation resulted in positive after-effects, better self-directed movement performance and better retention of gains over time than errorless strategies among the small number of stroke patients studied. Similarly, in a recent case study, error-accentuating in locomotor rehabilitation improved retention of walking recovery gains for one stroke patient (Reisman, McLean, and Bastian, 2010). The solution to the seemingly contradictory results regarding errorless and error-accentuating trainings may be that both error-eliminating and error-accentuating tasks can be performed in such a way as to engage implicit process. Helping a dancer lift their leg in battement may help them to preclude explicit control during movement execution; conversely, having a dancer practice battement while wearing weights around their ankles, then asking them to remove the weights and experience the after-effects, may also help them avoid executive control during performance of the battement motion. Furthermore, there is evidence that there is no such thing as pure implicit or pure explicit process (Kessels, Boekhorst, and Postma, 2005). It is possible that the interaction between implicit and explicit may be as important as each mode separately. Dance methods seem particularly good at training this interassociation between conscious control and implicit execution.

Interestingly, lack of sleep can limit patient recovery of force modulation as well. Sleep has been found to improve motor learning capacity in individuals who are neurologically intact and young as well as among individuals who have had a stroke (Siengsukon and Boyd, 2008). Perhaps encouraging healthy sleep

is a way to encourage optimization of skill acquisition among dancers as well as patients.

In addition to the potential usefulness of analogy learning, improvisational techniques used in dance movement training may also prove good candidates for training implicit force regulation processes. Stimulating the patient's ability to generate successful movement solutions is critical for those adapting to recent nervous system injury. Current protocols train patients to manage new factors such as a wheelchair or walker, but do not necessarily provide training that prepares patients to generate movement solutions for themselves. Dance training techniques such as structured 'contact improvisations' teach dance students to solve movement challenges for themselves and are an exciting area for further study. The dance form of contact improvisation, or CI, involves spontaneous generation of movement while in contact with another moving body. It requires dancers to operate simultaneously on levels of partner dancing and personal improvisation over time. Personally, I have found that CI is a uniquely challenging, and engaging, method for learning to modulate force while in contact with other things and other people. Training patients in the hospital with structured, improvisational exercises may offer a novel way to practice movement solutions needed for community re-integration. Dr. Gammon Earhart's group has demonstrated feasibility of teaching CI among patients with Parkinson disease (Marchant, Sylvester and Earhart, 2010); CI technique might prove feasible for others such as patients adapting to wheelchair use. Once a patient using a wheelchair is discharged, he or she faces new movement challenges within their community. She or he might be looking forward to eating at their favorite restaurant once discharged from the hospital. To enter this familiar restaurant in a wheelchair for the first time, a person must navigate between the car, the accessibility ramp, and the restaurant door and every rotation within this previously familiar journey is likely to contain novel movement states. The person will not know how that feels in their body until they are navigating the ramp, and in danger of falling or getting stuck. To accomplish the task of entering the favorite restaurant he or she will need to simultaneously tune in to force feedback loops while maintaining an awareness of overriding concerns such as obstacles and controlling the chair from tipping back. This experience could be described as performance of improvisational movement while in contact with another mobile body – in this case, his or her wheelchair. Contact improvisation exercises might enable patients to practice novel force negotiations in the clinic, giving them time to develop the skills required to generate spontaneous movement solutions before they are discharged.

One critical component for invoking implicit learning paradigms is the delivery of instruction. Both the method and frequency of external feedback have been reported to affect motor learning after stroke (van Vliet and Wulf, 2006). Analogy learning strategies designed to invoke implicit process have been found to enhance motor skill recovery among individuals living with post-stroke deficits (Orrell, Eves, and Masters, 2006) and skill acquisition among adults learning a novel, sport-specific motor task (Poolton, Masters, and Maxwell,

2006). In contrast, explicit instruction interferes with learning of discrete and continuous movement tasks in people who have had a stroke (Boyd and Winstein, 2004; Boyd and Winstein, 2006). Even encouraging a patient to 'try' can result in 'trying too hard' which has been found to impact negatively on pattern learning in older adults (Howard, 2001). This means that explicit, intentional focus in attaining movement goals has the potential to limit patient performance and recovery, suggesting that clinicians must be sensitive to both their method of instruction and to the patient's method of carrying out those instructions. Recently published work by Gureckis, James and Nosofsky (2010) addressing cognitive learning strategies (with no apparent motor component) among non-injured subjects, may reinforce these conclusions about the impact of instructional method on motor learning performance; verbal instructions were found to be at least as important as task environment for determining neural activity stimulated by specific cognitive tasks. As a whole, these studies indicate that the method of clinical instruction delivery can improve or limit patient recovery.

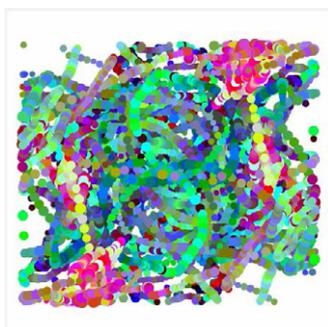
Thus far this literature review has focused on evidence from motor control and rehabilitation science. However, two concepts from cognitive psychology are important to note. First, feedback techniques that stimulate multi-modal inputs (meaning more than one sensory-motor feedback pathway at a time, e.g. visual and hearing and proprioception) have been shown to reinforce learning and positively impact rehabilitation outcomes (Huang, Wolf, and He, 2006). Dance techniques that involve dynamic somatic feedback and visual feedback from a responsive partner are an example of multi-modal movement training techniques. Incorporating digital, movement sensor data acquisition during movement practice in the clinic provides the practical means to implement an information/sensory fusion biofeedback approach which has been proposed as an important direction for future neuromotor rehabilitation techniques (Huang, Wolf, and He, 2006). While this paper addresses only visual feedback provided to users, the programme is actually used to provide both visual and auditory feedback. This functionality is important because some pathologies are associated with visual or auditory processing deficits and, also, because multi-modal, or multi-sensory, feedback has been shown to influence recovery. A second important point from cognitive rehabilitation concepts is that timing of inputs has been shown to encode neural output firings, meaning that sensory processing and related response execution are linked and are fundamentally responsive to time-based stimuli. Another way to put this is that rhythmic auditory stimuli influence motor learning and performance (Stefanics et al., 2010; Varela et al., 2001). The impact of repetitive, multi-modal inputs on motor processes highlights the importance of conceptualizing neurorecovery as a time-based, integrated, embodied process.

Dance educators seek to train their students to express nuance and awareness within force dynamics; physical medicine professionals have the same ultimate goal when addressing movement disorders and deficits. This project seeks to cross these disciplines in pursuit of new techniques to serve

neurorehabilitation patients. Techniques used by dance educators to train dance students, such as instruction that relies heavily on imagery and improvisational movement generation, may prove useful techniques for training acute care neurorehabilitation patients. The *Embedded Arts* programmes are a starting point for highlighting the creative and improvisational work possible within standard therapy protocols while simultaneously tracking efficacy of such innovations in rehabilitation practice.

EMBEDDING THE ARTS FOR NEURORECOVERY

'It is very interesting and inspirational work.' – Kathleen Sebelius, United States Secretary for Health and Human Services, personal communication 2010



Embedded Arts utilizes motion capture technology to present prescribed physical exercises as creative endeavors such that engaging in the work of rehabilitation allows patients to create their own visual image in real time as a type of feedback. The programme can be tailored so that visual feedback cues reinforce desired movement performance goals; the programme can also provide auditory feedback though that functionality; this will be addressed tangentially here and more fully in future papers. In current form, the visual images that can be produced with *Embedded Arts* technology are reminiscent of the music visualizers in computer programmes such as iTunes, but responsive to patient movement (and produced on a much smaller budget). I created the prototype *Embedded Arts* programme as my final project for a Master of Fine Arts degree in Dance (Dance and Technology area) from The Ohio State University. Starting in January 2010, I began implementing *Embedded Arts* programming at Dodd Hall Rehabilitation Hospital, where I was employed as a Clinical Research Manager. I am indebted to the many clinical leaders, staff and volunteers within the physical, occupational and recreational sub-specialties who supported this work (please see the Acknowledgements section of this paper for a fuller listing). Any cross-pollinated innovation requires the efforts of many multi-disciplinary individuals to achieve success and I have been fortunate to find such partners here at The Ohio State University.

To work with or 'play' *Embedded Arts*, a movement sensor such as a gyroscopic mouse is strapped to any body segment (arm, leg, torso, pelvis, head)

or, in the case of Xbox Kinect, is positioned in view of the user. Different sensors or sensor positions may be chosen based on rehabilitation goals such as balance training, smoothness of joint motion during reaching, or coordination during sit to stand tasks. It is possible to use any sensor that interfaces with an interactive programming environment such as Max/MSP/Jitter (produced by Cycling74) or Pd (open source software by Miller Puckette, University of California San Diego). Possible sensors that may be used include but are not limited to a Wii controller (Nintendo), I-CubeX sensors for detecting muscle activity, segment orientation, touch and vibration information (Infusion Systems) and, as mentioned, a Kinect camera (Microsoft); the simplest sensor solution amounts to anything that can control a computer's mouse pointer, such a gyroscopic mouse or the 'Mobile mouse' app that converts an iPhone to wireless mouse.

The prototype and subsequent applications have been purposefully simple to use, simple to look at, inexpensive and designed to work within common rehabilitation techniques that have existing billing codes. These design values were reinforced by design research feedback results from end users and experts. As Dr. Ernest Johnson, former Chairperson of The Ohio State University Physical Medicine department, is known to proclaim, 'forced applications of technology' do not belong in clinical settings (Mysiw, 2010). Many patients are dealing with an overload of new information as they learn to navigate their new physicality; virtuosic visual or aural effects do not necessarily serve rehabilitative goals. In addition, neither patients nor clinicians have time for more than a minute of set up or clean up. And none have the energy for frustration resulting from trying to operate a non-intuitive user interface.

The overall aesthetic impression of images created with this prototype was designed in the tradition of twentieth-century action paintings. Some random elements in the design, such as color, were purposefully included in order to acknowledge the role that random chance has played in the lives of individuals who have experienced central nervous system injury. Patient image data were saved in scalable vector graphic format to allow unlimited scaling of the saved image size without loss of resolution.

Approval was received from the Institutional Review Board at The Ohio State University to 1) solicit expert feedback from patients, artists, and clinicians regarding design and implementation (design study) and 2) collect pilot data from patients housed at the hospital in order to evaluate use of the technology during standard clinical sessions (clinical feasibility study). While explicit instructions regarding the purpose of the study were important for informed consent, once the consent process was complete, it was important to craft instruction regarding sensor use in order to facilitate an implicit learning environment. For these reasons, study participation started with an overview given by a researcher or clinician followed by review of a detailed informed consent document. The instructions regarding what would happen if the person participated were explicit descriptions and took five to ten minutes of verbal communication. Once consent was obtained, verbal, explicit instructions were reduced to a minimum. Only two levels of instruction were provided regarding how to create a drawing. Initial

instructions given to participants were: 'Here is the sensor to use [researcher holds sensor and briefly demonstrates]. Want to give it a try? [researcher hands or attaches sensor to participant].' If the participant requested more instruction after trying the sensor him or herself, these follow up instructions were given: 'And the sensor is a gyroscope so it detects angular movement. Try moving like this [researcher demonstrates by holding sensor in one hand, arm extended, and describing arc with the hand holding the sensor]. And you can see here that the programme draws both the mouse position and a second flipped image [researcher points to mouse and flipped traces].'

During the design study, I had intended to modify the design in accordance with the experts' interview responses, however, the prototype was accepted as successful without need for modifications by those subjects who tested it. I was left with the impression that people were so excited about a novel rehabilitation programme that could make the work of rehabilitation even a little more game-like, that options for improvements seemed irrelevant. Instead of aesthetic improvements for the prototype, expert feedback during the design phase tended to address applications for the prototype and a 'wish list' of specific exercises and goals for further *Embedded Arts* development. This feedback continues to inform current development. The feasibility of using the prototype programme in the clinics during standard therapy is currently being evaluated and preliminary results from subject testimonies from both studies are presented in this paper (Table 1). There is an important use for the digital movement data generated by the sensors beyond generating artistic visual or aural effects. These data can be used to quantify and document patients' rehabilitation for clinical tracking and outcomes research. Visual and audio data generated by the patient are rich representations of movement that can be analyzed using techniques similar to those used by scientists analyzing satellite motion or the interaction of molecules, but our analysis targets movement qualities for a person working to recover function. For instance, from one *Embedded Arts* image we can gather information about the movement session like: For how long was the exercise performed? What was the ratio of stillness to dynamic movement during a task? Was movement performed with stair stepping or smooth transitions? What was the frequency content of the movement performed? How did these characteristics change between sessions? Current rehabilitation techniques focus on improving clinical outcomes such those evaluated by the Fugl Meyer Assessment of Motor Recovery after Stroke or other validated scales providing a repeatable measure of patient function. However, motion capture techniques combined with new analysis techniques, such as principle components analysis which simplifies complex, inter-related data into principle component factors, provide unique opportunities to evaluate dynamic movement coordination in a more nuanced, more manageable, and potentially more clinically meaningful way (Bowden, Clark, and Kautz, 2010; Yadav et al., 2010).

The Embedded Arts work seeks to provide a platform for communication between patient and clinician with regard to movement performance. Abstracted

real-time feedback amounts to a visual imagery option that enables a patient to see the movement performed for him or herself. The drawing on screen becomes a real-time analogy to help patients visualize their movement in the moment. As stated, feedback and analogy learning have previously been shown to improve motor learning outcomes, and this technology implements those ideas within a new setting. The *Embedded Arts* work also leverages affordable, easy-to-use motion sensing technology to record movement in the clinic. The cost and size of motion capture equipment has dropped dramatically in the past 10 years, making this technology more attractive for widespread use. Standard clinical implementation of such affordable motion capture technology has remained unexplored, despite the potential power of such implementations. In addition to pioneering the use of motion capture in the rehabilitation clinic, the *Embedded Arts* work is designed to provide novel functionality in that it allows patients to engage prescribed movement as a creative, generative process. The importance of creative process within rehabilitation prescriptions has not been systematically studied previously.

PRELIMINARY RESULTS FROM DESIGN AND FEASIBILITY STUDIES

Direct observations and interviews of subjects using the *Embedded Arts* technology were conducted. Content and cluster analysis were performed and results to date are summarized in Table 1. For subjects with neurologic injury, direct observations were conducted during rehabilitation sessions and interviews were conducted after completion of each session. All patient sessions occurred in Dodd Hospital except for the session of one homebound subject, in which both observation and interview were conducted in the person's home with their permission. For artists/dancers, sessions occurred in the Sullivant Hall White Box studio. For clinicians, sessions occurred in Dodd Hospital clinical areas. Ethnographic data were recorded using audio and/or videotape in addition to handwritten notes. Data were recorded from three groups: patients (individuals recovering from spinal cord injury, stroke or Multiple Sclerosis), artists (mostly dancers, some designers), and clinicians (a mix of physiatrists, therapists and therapy aides). These three groups were identified as most important for giving expert feedback regarding interaction design.



DISCUSSION OF PRELIMINARY RESULTS

Patient self-reports indicate a sense of excitement when using the *Embedded Arts* technology, and an exploration of the possibilities within their new movement state. Clinician responses after watching patients use the programme reinforce the perception that patients are engaging for longer and with a different quality when given *Embedded Arts* real-time feedback in comparison to therapy without such feedback, though both of these perceptions will be important to evaluate in future studies. Direct observations of patients and feedback from clinicians indicate that patients tend to laugh more and enjoy their prescribed exercises more when using the programme than otherwise. This does not necessarily transform to playfulness in movement performance for patients, but does indicate that patients enjoy doing the work, take ownership of their movement, and use movement to actively explore their new physical state.

Differences between groups were also demonstrated. Of the three groups, the patients seemed to engage with the technology most comfortably and more quickly than participants from the other groups. Patients made the fewest requests for explicit instruction, and displayed an immediate comfort with the real-time feedback results. In contrast, a subset of 3 artists demonstrated an initial period of difficulty using the sensor indicated by at least one request for explicit help and at least one expression of frustration per subject. Such requests for explicit instruction were not noted among the patients and in fact several of the patients had the opposite reaction, tuning out the limited instruction given or asking those attending to stop talking and just let them work. Different again from artist and patient participants, the majority of clinicians engaged the technology long enough to get the idea but not long enough to create their own drawings. Once having developed a quick idea of how it worked (i.e. sensor movement is tracked on screen), clinicians tended to hand over the sensor to a researcher or nearby patient. In one last difference noted between groups, patients and clinicians seemed to engage with the movement as work, and expressed excitement to see the fruits of the patients' labor, while all of the artists interviewed finished their sessions with a playful period and artists generated more compositions than clinicians or patients. The artists seemed to move into this playful, prolific mode quickly once some threshold of comfort and/or physical learning was passed.

The ability of all groups to adopt the technology and the apparent tendency of all to personally engage with this technology-assisted movement exploration may prove a demonstration of a larger cultural trend toward digital arts participation in the United States. In an introduction to *Engaging Art: The Next Great Transformation of America's Cultural Life*, Bill Ivey paints digitally-mediated creativity as today's 'homemade art' (Tepper and Ivey, 2008). The analyses presented in this book, edited by Ivey and Steven Tepper, indicate that creative arts participation is blossoming in today's culture – it just looks different than it has for previous generations. According to these analyses, while older individuals may still frequent the symphony, ballet, or fine art auction, today's younger individuals are more likely to participate in generative, digital

Table 1. Summary of observational and interview data to date. Data presented for artists and clinicians were collected during the design study. Data presented for patients were collected during the design study and ongoing feasibility study.

Subjects (n)	Hours observation	Direct observations	Sample quotes
Patients (20 = 9 design + 11 feasibility)	23	<p>Overall responses: positive (23), neutral (1) and negative (0). Report having lost track of time or having ‘gone in the zone’.</p> <p>Learn how to operate the gyrosopic mouse by doing. No observable frustration during learning curve. No observable playful phase. Attention seems to shift the minute he/she sees the drawing respond to his/her movement.</p> <p>Stop moving in order to listen to instructions. Alternately, seem to ‘tune out’ to spoken instructions once have the sensor and can explore for themselves. Make emotionally engaged comments about the resulting images (poignant – ‘Looks like a sunset!’ – or funny – ‘Looks like mardi gras beads. Everybody take your shirts off!’).</p>	<p>‘Stop talking already and let me do it.’</p> <p>‘I couldn’t even use crayons before, but look what I made.’</p> <p>‘I did that – do you see? I didn’t think I could move that shoulder at all but I just drew that.’</p> <p>‘Can I do the computer thing again tomorrow? I’ll get up early for it.’</p> <p>‘I really feel like I need this – when can I take it home to work with?’</p> <p>‘Can I take a copy of my drawing home to my [daughter, son, wife, husband, sister-in-law]? I can’t believe I made this.’</p>
Artists (9)	6	<p>Demonstrate two responses: before and after gaining physical understanding of how to manipulate sensor to effect drawing.</p> <p>Overall response before: positive (5), neutral (3), negative (1)</p> <p>Overall response after: positive (9).</p> <p>Cycle between committed focus and frustration until learn to manipulate sensor.</p>	<p>‘Can I use it on my [leg, foot, torso]? I want to see what kind of drawing a [battement, développé, Limon warm up sequence] makes.’</p> <p>‘Whoa – that did not move the way I expected. Makes me a little nauseous.’</p> <p>‘Can I use this for my own training?’</p>

Table 1. Continued

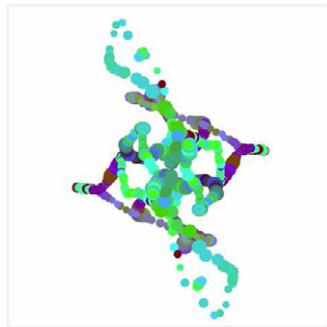
Subjects (n)	Hours observation	Direct observations	Sample quotes
		Engagement once figure out how to manipulate sensor. Quick to ask for help regarding how to control sensor. Once reach level of comfort, become playful. Wide range of movement qualities explored once in playful phase.	'How are you going to teach patients to use the sensor? You'll need to give them explicit instructions.' 'I think you're on to something. This is really interesting.' 'How fun!'
Clinicians (10)	6	Overall response: positive (10). Generally, once figure out how to manipulate drawing, then hand sensor back and stop using. One clinician, a recreation therapist, demonstrated a playful phase. Clinicians tended to participate more by observing other participants. In several cases, clinicians watched from across the room as patients worked with the programme and then offered their observations of these sessions using the programme. Frequent comments on quality and length of patient attention when the arts-generation programme was in use in contrast to previous training sessions without.	'Oh wow—I get it! Can I use this to do [specific motor goal such as reaching, balancing, walking]?' 'I could really use this to work with patients on [quality of motion such as smoothness, range, speed].' 'My patients are going to love this!' 'Can I use it with my patients now?' 'I need to know how to calibrate so that I can compare movement qualities from session to session.' 'Can we print the images out for patients at the end of their sessions so that they have evidence of their work?' 'That's the longest I've seen [patient] practice in one sitting. And they were more focused on their performance than normal, too.' 'I'd never heard [that patient's] laugh before. What a great sound!'

arts experiences – perhaps by composing in Garage Band freeware and sharing it with friends on Facebook or by role-playing in Second Life. The ethnographic data presented here indicate that *Embedded Arts* may tap into this cultural shift, by allowing people recovering from CNS injury to translate their recovery work into digital images, aesthetically evaluate the compositions, email their favorites to loved ones or sell their favorites as merchandise (e.g. cafepress.com). While our physical medicine innovations are designed to work within medical funding structures, they are also designed to work with the current landscape of arts participation that has been democratized by the digital age.

NOTE ABOUT CROSS-DISCIPLINARY WORK

'Dualism is not a helpful starting point for multi-disciplinary collaborations.'

-Professor Susan Petry, Chair, Department of Dance, The Ohio State University, 2010



This work crosses disciplines. Vocabularies and values required, and continue to require, translation. There are many challenges around multi-disciplinary efforts, but many of the challenges for the current project were overcome by maintaining context.

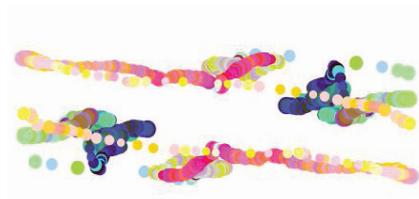
For example, it was important to avoid offering an overarching definition of dance, even for the noble purpose of communicating about dance with other disciplines. Encapsulating the art form of dance within a succinct definition is not possible. Dr. Karen Eliot, Professor of Dance at The Ohio State University and former Cunningham company member, states: 'Definitions of dance are culturally- and temporally-specific (varying widely across cultures and across time) and the whole argument about what is dance has occupied philosophers for centuries. Dance encompasses a spectrum of functions, ranging from, for instance, ritual–recreation–entertainment–exercise–self-expression, each with important outcomes' (Eliot, 2010). Dr. Eliot's description outlines the multiple culturally – and temporally – relative aspects of the phenomenon of dance. Each of these aspects can be studied for potential therapeutic value (see Block and Kissell, 2001 for further discussion). In this work I have tried to open a specific window into the rich art form of dance and have defined what I see within that small window. By defining elements within dance to be investigated we are able

to give context to the work at hand without trying to represent or contain a vast, context-rich art form.

The rationale for resistance to definition can be difficult to explain to my non-dance peers. It is counter-intuitive for many. In medicine, for example, the vocabulary of diagnosis requires strict definitions; otherwise, how could a therapist in one facility write a clear note to a clinician in another facility to warn of evolving deficits such as, ‘hemi-spatial neglect noted in morning of second day in acute care.’ If the hemi-spatial neglect deficit were accepted as a culturally and temporally-relative phenomenon, diagnosis and treatment of our loved ones with stroke would suffer. Hard and fast definitions are fundamentally important in the medical context. To add to the confusion, there are precise definitions within dance, for instance within ballet or West African technique; it is hard to explain why some dance concepts are definable while others defy definition, deriving meaning instead from subjective context. This difficulty surrounding formulation of meaning doesn’t just run one way. The relevance of working definitions for the purpose of research can be counter-intuitive for my dance peers. While definitions of concepts are important to all disciplines, they are more prioritized in some than in others. And they are complicated by context-specificity such that expecting one context when in another can lead to misunderstandings. It is helpful for both artists and scientists to keep this in mind while crafting rigorous cross-disciplinary investigations.

CONCLUSION

‘We’re asking whether the prescribed exercise, transformed into a creative experience, allows a person to perform therapy differently than when following explicit directions.’—Dr. D. Michele Basso, School of Health and Rehabilitation Sciences, The Ohio State University, 2010



This work seeks to improve recovery for individuals who have experienced central nervous system injuries and to explore best practices for embedding creative practices in physical medicine exercise prescriptions. Our first step in this exploration is to test an arts-generative, feedback interaction embedded within standard physical medicine exercises performed by patients receiving acute care at Dodd Rehabilitation Hospital. This innovation is made possible by movement sensing technologies, interactive digital media programming platforms, and biomechanical data analysis techniques that enable us to represent movement

as numbers for the purpose of providing digital media feedback and measuring clinical outcomes.

In order for novel ideas to become practical solutions, we must first show positive change. With neurorehabilitation of our stroke, spinal cord, and traumatic brain injury patients we must demonstrate positive changes in clinically meaningful parameters such as increased gait speed, improved depression scores, more frequent successful grasp attempts, improved locomotor propulsion, or improved postural stability despite perturbation. This dance-based programme is crossing traditional disciplinary lines seeking innovative methods for delivery and evaluation of medical care that works.

The work started as a Master of Fine Arts project for the Department of Dance (Dance and Technology area) and has evolved into a cornerstone for clinical innovation efforts within the Physical Medicine Department. I offer it as an example of a project-based approach to the sort of cross-pollination between art and science that drives innovation in the 'post-Google' world (Edwards, 2008). In summary, for dance and for rehabilitation medicine, movement is both method and result. In the rehabilitation paradigm, movement is medicine. In the dance paradigm, movement is art. Often, a single movement can be both. Perhaps, through this phenomenon of movement, the arts and medicine are more interdependent than we previously imagined.

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