An applied neurobiological model of dance, why it matters, and how it heals

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A Dissertation submitted to the Faculty of Graduate Studies in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

Graduate Program in Dance Studies

York University

Toronto, Ontario

December 2020

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Abstract:

Dance-based programs for neurodegenerative conditions such as Parkinson's and Alzheimer's (PD/AD) diseases are growing, with reported benefits including physical, cognitive, and affective improvements. This is not a new phenomenon; throughout history in cultures around the world, dance has played a role in promoting health and changing the course of maladies; however, it is only recently that research has attempted to identify and understand the mechanisms through which these benefits occur. A neurobiological model of dance, grounded in tools and practices from the field of dance studies, elucidates aspects of dancemaking that are effective in the treatment of specific disorders while promoting health and optimising function. Dance studies can and should play a central role in the development of dance-based interventions and research, contributing to our understanding of the impacts of motor learning and performance on the nervous system, and demonstrating the importance of skillful creative movement for well-being across the lifespan.

Thank you for dancing with me

ACKNOWLEDGEMENTS

The projects outlined in this dissertation are the tip of an iceberg, beneath which is a body of extensive and ongoing collaboration with talented people who believe in dance and science.

With thanks to the teams at Wake Forest University (IMPROVment); TU Berlin (MoBI Lab); Chigamik Community Health Centre; Dance Studies and JOElab at York University; friends and colleagues from the National Centre for Dance Therapy in Montreal, Dance Movement Therapy Ontario, and the American Dance Therapy Association.

We can dance alone, but it’s more fun when we’re together.

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Introduction

The multifaceted benefits of dance are increasingly prevalent in the media; a recent New York Times article asked, “Is Dancing the Kale of Exercise?” (Friedman, 2019), the Huffington Post stated “Dancing isn’t just fun – It’s really good for your health” (Holmes, 2016), and Psychology Today suggested “Want to keep your brain youthful? You should be dancing” (Bergland, 2017). Popular interest in what dance can do for our health has been fuelled by unprecedented levels of research on dance in the sciences; studies have reported benefits of dance across the lifespan, in the treatment of neurodegenerative conditions, such as Parkinson’s and Alzheimer’s diseases, in support of healthy aging, and for fostering good health in general.

For dancers and dance educators, these findings are no surprise – the integrated physical and mental challenges associated with learning or performing any dance form provide fertile ground for achieving grace, skill, and satisfaction. Dancing requires full engagement of our embodied selves in and through an atmosphere replete with music, culture, other bodies, and meaning. To dance, we must study and gain control of our almost limitless capacity to produce movement – small, large, nuanced or impactful; jumping, turning, growing, shrinking; limbs or torso; expressive or self-oriented; bodies flying through space, or held in riveting stillness. Dance can be, and is, expressed in innumerable ways and forms throughout history and across cultures; both the specific and the commonalities of forms, which may include cultural elements, narrative structures, material objects, music, and patterns of group interaction, must be acknowledged and clearly identified to determine the “active ingredients” in research pertaining to dance and health (for an excellent review of this issue, see Fortin, 2018). This is one of the primary contributions to be made by the field of dance studies to dance and health research; a nuanced appreciation of cultural and aesthetic aspects of dance in spaces, studios, and studies.

There is much to be gained for the field of dance studies by engaging with research into the biological dimensions of dance, particularly as these pertain to health and well-being. While the language of scientific research can be very different than that of dance, there is much at stake that merits our coming to a better understanding of each field's terminology, methods, and approach. From the perspective of dance studies, scientific and health research has revealed a huge number of applications for the skills and knowledge that are central to dance. And for researchers in the sciences, a fuller appreciation of the skills involved in dance can contribute to better research, stronger outcomes, and ultimately identification of core elements that will be of the most benefit when considering dance as a treatment modality.

This thesis is an exploration of what it means to dance from a neurobiological perspective. It aims for a translational model that uses terms from recent research in the neurosciences when considering dance-based practices, while remaining true to what makes an experience a dance. Dancing is not merely body actions accompanied by sounds; to dance is to explore and push the parameters of what makes us human. Dancing reflects our engagement with time, space, and others; our histories, dreams, visions, and habitat. "To dance is to matter" writes LaMothe (2015) in her seminal text *Why we dance*; this thesis examines the intimate relationship between culture and biology, as expressed in one of the most ancient human arts.

Aims and Scope

Neuroscience of dance is an emerging field with important applications pertaining to health and well-being. While dance has long been recognised as a potent form of medicine (Hammershlag, 1998) and continues to hold this place for many indigenous communities, Western medicine has only recently begun to probe the role dance might play in preventing disease and preserving health. Over the last two decades, a growing number of studies have investigated applications for dance in the treatment of some of our most pervasive health challenges: neurodegenerative disorders, most notably Parkinson's disease (PD), Alzheimer's disease (AD), mild cognitive impairment (MCI), and multiple sclerosis (MS). These conditions present with a host of progressive symptoms affecting all aspects of daily life; all are incurable, and treatment options range from pharmaceuticals with limited effects to invasive neurology. Participating in dance, however, has been shown to offer a host of benefits, ranging from improvements in motor symptoms such as balance and gait, performance on memory and concentration tasks, and better mood and self-efficacy scores. Despite the accumulating evidence, mechanisms behind these improvements are not yet well understood, and there is no broad agreement among dance practitioners, researchers, and health-care providers as to what, specifically, about *dance* contributes to the success of these programs. There is a need for a translational theoretical model explicating the ways in which dance is effective in restoring health and improving function, combining dance-based literacy with an understanding of recent developments in biological research on dance.

Drawing on dual competencies in dancemaking[1] and systems neuroscience, I propose a neurobiological framework for dance that makes explicit *how* aspects of dance may be effective in the treatment of specific disorders, aiming to clarify *why* participation in dance can promote health and well-being. The purpose of this framework is to identify applicable elements of dance and detail how they may be implemented in the treatment of health conditions, supported by testable methods and theories from neurobiology. These principles are used to illustrate a theoretical framework for how and why dance may be used as an effective adjunct treatment,

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[1] I use "dancemaking" in the vein of Batson & Wilson (2014) to emphasise "...the generative capacity and agency within dance choreography – not as thing or product, but as an embodied act of deliberate aesthetic transmission across all phases of the evolution of a dance" (p. xvii).

supported by a clear and functional understanding of dance that will be useful to researchers, dance therapists, community and adapted dance leaders, health care providers, and participants in dance programs. While this may seem reductive, it is by no means intended to diminish the creative possibilities inherent in dance; on the contrary, as neuroscientist Eric Kandel, who has a long-standing interest in bridging the gap between science and art, writes:

> Reductionism, taken from the Latin word *reducere*, "to lead back," does not necessarily imply analysis on a more limited scale. Scientific reductionism often seeks to explain a complex phenomenon by examining one of its components on a more elementary, mechanistic level. Understanding discrete levels of meaning then paves the way for exploration of broader questions – how these levels are organized and integrated to orchestrate a higher function (2016, p. 5).

Dance, a highly complex activity, could benefit greatly from this type of analysis, particularly in relation to potential applications aimed at restoring or promoting the equally complex concept of health. Dance mobilizes all our faculties by simultaneously involving movement, cognition, attention, and affect; dancemaking challenges us to attempt novel movement combinations, hold multiple tasks in memory, and attend to multisensory cues, all while aiming for an aesthetic output. Interoceptive while remaining attuned to the environment, bridging the space between worlds, dance is one of the most demanding and rewarding activities we can engage in. Popular conceptions of dance, which tend to focus on its performative dimensions, marginalise the *practice* of dancing as a lively activity and expression of knowledge. A reductive analysis can help define the components of dance that contribute to the complex phenomenological and physiological experience of dancemaking.

My goal is to identify aspects of dance which transcend/underlie disciplinary categories, relating these to biological function and development for the purposes of creating an applied model suited to the treatment of neurodegenerative (and potentially other chronic/complex) conditions. Dance may be understood in this sense as a direct means of engaging with the most fundamentals parameters of human experience and behaviour: understanding and creating movement in space and time. Our ability to do this is instantiated in the nervous system itself, which has evolved around coordinating motor learning and motor control. Dance is indicative of *volition*, our capacity to generate voluntary actions that respond to, comment on, or change features of our environment. We do not need to dance, in the immediate sense, when faced with any situation; however, our ability to do so demonstrates how adaptive and creative we can be. This distillation of motor abilities developed by human organisms over time provides a suitably complex and appealing biological explanation as to why engaging in dance may promote health and healing: dancing coalesces our capacity for creative response and reflexive reactivity. This approach to dance is widely applicable in the treatment of conditions that reflect degeneration in the nervous system related to illness or aging.

This thesis outlines a neurobiological perspective for dance studies associated with the study of brain-based changes in the individual participants who dance. While there are important social aspects of dancemaking such as group cohesion and synchrony (Vicary et al., 2017), entrainment between group members, mirroring, mimicry as mimesis (Barnstaple 2016), this treatise more directly addresses theories and techniques that pertain to aspects of dance operating at the level of the individual, such as motor learning and spatial orienting. This choice has been made to foster a wider understanding of "ground truths" as to how aspects of culture are instantiated in the structure and function of the nervous system, with the intention of clarifying how and why dance may be used to address pervasive health conditions. This understanding can expand the relevancy of dance applications, extending benefits to a wider audience and facilitating best practices. In current literature and practice, competing definitions of therapeutic dance constrain a broader understanding of how and why (and by whom, and where) it can be used effectively. Dance/movement therapy (D/MT), for example, emphasises *mental* health in its scope of practice, and uses the language and theories of psychotherapy to describe its tools and primary effects. D/MT is defined by the American Dance Therapy Association (ADTA) as "the psychotherapeutic use of movement to promote emotional, social, cognitive and physical integration of the individual" (ADTA website), and dance therapists seek and obtain mental health accreditations in many countries. In contrast, dance programs for specific populations such as *Dance for PD* and various adapted dance classes often explicitly distance themselves from language associated with therapy, instead emphasising pleasure and agency, with stated aims to "explore movement and music in ways that are refreshing, enjoyable, stimulating and creative" (Dance for PD website). Programs that focus on artistic aspects of dancemaking are an example of "Dance for Health", a growing sector recently defined by the International Association of Dance Medicine Science (IADMS) as being comprised of "…holistic, evidence-based alternatives for the individual to manage and adapt to physical, mental and social health challenges. In Dance for Health sessions, trained teaching artists engage people as dancers, rather than patients, in joyful, interactive, artistic activity" (IADMS Dance for Health committee Facebook post, August 7th, 2020).

The commonality between these approaches and others is that they do involve, in at least some respect, engaging participants in learning or experiencing elements of dance. Determining how the practice and inclusion of specific dance elements in each case relates to its efficacy as a treatment modality would be helpful in establishing best/better practices. Current definitions do not always articulate this in a way that offers readily testable models or frameworks, impeding research and limiting applications. A consideration of how the practice of dance interacts with structural and functional aspects of the nervous system would benefit *all* approaches concerned with dance in therapeutic contexts. Dancemaking from this perspective may be understood as an effective means of calibrating our functional capacities and enhancing our ability to respond to changing circumstances, whether environmental, in the sense of adapting to physical space or culture, or biological, as in the context of adapting to life with a progressive disease, or reduced mobility associated with aging.

Dance and the brain

Both dance and the nervous system are built around movement and complexity. While we have 7 sensory "inputs" (visual, auditory, olfactory, tactile, gustatory, vestibular, and proprioceptive) to our central nervous system, we have only one "output" – motor behaviour. Dance is concerned with how we create, manage, train and modulate that output, often in coordination with complex multisensory stimuli including music, spatial configurations, and other people. Systems neuroscientists Rudolfo Llinas (2001) and Gyorgy Buszaki (2006) write extensively on how coordinating our motor responses with the environment generates the substrate of neural networks, which are the basis of, and involved in, everything we do; it is these systems that are also affected by neurodegenerative disorders. A neurobiological model of dance takes a complex evolutionary view of the central nervous system (CNS) such as that advanced by Llinas (2001), and includes the role of neural oscillations in networks and behaviour (Buszaki, Spoorns), observable through techniques such as resting state electroencephalography (rsEEG) and functional magnetic resonance imaging (fMRI). Investigating brain connectivity patterns through network analysis can help us to better understand the role of dance in (re)shaping brain dynamics and cognitive architecture. Novel theories and techniques such as *connectomics* (how brain networks flexibly connect and communicate; see Kucyi & Davis 2014) and dynamic resting state analysis, which look at functional (rather than structural) neural organisation and implicit brain activity are well-suited to investigate dance-related changes such as sensory integration, learning and memory.

From the phenomenological perspective of the "lived body", as described by dance scholars/practitioners such as Laban, Bartenieff, Fraleigh, Sheets-Johnstone, and LaMothe, all forms of dance share common parameters and elements, such as motor control, tempo, directionality, and attention/intention; engaging with these involves skill development (learning) and creativity (exploration). These aspects of dance can only recently be explored via scientific tools and imaging methods such as those described above, and the potential to gain a clearer neurobiological understanding of how these elements interact and combine in the CNS offers tantalising possibilities of building new holistic models of health and recovery that include creative and motor aspects. Reductive and data-informed analysis aimed at identifying components and mechanisms involved in dance can provide new insight into how and why specific techniques may be more optimal in relation to a condition or disease.

The explosion of scientific research on dance in both expert and clinical populations is evident in the number of peer-reviewed studies which have investigated various neurobiological impacts of dance. Some compare dancers and non-dancers (Hanggi, Koeneke, Bezzola & Jacke, 2010; Lu et al., 2018) and dancers and musicians (Poikonen, Toivianen & Tervaniemi 2016; Kung, Chen, Zatorre & Penhume, 2013), others investigate dance learning or expertise (Blasing, Tenenbaum & Schack, 2009; Bar RJ, DeSouza JFX, 2016; Burzynska et al., 2017; Rehfeld et al., 2018; Douka et al., 2019); all have shown differences in structure and function of the nervous system that can be attributed to experience with dance. In clinical research, dancing has been shown to positively influence outcomes on measures including those associated with motor symptoms, such as balance and gait disturbances (Hackney and Earhart 2009, 2010; Duncan and

Earhart 2012; Volpe et al., 2013; Houston & McGill 2013; Sharp & Hewitt 2014; de Natale et al., 2017; Kunkel et al., 2017; Scheidler et al., 2018), cognition, as measured by memory and concentration tasks (McKee & Hackney 2013; Hashimoto et al., 2015; de Natale et al., 2017), and affective improvements, as measured by mood and self-efficacy scores (Hackney & Earhart 2010; Hashimoto et al., 2015; Kunkel et al., 2017; Koch et al., 2016). Much of this research is conducted in fields such as physiotherapy, occupational therapy, kinesiology, geriatrics, rehabilitative medicine, and other subdisciplines of neuroscience such as motor control and cognitive neuroscience. While a full appreciation and understanding of recent research developments involving dance requires fluency in the language and methods of these disciplines, it is essential that the field of dance studies becomes aware of, and actively contributes to, this evolving landscape. As our global population ages, there is an urgent need for treatments that address the challenges associated with later years while providing hope, functional improvements, and increased quality of life. Applications for dance in the maintenance of health and treatment of disease present a unique interstice between artistic practice and well-being that is accessible, and increasingly, necessary.

As a field of movement professionals, dancers are well-versed in movement techniques; we know what we need to do to achieve or teach proficiency in specific elements of a dance or dance form. A neurobiological understanding of dance, particularly in the context of health and disease, expands this inquiry to ask: but what does dancing *do to us*? This thesis is an exploration of that question, presenting a transdisciplinary model that links specific biological features of the nervous system with core elements of dance. The first chapter provides context demonstrating how this perspective is in many ways a return to, or extension of, some of the primary concerns of Dance Studies, and positions this work in relation to the broader field.

Subsequent chapters provide a model of transdisciplinary research activities that bring together a biological understanding with dance-based competencies. Chapter 2, *Mechanisms of dance in the rehabilitation of neurodegenerative conditions*, proposes a general framework for understanding how elements of dance contribute to the slowing of disease progression in neurodegenerative conditions, and more specifically, models ways in which dance involves multi-network activation elicited through motor learning and changes in attention. Chapter 3, *Dance me to the end of love: Enabling cognitively impaired older adults through improvisational dance and movement,* lays out a neurodevelopmental framework and focusses on how challenges associated with aging, such as difficulties with multisensory integration, dual-tasking, slowed response times, and motor challenges may be addressed specifically through improvisatory movement prompts. Chapter 4, *Mobile brain/body imaging in dance: A dynamic transdisciplinary field for applied research*, demonstrates how we might investigate the specific contribution of motor learning to rehabilitation through the application of new neuroimaging and motion capture technologies enabling ecologically valid research involving dance. Chapter 5, *Multinetwork motor learning as a model for dance in neurorehabilitation*, further outlines a neurobiological model of dance based on an understanding of motor control, motor learning, and the phenomenological experience of dancing, and concludes with a vision for dance studies that includes biological understanding as a primary means of thinking about how dance might be used in the treatment of specific health conditions, and in promoting well-being across the lifespan.

Dancemaking is a powerful, transformative activity that involves our entire organism, shaping complex responses to a closely attended environment. These features make it an ideal practice to explore when addressing the challenges of neurodegenerative conditions which affect our ability to act in coordinated ways, expressive of agency and ability. Dance, as a manifestation of volition, motor control and exploration, is more than pleasurable – it coalesces the means through which we adapt, learn and grow as humans. Through providing a neurobiologically grounded framework for dance, I aim to extend the reach and impact of programs that restore hope and function to people when they need these most.

Chapter 1: Theories and Literature

Part One: Embodiment, enskillment, plasticity and knowledge

The projects described in this thesis build on historical occupations in dance studies with embodied investigations of movement and culture, contributing to new theoretical frameworks and demonstrating a range of applications. My aim is to clarify how bridging movement expertise and exploration (dance) with understanding the way the central nervous system develops, functions, and is organised (neurobiology) can be a highly beneficial combination, offering a rich explanatory framework for the use of dance in the treatment of neurodegenerative conditions. Neuroscience comprises a growing body of knowledge concerning how our complex organisms work, grow, adapt, and function, providing a clearer picture of what we need to do and learn to optimally function. Bringing perspectives from this arena of evolving research to dance studies brings new insights to important questions concerning our humanity, health, and happiness. My aim of building a neurobiological model of dance emerges from, and extends, foundational research in dance studies concerning embodiment, skill development, and plasticity. These categories, which weave through seminal texts in dance philosophy and ethnography, point towards an evolving branch in the field of dance studies in which biological impacts might usefully be understood in relation to participation in cultural practices.

All dancing refers to phenomena that are fundamentally *embodied* - the practice and the person are synonymous; the materiality of dance is in the body (or more specifically, the movement) itself. Embodiment[2] collapses categories (body/mind; inside/outside), and I suspect

[2] The term "embodiment" has come to signal the presence of the body in all activity (including that which was previously conceived of as "purely" mental or theoretical). Sheets- Johnstone takes issue with the term, suggesting it is no more than a "lexical band-aid covering a three-hundred-year-old Western wound" (1999, p. 359). For the purposes of my argument, I will use the term "embodiment" as it gestures towards knowledge as situated learning,

this to be a reason why scholarship in dance has both foreshadowed and fed many recent discursive “turns”[3] – corporeal, practice-based, and sensory. Dance scholars employ their skilled “bodies of knowledge” in conducting research, and key texts in dance anthropology have been written by scholars with extensive training in dance and/or movement analysis (Ness, Foster, Kaeppler). The moving, learning, and sensuously attuned body is a source of insight in the field; simultaneously the site of transfer (Hahn, 2007) and inscription (Ness, 2008), it presents a living record of the work, study, or encounter that has occurred. This exemplifies *embodied knowledge*, distinct from how knowledge has been conceived throughout much of the Western tradition. We could clarify the difference by referring to standard academic knowledge as *dis*embodied, an attempt at an “objective” view from nowhere of an unchanging world “according to which human experience is constitutionally split between being *in* the world and knowing about *it*.” (Ingold, 2014, p. 387). In contrast, models which use embodied knowledge, according to philosopher Mark Johnson, “emphasize non-propositional, pre-reflective dimension of meaning that arise in our spatiotemporal orientations, perceptual interactions, and bodily movements” (1989, p. 361). This description, which emphasises bodily dimensions, makes evident the terms by which we may consider dance as knowledge: the senses, perception, movement, and learning.

Scholarship in dance studies (and related research in anthropology, philosophy, and performance studies) has played a pivotal role in contributing to this shift. Dance ethnographers and scholars refer to “kinesthetic” aspects of their research, indicating how their repertoires or

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an outgrowth of the definition provided by Mark Johnson: “embodiment is meant to indicate the developing process of organism-environment interactions that constitutes our ever-changing reality.” (Johnson, 367)

[3] There have apparently been many recent “turns”. I suspect that these have (buried) roots in the *turn* (*kehre*) of *Being and Time*; a turn away from "ontic" questions (about beings in the specific) to ontological questions (about Being itself), a maneuver by which Heidegger attempts to recover what he feels to be the most essential philosophical question – what is Being? The turns described in various literatures, in their own ways, could be understood as proposing or remediating ontological orientations to the question of Being.

training provide access to cultural phenomena that emphasise movement. While the definition of "dance" continues to evolve[4], dance practices (or what have been framed as such) across cultures have persistently been understood as more than entertainment[5] by the field of dance studies. In foundational texts, anthropologists whose backgrounds include dance took these insights further; Kaeppler's discussion of "structured movement systems" in Tonga (in Spencer, 1985) and Hanna's structural-linguistic perspective in *To Dance is Human* (1987) recognise the inherent complexity of dance, and infer organisation and production of meaning in the activities they describe. In this literature review, I offer that dance, broadly defined[6], has clear epistemological and ontological dimensions, as has been signalled within the field of dance ethnography; that the knowledge dance creates and contains is written on, in, and by embodied techniques associated with research, learning, and practice, which alter and are altered by their performance; and that the study of these aspects has contributed to the "practice" and "sensory" turns in recent scholarship, which have wide-ranging repercussions across disciplines. The integration of embodied knowledge and/or technique is stimulating the development of new methods of research and dissemination that include biological dimensions, with implications for health, well-being, and the application of dance procedures and practices beyond the studio.

The concept of embodied knowledge alters the scope of dance and performance studies. Historically, branches of dance studies addressed concerns of ephemerality or transience, reflecting an anxiety as to the value (or persistence) of the field and its products. This focus on

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[4] Given that the category of "dance" is a Western-European construct, many authors have attempted to broaden the definition to include other embodied practices (movement, ritual, symbolic activity) while maintaining the "special" nature of dance (as opposed to quotidian movement). LaMothe details these binary oppositions as attempts to distinguish between "whether the movement in question is intentional or not, functional or not, formal or not, expressive or not, rehearsed or not" (2015, p. 7), which fail to get at the crux of the (embodied) action.

[5] For an overview of early work in Anthropology of Dance, see Paul Spencer, *Society and the dance* (1985)

[6] Working definition: Dance is an embodiment of the possibilities of movement, for specific bodies, in a place; dance describes both what we know and is the means by which we come to know it.

(im)permanence promotes a view of dance-as-spectacle, to the neglect of investigation into what dance *is* or *does* outside of a given performance. What knowledge consists of, and how it can be preserved, valued, and transferred are questions at the heart of this concern. Diana Taylor addresses this in *The Archive and the Repertoire* (2003), in which she distinguishes the *archive*, which holds “documents, maps, literary texts, letters, archaeological remains, bones, videos, films, CDs, all those items supposedly resistant to change” (p. 19), from the *repertoire*, which “enacts embodied memory: performances, gestures, orality, movement, dance, singing...all those acts usually thought of as ephemeral, nonreproducible knowledge” (p. 20). When we transition to a consideration of dance as *embodied knowledge*, the repertoire *is* the archive. Rather than a singular performance, what is here of interest is the embodied training, practice, and “enskillment” (Ingold) that contributed to it. This is a major shift in how we think about dance, and the parameters of any related practice; it is the learning, or attention, up to and including that point which allows the specific activity to occur that is now emphasised. What does the body *know* that has made this instance of dance/performance possible? And how is this knowledge biologically instantiated in the structure and function of the nervous system?

According to Terry Eagleton, “The very word ‘culture’ contains a tension between making and being made, rationality and spontaneity, which upbraids the disembodied intellect of the Enlightenment as much as it defies the cultural reductionism of so much contemporary thought.” (Eagleton, p. 5). This tension is precisely the dynamic in play when we turn to investigating the biological dimensions of cultural practices such as dance. Within the field of dance studies, key figures such as Laban and Bartenieff explore the two-fold potential for movement to indicate organismic states and transform them. Their theories are readily adapted to the contemporary idea of *plasticity*: our ability to adapt to changes in our environment, reflected in all levels of our organism from neural architecture to motor learning. On this topic, Greg Downey writes: “human bodies and brains are surprisingly plastic, responding to patterns of activity by changing physiology. Different physical disciplines…might have profound effects on how our bodies develop physically, effacing the division sometimes drawn between biology and culture.” (2005, p. 166-7). Ben Spatz refers to this phenomenon as *sedimented agency*: “The plasticity of embodiment – the degree to which it can be shaped by technique – is not unlimited. But to whatever extent the anatomy of the body is shaped through technique, physiology itself can be understood as a form of sedimented agency.” (2015, p. 56). Questions concerning agency have been central to dance studies since Kaeppler, Hanna, Ness, Novack and Reed announced the interstitial significance and import of body, movement and culture in their studies of anthropology of dance. In her treatise *Dancing and Dances in Tonga*, Kaeppler calls for the study of dances as historical *and* cultural discourses (1974, p. 25). I aim to extend this trajectory by enlarging its scope to include *biological discourse*: the way dance physiologically affects those who engage in it.

This is in line with the “biocultural” perspective proposed by Downey and Lende in their treatise on the emerging subdiscipline of Neuroanthropology, which suggests that cultural phenomena may be productively studied through examining the interaction between training and anatomy (2012). According to Downey, “One way to incorporate neurological research and cultural theory is to treat culture, not as information, but rather as skill acquisition” (Downey & Lende 2012, p. 21). An examination of dance as skill acquisition which shapes biology provides a fertile interdisciplinary ground for an extended investigation of agency in the context of health and well-being. Ben Spatz refers to this co-determination of body, place, and skill as “the plasticity of embodiment – the degree to which it can be shaped by technique” (2015, p. 56). In

What a body can do (2015), Spatz disentangles references to embodied epistemology in performance studies and somatic practices, giving us a fully fleshed "*epistemology of practice*". He accomplishes this by rather adroitly disambiguating *practice* and *technique*, positing that while the latter refers to knowledge, which is transferable, the former cannot be universalised (as in "the practice of walking") but can only refer to an *instance* of walking. Each instance, or practice, necessarily deploys technique while at the same time, may also extend it – thus practice is an arena of *research*, while technique, which can be taught, implies *knowledge*:

> *Embodied practice is epistemic*. It is structured by and productive of knowledge. Accordingly, an epistemological account of embodied practice is one according to which such practice actively encounters and comes to know reality through technique, rather than simply producing or constructing it." (p. 26; italics in original)

This distinction allows Spatz to connect with the "practice" turn, initiated by theorists such as Mauss and Bourdieu, while usefully extending it. His maneuver brings embodied epistemology in line with the practice metaphor, which "stresses the central importance of our embodiment in the meaning, conduct, and understanding of (any) practice." (Johnson 1989, p. 366). This move shifts our attention to how we discover the world through our engagements with it, and how the knowledge thus acquired accrues in technique: "Technique, here, involves a detailed and context-dependent negotiation between socially defined or symbolic meaning and the concrete possibilities offered by the material world. In this thick relationality, humanity attunes itself to its world." (Spatz, p. 31). This conceptualisation of the relationship between technique and practice "opens the door to an epistemological understanding of practice that can inform our thinking about power, agency, society, and material reality." (p. 40-1).

For anthropologist Tim Ingold, the "thick relationality" of body, mind, and *place* shapes the activity of organisms. We are always situated; every place (even a lab) affords a unique environment. The idea of *affordances*, or material possibilities of a given environment, comes from ecological psychologist J.J. Gibson, and is of central importance to both Spatz and Ingold. The theory of affordances recognises that as we tune ourselves to our environment, it emerges for us, and we to it, in a mutual expansion of what is possible (or known). According to Ingold, a "perceptually acute organism is one whose movements are closely tuned and ever responsive to environmental perturbations" (2000, p. 261). This tuning is accomplished through exploratory movement, which leads to the discovery and/or exploitation of affordances; the "activity of the organism within its environment…(which) guides the organism along in the furtherance of its project" (Ingold 2000, p. 261) unites the concept of technique with that of affordances, while showing how movement (dance) begets knowledge. Technique structures practice "through an epistemic engagement with the relative reliability of material reality" (Spatz 2015, p. 42). What dance philosopher Kimerer LaMothe describes in her work can thus be understood as a *practice*, the focus of which is, in her terms, *to cultivate sensory awareness of the rhythms of bodily becoming* (2015). With Spatz and Ingold's clarification, embodied ethnographies such that provided by LaMothe can be taken as research enterprises focussed on developing an *ontology* in and through movement. In the example of LaMothe, she is less interested in finding out *how* to do something, as she is concerned with *what is*; what are the parameters of her human being in the world, and how can she come to know/change these?

LaMothe suggests that dance is a form of knowledge, based on our ability to "*create and become patterns of sensation and response*…in ways that *cultivate a sensory awareness* of our participation", implying a verifiable proposition: dance can shift experience and perception in ways that may shape or change biological features. In her seminal text *Why we dance* (2015), LaMothe positions dance as a vital art, necessary for human development and survival. This is "…as much a vision *for* dance as a vision *of* dance, informed by equal parts empirical evidence, scholarly research, kinetic imagination, and personal experience" (p. 4). Both the claim and her means of supporting it are indicative of the broad shift in scholarship implicating embodiment as both a methodological instrument and site of knowledge. Understanding the body as a path to, source of, and repository for knowledge has impacted scholarship across disciplines, heralding a swath of changes in the academy, as embodied research and multi-platform/multisensory presentation strategies are increasingly in evidence (Spatz, 2015). These changes are founded on recognition of the corporeal dimensions of knowledge, which have always been present, despite their neglect.

In her "Reprise on Dance Ethnography" (2000), Dierdre Sklar points to two trajectories emerging in the field since the publication of her original article a decade earlier (1991). The first trajectory relates to cultural theory, while the second trajectory is "kinesthetic…we seek deeper understanding of movement itself as a way of knowing, a medium that carries meaning in an immediately felt, somatic mode." (Sklar 2000, p. 70). This second trajectory marks the shift from viewing dance as a spectacle requiring interpretation by an educated observer, to dance *as a way of knowing*. Dance ethnographies before this period viewed dance through the lens of cultural theory (Foster), or read it as a form of communication resembling linguistics (Hanna, Kaeppler); these views reflected a search for meaning from an external perspective, which neglects the felt-sense of dancing itself as an epistemological project with ontological aims.

Ethnography that purports to explore "culture", understood as the world in which one finds oneself, from an embodied, somatic perspective, is essentially an ontological project. It takes as its subject the realm and scope of being-in-the world. Agentive and emplaced, involving language that is embodied and pertains to movement, this type of ethnography describes how things are known through action. Sklar's second trajectory is in this vein: "We discuss embodied knowledge, proprioception, somaesthesia, kinesthetic ambiance, kinesthetic empathy, and synaesthesia, all of which address the somatic dimensions of movement knowledge." (Sklar 2000, p. 70). This contrasts with the "scriptocentrism" (Conquergood) of classic academia and the "world-as-text" perspective of interpretive anthropology. Fieldwork reconsidered as a collaborative practice, a dance to be enjoined, subverts hierarchies of observer/observed and supplants traditional modes of documentation with living, breathing, interpersonal narratives. As Dwight Conquergood writes, this kind of "Ethnography is an *embodied practice*; it is an intensely sensuous way of knowing. The embodied researcher is the instrument." (2013, p. 83). Dance ethnographers, through the instrumental use of their skilled bodies, develop knowledge that may have been overlooked in earlier studies because it did not fit the mode of observation.

Many of the works signaling this change are recent, composed over the last thirty years. Sklar identifies Sally Ann Ness' *Body, Movement, and Culture* (1992) and Cynthia Novack's *Sharing the Dance* (1991) as two key contributions to this shift, as their authors leverage movement experiences "not so much to facilitate description of particular steps or choreographies, as to understand the way sensation itself is organized, in the dancing certainly, and also, in Ness's words, as 'latent symbolism' of social action" (Sklar 2000, p. 71). I feel that these early examples mark the border between symbolic and embodied readings of dance; Ness, for example, describes her text as a "choreographic ethnography" combining methods from movement studies, anthropology and linguistics, and while she relies on movement as a method, she is simultaneously working through assertions such as Geertz' that societies contain their own interpretations (1992, p. 230). However, by prioritizing body and movement as central to the development of culture in her text, Ness aligns with the second trajectory identified by Sklar. Ness' suggestion that choreographic phenomena represent "the recent findings of culture bearers, findings about the world they physically inhabit, findings about the society they embody, findings about what it means to be a living, breathing human being in their particular place, in their particular historical moment" (p. 233) is an ontological statement. She is describing how movement is both epistemological – it is the means though which the world is explored – and ontological – it comes to embody what that world is and means. In the same vein, Novack's investigation of the embodiment of culture in the history and practice of Contact Improvisation includes a careful unpacking of how the body (and movement) represent meaning and value, while simultaneously pointing to how specific techniques comprise the limitations and possibilities of our existence[7]. Relying on her embodied experience as a Contact Improviser, she describes details such as how body boundaries can be both clear (specific) and flexible (distributed), modelling a new kind of self through direct engagement with the possibilities of embodiment (and other bodies). Novack's use of her embodied experience is meant to draw attention to salient sensations in her research (practice), and is essential to the thrust of her project; as Sklar indicates, her "subjective' bodily engagement is tacit in the process of trying to make sense of another's somatic knowledge. There is no other way to approach the felt dimensions of movement experience than through the researcher's own body" (2000, p. 72). Ness and Novack epitomise Sklar's kinesthetic trajectory, as they employ their movement training to uncover deeply resonant meanings in the worlds they investigate.

This "incorporation" of the body as method and material in ethnographic inquiry, a means of acquiring knowledge through learning (repertoire) which becomes the repository of what has been experienced (archive) marks a shift in the field of ethnography more generally

[7] For example, she describes how dancers push the limits of what they know and could know by prioritising their experiences as bodies in motion with a shared centre of gravity

over the past three decades. Thomas Csordas, in his essay "Embodiment as a paradigm for anthropology" (1988), describes an embodied approach that "begins from the methodological postulate that the body is not an *object* to be studied in relation to culture, but is to be considered as the *subject* of culture, or in other words, as the existential ground of culture." (p. 5). This emphasis on embodiment as "the existential ground of culture" suggests an ontological project. Sarah Pink, on what she terms *sensory ethnography*, states that one of the goals of this approach is "to seek to know places in other people's worlds that are similar to how they are known by those people…we aim to come closer to understanding how other people experience, remember, and imagine." (Pink 2015, p. 25). This intimate engagement with, and inhabitation of, other worlds (ontologies) may only be accomplished through attention to embodiment, in recognition that the ethnographer is "her- or himself part of a social, sensory and material environment" (ibid). In Ingold's words, anthropology cannot acquiesce to the "excision of knowing from being" (2014, p. 387) attempted by the protocols of what he terms "normal science". He affirms "that knowledge…grows and is grown in the forge of our relations with others." (ibid, p. 391). Thus knowledge, "consists not in propositions about the world but in the skills of perception and capacities of judgment that develop in the course of direct, practical, and sensuous engagements with our surroundings." (ibid, p. 387).

Dance scholar and philosopher Maxine Sheets-Johnstone argues for the "necessity of incorporating movement in our epistemological and metaphysical investigations of the animate world from the very beginning, and in our scientific and historical investigations of the animate world as well." (1999, p. xv). Movement possibilities structure both our *archive* and *repertoire* of behavioural possibilities; although an essential aspect of embodiment, movement has long been excluded from considerations of what we know and how we know it. Knowledge in the

Western tradition has been taken to infer an abstract category associated with "truth" or "belief", propositional statements, and/or theory of mind. The body has been cast as a source of confusion, illusion, and even anti-knowledge in the philosophy of Descartes, extending Plato. However, the (re)turn to the body (*The Coroporeal Turn* suggested by Sheets-Johnstone, 2009), offers a vindication of embodiment based on a life dedicated to the study of movement. According to Sheets-Johnstone, from infancy onwards "moving is a way of knowing and…thinking in movement is foundational to the lives of animate forms." (1999, p. xv). She proposes "to demonstrate that movement offers us the possibility not only of formulating an epistemology true to the truths of experience, but of articulating a metaphysics true to the dynamic nature of the world and to the foundationally animated nature of life." (ibid, p. xvii).

This movement epistemology is exemplified by LaMothe in her treatment of dance, informed by attention to her own experience over many years as a dancer and dance educator. One of the key moves in her philosophy is to shift the definition of dance from noun to verb – "to dance is to *create and become patterns of sensation and response*…in ways that *cultivate a sensory awareness* of our participation in it" (2015. p. 4-5, italics in the original). The emphasis is on conscious participation in this definition, which can be applied to "any movement or activity – whether sport or chore or ordinary action" which offers "a chance (1) to create and become our bodily selves, (2) shift our sensory experience, and (3) do so attentive to what we are creating and becoming" (ibid, p. 8). The attention to agency and awareness in LaMothe's description highlights the activity of dance as something that we *do*, an exploration of our embodied condition, involving creativity, and transformation – dance is not a product, it is a living process that allows us to *create* and *become* our bodily selves, and sensory perception is integral to her definition. Not just *what* we know, but *the way in which* we know it is the role of dance for these theorists. Dance and movement are routes to the discovery/recovery and creation of knowledge, which has implications for our way of being-in-the-world.

LaMothe and Sheets-Johnstone point to something which is of utmost importance: embodiment implies *movement*. Embodiment does not refer to a static body-object or the body as a signifying figure; nor is embodiment an indication of a reified and unchanging state. Embodiment is a process, which inherently involves transformation and metamorphosis. This distinction is critical to bear in mind for considerations involving biology, which are the inevitable extension of the embodied hypothesis. For many years, the nature/culture debate has railed against "biological determinism". However, as we understand more about the dynamic organisation of bodies (brains, nervous systems, movement patterns), it becomes clear that biology is plastic; we are simultaneously made from, and involved in the making of, our environments, and determinism is neither a natural nor adequate description of how this works.

The aims of science, and those of disciplines that aim towards understanding human experience, such as anthropology, philosophy, and dance, are not incommensurable. Rather, they require each other to fulfill their projects of elucidating and understanding the conditions and dynamics in which we find ourselves. Tim Ingold suggests biological and social processes mutually comprise a field which he terms *biosocial* (2013); in his view, these domains are not "complementary, or …pertain respectively to the level of discrete individuals and to that of the wider groupings into which they are incorporated…there is no division between them. *The domains of the social and the biological are one and the same*" (ibid, p. 9; italics in original). Embodied or enactive cognition, a relatively recent development in cognitive science signalled by the publication of *The Embodied Mind* in 1991, contributes to this view, both by lending support to the embodiment thesis, and through acknowledging the role of experience, action, and environment in cognition. I quote authors Varela, Thompson, and Rosch at length here, as their words resonate in later chapters exploring sensorimotor capacities and dance:

> Let us explain what we mean by this phrase *embodied action*. By using the term *embodied* we mean to highlight two points: first, that cognition depends upon the kinds of experiences that come from having a body with various sensorimotor capacities, and second, that these individual sensorimotor capacities are themselves embedded in a more encompassing biological, psychological, cultural context. By using the term *action* we mean to emphasize once again that sensory and motor processes, perception and action, are fundamentally inseparable in lived cognition. Indeed, the two are not merely contingently linked in individuals, they have also evolved together." (1991, p. 172-3).

If "cognition depends upon the kinds of experiences that come from having a body with various sensorimotor capacities", then LaMothe's claim that dance is a kind of knowledge, based on our ability to "*create and become patterns of sensation and response*…in ways that *cultivate a sensory awareness* of our participation" implies a scientifically verifiable proposition: dance can shift experience and perception in ways that may shape or change biological features. Sheets-Johnstone's statement that "moving is a way of knowing and…thinking in movement is foundational to the lives of animate forms" is also echoed here. The position that movement is central to development and evolution is shared by neuroscientists such as Gyorgy Buszaki and Rudolpho Llinas, who suggest the brain evolved as a consequence of our capacity for movement, and through the complex process of calibrating our internal rhythms and responses with the external environment. (2006; 2001). This reciprocity is echoed by Ingold: "The characteristics of organisms...are not so much expressed as generated in the course of development, arising as emergent properties of the fields of relationship set up through their presence and activity within a particular environment" (2000, p. 4). If these (biological) characteristics are generated through development, then change is implied; and as emergent properties of fields of relationships, they serve to indicate how specific types of presence and activity within an environment shapes perception. These characteristics may exhibit measurable differences that demonstrate the plasticity and permeability of biology, and the interdependence of organism, action, and place. As such, they represent a fertile ground for research.

Theories which integrate biology and culture, and research designs that incorporate biological markers with an ethnographic approach, have exciting applications; nowhere is this more evident or urgent than in what has been described as the "transdiscipline" of health. Improving our understanding and models of how and why we become ill, remain well, or flourish is of utmost importance. Health is necessarily embodied – there is no illness, wellness, ability or disability without a living body attached. Developments in medicine are being transformed by approaches such as Patient-Oriented Research; critical disability studies, medical sociology and anthropology are bringing more embodied perspectives to theory in health science. My research employs neurobiology in both theory and measurement, asking how activity, such as specific forms of dance/movement, might alter neural signals or organisation, and how these measures serve to indicate experiential or qualitative changes. This approach develops out of theories associated with embodied knowledge; how what we know, through what we do, becomes instantiated in our organismic being, and looks for applications and methods that can be deployed from this standpoint.

There is precedence for this approach in Dance Ethnography; Greg Downey's studies of Brazilian Capoeira (2005, 2007) make broad use of neuroscientific research. Learning the *bananeira na cabeca* (the 'Banana Tree'), a maneuver in which the entire weight of the body rests on the head, is provided as an example of skill acquisition interacting with biology and perception: "Developing expert technique entails not so much the internalisation of a model movement as the realisation of a fundamental quality in the body – the extraordinary strength and resilience of the spine and head – just as training makes the spine and head more suitable to this movement." (in Ingold, 2011, p. 85). Downey's work demonstrates, and correlates with, current research on neuroplasticity, which shows that neural organisation is not "hard-wired"; rather experience, learning, and training can alter synaptic connections, reflected in structural and functional brain changes. Plasticity manifests the intimate relationship between experience and biology; to reiterate Downey, "human bodies and brains are surprisingly plastic, responding to patterns of activity by changing physiology. Different physical disciplines…might have profound effects on how our bodies develop physically, effacing the division sometimes drawn between biology and culture." (2005, p. 166-7). The implications of this are, in his words, obvious, and in my words, measurable: "forms of enculturation, social norms, training regimens, ritual, language, and patterns of experience shape how our brains work and are structured." (Downey & Lende 2012, p. 37). The concept of *embodied knowledge* and culture, recognised by dance ethnography, is biologically instantiated from this perspective: "The predominant reason that culture becomes embodied, even though many anthropologists overlook it, is that neuroanatomy inherently makes experience material." (ibid). Downey and Lende refer to this as "deep enculturation", through which "Cultural concepts and meanings become neurological anatomy" (ibid). Spatz refers to this phenomenon as *sedimented agency*, and draws a line from what he terms as the "sedimentation of technique" to Ness' "inward migrations" (ibid) of gesture and embodied practices, in which she observes how different dance forms alter bone structure and anatomy (Ness, 1996).

There is a complex relationship between training, agency, awareness, and embodiment. As Spatz points out, the automaticity that develops alongside expertise does not necessarily imply a diminution in agency, although it may indicate that agency is now sub- or pre-conscious; rigorously trained performers and athletes regularly demonstrate automaticity, along with different activations of neural networks when they engage in their field of expertise[8], in comparison with non-expert controls. Thus, while I agree with Spatz' statement that "we cannot assume (a) causal link between consciousness and agency…we must expand our idea of agency so that it extends beyond the conscious mind" (2015, p. 55), I want to point out that *sedimented technique* equates with *sedimented agency*, and must therefore by synonymous with *embodied knowledge.*[9] A biocultural perspective, at the intersection of biology and culture, gives us a complete theory and approach for investigating dance as knowledge, by examining the mutual interactions of organisms, activities, and environments.

[8] For a recent examination of network plasticity in expert dancers, see Bar & DeSouza, 2016.
[9] Spatz subtitle contains this suggestion - "technique as knowledge" implies: technique = agency = knowledge. This equation determines *what a body can do*, and further to this, what dance *does* to a body.

Part Two: Neuroscience of Dance – Roots and Development

The first academic program to offer a major in dance was housed in the Physical Education Department of the University of Wisconsin in 1926. This program, overseen by Margaret H'Doubler, offers some context and precedent for a biological approach in dance studies, marrying an understanding of the workings of the nervous system with dance training. H'Doubler studied biology and philosophy as an undergraduate and was an avid basketball player before being tasked with developing a dance curriculum "…worth a college woman's time" (Remley 1975, 180; in Hagood 2000). H'Doubler employed an understanding of the nervous system, motor learning, and physiology in designing her program, which emphasised the "kinesthetic sense", our awareness of movement driven by feedback involving joint position, velocity, and momentum. H'Doubler's legacy to the field of dance studies, according to Hagood, was in demonstrating "the substance of dance and its potential as an academic discipline" (p. 48), drawing on various conceptual approaches, including:

> …the science of movement (kinesiology); fundamental movement skills (technique); theoretical perspectives (dance theory); creative manipulation of movement (composition); the relation of movement to rhythm (rhythmic analysis); how the body should move (teaching methods); and classic and contemporary thinking on the moving body (dance philosophy). (ibid, p. 49)

This holistic understanding of dance is remarkably prescient; current studies on the biological effects of dance and the field of Dance Science are a direct extension of what H'Doubler intuited as the potential span and influence of the field of dance studies more than a century ago. That vision, however, splintered over time as dance studies within the academy became more focussed on performance, or more recently, cultural theory. A conservatory model, initiated in part by one of H'Doubler's students, performer Martha Hill (see Vertinsky, 2010) remains in colleges and universities globally, with technique and training comprising a large part of the primary curriculum for dance studies at most institutions. H'Doubler was not, however, interested in dance as performance; rather she was invested in how "attention to movement in creative and theoretical contexts had tremendous potential in liberating both mind and body" (ibid). This belief intersects with and supports core ideas associated with therapeutic dance. During the development of her program, H'Doubler's "Corrective Program classes in posture, relaxation, dance, and corrective exercise led to the eventual development of a program in Physical Therapy (1929) and later in Dance Therapy (1949) (Trilling, 1951; in Hagood 2000).

Other theorists who extended or contributed to the growth of dance science include Irmgard Bartenieff (1900-1981), whose integration of Laban Movement Analysis (LMA) with physiotherapy provided dancers and dance therapists with a language for describing movement and a means of introducing patterned change. Her contribution to movement (re)education, Bartenieff Fundamentals (BF), is spatially oriented and anatomically enriched, stressing the importance of relationships within the body and of the body within its environment (Bartenieff, 1980). Gertrude Colby contributed to the development of new ways of considering and teaching dance at Teachers College, Columbia University through the introduction of her "natural dance" program in the department of Physical Education from 1915 to her retirement in 1933 (In Memoriam, 1961). Mabel Ellsworth Todd, author of *The Thinking Body* (1937), taught anatomy, posture, and neuromuscular awareness to physical education and dance professionals within the same department; her work was further developed by her protégé, Lulu Sweigard (1974), author of the comprehensive 2013 text *Human Movement Potential* (Eddy, 2009). Currently, Irene Dowd teaches dance, composition, functional and kinesthetic anatomy and neuromuscular re-education throughout the US, Canada and Europe, and is on the faculty of the graduate program in dance at Hollins University and Julliard (https://www.juilliard.edu/dance/faculty/dowd-irene).

Recent programs in Dance Science, such as the flagship program at Trinity Laban in London, UK founded in 2001(https://www.trinitylaban.ac.uk/study/dance/dance-science/) and the combined bachelor's in Dance and Kinesiology offered by University of Calgary (2013) show an ongoing influence of the legacy of these dance and somatic innovators, although the emphasis in these programs is more on the training and rehabilitation needs of professional dancers rather than general applications. However, recent interest in the rehabilitative potential for dance resuscitates H'Doubler's vision of placing "…an understanding of the fundamental nature of human movement" (p.43) at the centre of dance education and training. This perforce includes more than merely the mechanics of joints and musculature; an understanding of the involvement of the brain in motor control and motor learning is required to appreciate the complex interrelationships between the practice of dancing and the workings of the nervous system.

The emerging field of dance neuroscience illustrates this point, as a growing body of literature investigates the biological dimensions of dancing in both expert and clinical populations, with important applications for the field of dance studies. In 2011, Dance Research Journal published a special online issue dedicated to dance and neuroscience, in recognition of research then occurring at the intersection of these disciplines. The issue specifically addressed the emergence of new techniques in cognitive neuroscience, such as fMRI and EEG, which made it "…possible to explore the neuronal processes in the brains of those who create, perform, and watch dance, and also to identify neuronal evidence for dancers' expertise" (Reynolds, Jola & Pollick, p. 261). The authors suggest that neuroscience had now "entered onto the dance scene as a partner which facilitated and promoted understanding of dance as a sophisticated practice demanding highly developed perceptual, cognitive and action systems" (ibid). Around the same time, *The Neurocognition of Dance: Mind, Movement and Motor Skills,* edited by Blasing, Puttke and Schack (2010), was published as one of the first texts to bring together writing by and about dance artists with scientific research; this text has since issued a second edition (May/July 2018). Batson and Wilson's textbook *Body and Mind in Motion – Dance and Neuroscience in Conversation* (2014) brings together dance and somatic practices with cognitive neuroscience, and the *Oxford Handbook of Dance and Well-Being* published September 2017 starts with a section on "Dance and the Body", which includes several chapters on neurophysiology. These sources primarily highlight cognitive aspects of dance, and more specifically, theories related to embodied cognition. While useful, these do not provide a specific biological or physiological basis for understanding what dance is and how it works in an applied sense. A biological model of dance requires that we align these perspectives with neurobiology, providing a sound and testable set of hypothesises for how and why dance can be effective as a treatment modality.

The recent advances in neuroimaging allowing investigation into neural mechanisms associated with dance have contributed much towards furthering our understanding of how dancing impacts the nervous system. However, these imaging techniques also come with attendant limitations that constrain our ability to study complex phenomena in a "naturalistic" or ecologically valid fashion. Most imaging techniques require subjects to remain still during data acquisition, as movement artifacts can bury subtle brain signals in noise. This means that most of the research on neural correlates and mechanisms of dance has occurred in static set-ups – studying the effects of movement on subjects who are not moving; see table 1 for an overview of primary imaging techniques and their respective limitations.

TABLE 1: Neuroimaging Techniques

Technique	How it works	Limitations
Single cell recording	Measures action potentials from individual neurons via electrodes implanted in the brain	Requires brain surgery; cannot be performed on humans unless they are already having brain surgery and give consent. Does not show connections to other neurons or brain areas.
fMRI Functional Magnetic Resonance Imaging	Measures changes in oxygen levels in the blood related to BOLD signal (blood oxygenation level response) by taking many images and combining them over time.	Signal change can imply *either* excitation or inhibition, as both involve neural activity that requires oxygen. Good spatial resolution (within millimeters); temporal resolution on the order of full seconds. Requires complex statistical analysis and the combination of multiple images.
EEG Electroencephalography	Measures electrical activity of large populations of neurons near the surface of the brain (cortical) via electrodes places on the scalp.	Good temporal but poor spatial resolution; signal is generated by many neurons, sometimes is disparate regions of the brain, and is affected/diffused by passing through the scalp.
TMS Transcranial Magnetic Stimulation	Uses a magnetic pulse to create a temporary "lesion" in the brain (knock-out an area).	Allows for speculation about function without causing permanent changes; still limited in terms of spatial accuracy – effects populations of neurons in an area of >5mm.
PET Positron Emission Tomography	Measures brain activity indirectly through changes in blood flow, indicated by the introduction of a radioactive tracer.	Fairly high spatial resolution (around 1cm), very poor temporal resolution (on the order of minutes). Also requires the use of radioactive isotopes – cannot be repeated frequently on the same subject.
MEG Magnetelencephalography	Measures magnetic fields associated with large populations of neurons using magnetometers; similar to EEG. Can be combined with fMRI for greater localisation specificity.	Good temporal resolution, and signal is not diffused by the scalp; however, there are problems with signal intermixing and spatial resolution is still poor.

The first study to investigate neural correlates of dance used Positron Emission Tomography (PET; Brown et al., 2005). In this study, amateur Argentine tango dancers lay on their backs with their heads inside the PET scanner and performed "simple bipedal dance movements on a laminated grid…The subjects were trained to be proficient at these dance steps in advance of the scanning session, so very little motor learning likely occurred during the experiment" (ibid, p. 1158). Subjects were instructed to slide their feet over an inclined surface while lying in the supine position; only their lower limbs had any spatial displacement. Tasks included following a 6-step box patterned movement based on the "salida" of tango, synchronized with regularly timed tango music; executing the same pattern with non-metric, irregularly timed tango music; a matched pattern with no music; performing isometric leg-muscle contractions synchronized with music; passive listening with no movement; and stillness/silence (rest). These conditions suggest that one of the aims of the study was the dissection of auditory inputs contributing to movement output from a neural perspective. The authors findings that dance "…involves a complex combination of processes related to the patterning of bipedal motion and metric entrainment to musical rhythms" (ibid, p. 1165) reflects their hypothesis that dance is primarily concerned with auditory-motor integration; the linking of dance with the concept of entrainment has since become one of the defining ideas of what "dance" is in scientific literature and research studies on dance and in the related field of music. Entrainment refers to the synchronization of movement with an external beat or pulse; while this is an aspect of many dance forms, and an understanding of auditory-motor signals may be of benefit in considering how dance may be rehabilitative in some forms of disease, reducing dance to entrainment leaves out many aspects unrelated to rhythm, such as motor learning, artistry, and expression.

An fMRI study published the same year by Calvo-Merino et al., (2005) investigates another aspect of dance – how visual information (watching dance) relates to motor experience. Ten professional ballet dancers, 9 professional capoeira dancers and 10 non-expert control subjects watched and rated twelve 3-second video clips showing matched movements from each of these forms. The authors showed "the brain's response to seeing an action is influenced by the acquired motor skills of the observer" (p. 1245) and that the network of motor areas involved in the preparation and execution of action could also be activated through observation (ibid). They suggest these findings relate to the so-called "mirror neuron system", however, it is more likely that these activations reflect what Cross and others have termed the Action Observation Network (AON), which has shown greater involvement for experts viewing dance than non-dancers (Burzynska et al., 2017).

A "network" refers to the mapping of a configuration of anatomical circuits in the human brain, involving an estimated 10^{11} approximately 10^{15} connections (synapses) between them (Spoorns et al., 2005). Networks are comprised of "coherent physiological activity, such as phase-locked high-frequency electromagnetic oscillations, that can span…multiple spatially distinct brain regions" (Bullmore & Spoorns 2009). As neuronal activation involves both chemical and electrical signalling accompanied by biological changes such as blood oxygenation levels, neuroimaging techniques such as functional magnetic resonance imaging (fMRI) and high-density electroencephalography (EEG) can detect coherence (or co-activation) between brain areas at increasingly fine levels of detail. Using these tools, some researchers have proposed a "dance network", which includes areas related to music perception and motor control (Zatorre, Chen, & Penhune, 2007; Kung et al., 2013). This network has been investigated primarily in expert dancers; areas involved are the primary sensory cortices (Auditory, Visual, Somatosensory), the cerebellum, the superior temporal gyri, the dorsal premotor cortex, the supplemental motor area (SMA) and pre-SMA. Primary sensory cortices are involved in music perception, mental imagery, processing rhythmic patterns and melodies, and multisensory integration. The cerebellum maintains balance and posture and helps coordinate voluntary movements, motor learning, and aspects of cognitive function. The SMA is crucial for motor planning, sequencing movement (Makoshi et al., 2011; Thickbroom et al., 2000), and mediating beat perception (Merchant et al., 2015). Studies showing differences in the anatomical connections between these areas, reflected in white and grey matter volumes in expert dancers (Hanggi et al., 2010), may be indicative of neuroplastic changes or alterations in neural networks associated with dance such as those described by Bar & DeSouza (2016).

Dance is intensively multimodal; all dance forms engage top-down and bottom-up networks simultaneously, while requiring constant monitoring and integration of multisensory signals. Performing, learning, or practicing any dance involves, in the language of neuroscience, memory, visual-spatial awareness, kinesthetic and vestibular information, motor imagery, touch, imagination, timing, and musical/social elements, challenging the CNS in novel and stimulating ways. Beyond the known physiological benefits of exercise (Kramer & Colcombe 2003) dance adds high cognitive demands (Blasing et al., 2012), positive social interaction (McGill, Houston & Lee 2014), and the use of memory and learning in coordination with complex imagery, both motor (DiNota et al., 2017) and creative (Batson & Sentler 2017). As evidence accrues that participation in dance can be neuroprotective (Verghese et al., 2003), supporting motor (balance, walking speed, gait) and cognitive (memory, mood) improvements among experts and the elderly alike, there is need for a suitable neurobiological model to frame these findings and support future research.

Intimations of a research agenda assessing the role of neural networks in therapeutic dance is emerging in literature on Parkinson's Disease. Recent reviews examine the role of specific types of movement or exercise in affecting neural networks (Hackney et al., 2015; Petzinger ., 2013), while others discuss how rhythm and music modulate activity in networks of people with PD (Koshimori & Thaut 2018). Given that dance interventions involve both movement and music, it is reasonable to conclude research in these areas is more widely applicable to dance (Dhami et al., 2014). Research on experts also provides evidence for dance-related brain changes, including specific training-induced differences in functional connectivity. Buzynska et al., (2017) have shown altered connectivity of the action observation network (AON) and motor learning networks in expert dancers, while Li et al., (2015) found increased connectivity density in cortico-basal ganglia loops, between the middle cingulate cortex and the bilateral putamen, and between the precentral and postcentral gyri. Given the challenge presented by AD/PD and the potential impact, there is an urgent need for research from a multivariate and systems perspective into the functional benefits of dance. A recent review in the *Annals of the New York Academy of Sciences* aims at this by offering a "systematization of an emerging avenue of research: a neuro- and biobehavioural science of dance" (Christensen et al., 2017), which includes six functions of dance: the experience of flow, feeling emotions, imagery, communication, self-intimation, and social cohesion. While these are indeed aspects of dance, they do not offer neurobiological correlates for further investigation and limit effects to specific domains rather than providing a more widely adaptive model. A neurobiological perspective, including neural dynamics and network organisation, offers a clear mechanism for improved investigation into the effects of dance which can serve to contextualise previous findings across expert and clinical populations, while guiding the development of treatment strategies in the emerging field of dance for health. The following chapters represent several projects that explore various means by which aspects of the nervous system can be engaged and altered by participation in dance. In Chapter 2, I describe how aspects of motor learning might intersect with changes in multisensory networks, leading to adaptive plasticity. My primary hypothesis is that dance facilitates increased/diverse network engagement and flexible switching (variability), promoting resilience in the central nervous system (CNS) that may prevent or slow the progression of neurodegenerative diseases while supporting general well-being. This effect is due to the holistic and multisensory nature of dance, which simultaneously engages core networks by involving attention, the sensorimotor system, pleasure/reward, the emotional/limbic system, and auditory/visual/multisensory signals. Understanding the mechanisms by which networks are engaged through dance could have wide-ranging applications for research and practice in the emerging interdisciplinary field of dance and health. Chapter 3 presents a neurodevelopmental model across the lifespan that looks more specifically at how multisensory integration, timing deficits, and dual-tasking are challenged and stimulated by improvisational dance. Here I also suggest that body schema and limb mapping (kinesthesia!) as well as interactions between working memory and creativity play a role in dance programs for older adults facing memory loss and impairments. Chapter 4 delves into a more technical exploration of how we might further our understanding of adaptive plasticity through leveraging advances in neuroimaging that allow us to explore brain dynamics during movement through space, an approach that will allow investigation into learning-induced plasticity in the context of dance. Chapter 5 is an exploration of hypotheses pertaining to how dance fosters neuroplasticity, including how motor learning may reflect plasticity and network reorganisation, while possible differences in learning strategies between experts and novices can reflect embodied knowledge.

CHAPTER 2: Mechanisms of dance in the rehabilitation of neurodegenerative conditions

The following Chapter is a pre-print version of the following published article:

Barnstaple R, Hackney ME, Fontanesi C & DeSouza JFX. (2019). Mechanisms of dance in the rehabilitation of neurodegenerative conditions. *Brain, Body and Cognition* Vol 8, Issue 1. Nova Science Publishers. Editor-in-chief: Gerry Leisman. 17 – 28.

AUTHOR CONTRIBUTIONS

I conceived of, initiated, and led the panel discussion which preceded this paper at the *MOVEMENTIS: Brain, Body, and Cognition* conference held at Harvard Medical School in Boston, July 2018; I also proposed and directed the drafting of this paper. My contributions are within the introduction, conclusion, and "Mechanism three: Motor learning, multisensory networks, and plasticity".

Throughout history and in cultures around the world, dance has played a role in promoting health and preventing or changing the course of various maladies; however, it is only recently that research has attempted to identify and understand the *mechanisms* through which these putative benefits may occur. Dance interventions, most notably for Parkinson's disease and other disorders including Alzheimer's, multiple sclerosis, chronic pain, cerebral palsy, and mental health, have been the subject of numerous studies over the last decade, with observed benefits ranging from physical (balance, gait, reduction of motor symptoms) to cognitive (improved performance on memory and concentration tasks) and emotional improvements (mood scores and self-efficacy). Given the potential for dance to improve function and quality of life for people with progressive and pervasive disorders, while having few, if any, negative side-effects, dance seems to represent a promising area for new research as a holistic, integrative treatment model. This paper explores possible mechanisms for the efficacy of dance investigated in the authors' various research programs, each of which propose models for how dance may facilitate improvements in symptoms associated with neurodegenerative disorders.

Introduction

Dance is an intensively multimodal activity, engaging both top-down and bottom-up brain processes. Dance simultaneously involves memory, visual-spatial awareness, kinesthetic and vestibular information, motor imagery, touch, imagination, timing, and musical/social elements, challenging the central nervous system (CNS) in novel and stimulating ways. Dance practices combine the physiological benefits of exercise (PAGAC, 2008; Petzinger et al., 2013) with high cognitive demand (Bläsing et al., 2012), positive social interaction (McGill et al., 2014), and the use of memory and learning in coordination with complex imagery, both motor (DiNoto et al., 2017) and creative (Batson & Setler, 2017). Since 2007, various studies have focused on changes in motor performance after several weeks of dance training in patients with Parkinson's Disease (PD), showing increased balance (Hackney and Earhart., 2009, 2010; Duncan and Earhart, 2012; Volpe et al., 2013; Houston and McGill, 2013; Sharp and Hewitt, 2014), functional mobility (Volpe et al., 2013; de Natale et al., 2017), gait velocity (Hackney and Earhart., 2009, 2010; Duncan and Earhart, 2012; Sharp and Hewitt, 2014; de Natale et al., 2017; Kunkel et al., 2017), and decreased freezing of gait (Duncan and Earhart, 2012; Volpe et al., 2013). Further to this, additional studies have shown improvements in cognition (McKee & Hackney, 2013; Hashimoto et al., 2015; de Natale et al., 2017), mood (Hackney and Earhart, 2010; Hashimoto et al., 2015; Kunkel et al., 2017), quality of life (Heiberger et al., 2011; Volpe et al., 2013; Sharp and Hewitt, 2014; Westheimer et al., 2015), self-efficacy (Koch et al., 2016), participation and social-connectedness (Foster et al., 2013; Houston and McGill, 2013; Rocha et al, 2017).

Neuroimaging studies involving expert dancers have shown there are measurable biological changes associated with dance, that may be both neuroprotective and neurorehabilitative (Dhami, Moreno & DeSouza, 2015). From studies of regions involved in learning choreography (Olshansky et al., 2015; Bar & DeSouza, 2017, to looking at how long-term practice of dance may be reflected in structural and functional differences (Hanggi et al., 2010; Karpati et al., 2017) these investigations provide a basis, and potential explanatory framework for, the emerging trend of using dance in the treatment of neurodegenerative disorders, such as PD (Bearss, McDonald, Bar & DeSouza, 2017; http://dx.doi.org/10.1016/j.aimed.2017.02.002). Dance programs specifically for PD include those using adapted tango, Dance for Parkinson's (DfP - now offered in 24 countries around the world https://danceforparkinsons.org/), and initiatives by professional dance organisations such as Mark Morris Dance Center in New York, English National Ballet in London, Houston Ballet in Texas, Queensland Ballet in Australia, and Les Grands Ballets in Montreal, Canada. In Toronto, a pilot study conducted by members of our group, in conjunction with National Ballet School's Dancing with Parkinson's program, investigates the neurobiological correlates of improvements in motor and non-motor symptoms. Participants commonly report that their Parkinson's symptoms seem to diminish in conjunction with the dance classes, and these impressions are supported by results on behavioural tests (Bearss, Mcdonald, Bar, & DeSouza, 2017)

Why and how, precisely, can participation in dance produce these benefits, or at the very least, be linked to experiences reported by participants of reduction in the severity of symptoms? If we consider what is involved in the practice of dance, it becomes apparent that it is a highly complex activity, requiring mobilization and involvement of all our faculties – motion, cognition, attention, and affect. At the same time, the creative environment of a dance intervention can offer participants almost limitless ways of achieving various ends, producing novel strategies for movement and cultivating an atmosphere of exploration which is empowering and supportive. Dance programs challenge participants to attempt both unfamiliar and rehearsed movement combinations, hold multiple tasks in their memory, and attend to multisensory cues, all while aiming for an aesthetic output. Highly interoceptive while remaining attuned to the environment, dance is one of the most demanding, and rewarding, activities we can engage in. The next sections explore various possible mechanisms through which dance elicits improvements in neurological function, particularly where this has been compromised by neurodegeneration.

Mechanism one - Motor Control: internally/externally guided movements

PD is a neurodegenerative disorder which impairs motor, cognitive and autonomic function. As both alternative therapy and as an adjuvant to conventional approaches, several types of movement used in a rehabilitative context (e.g., partnered and solo dance, tandem biking, boxing and Tai Chi) have been shown to improve motor symptoms, lower limb control, and postural stability in people with PD. While these programs are gaining popularity, the neural mechanisms underlying motor improvements attained with these interventions, particularly partnered dance, are unclear. Studying motor control under task-specific contexts can help determine the mechanisms of rehabilitation effectiveness.

Both internally guided (IG) and externally guided (EG) movement strategies have evidence to support their use in rehabilitative programs. Yet, there appears to be a degree of differentiation in the neural substrates involved in IG vs. EG designs. Because of the potential task-specific benefits of rhythmic training within a rehabilitative context, here we consider the use of IG and EG movement strategies in a dance context.

Culturally, and historically, individuals have chosen to dance either the leader or follower role in partnered dance, usually as per gender role. In adapted tango, which has been shown to improve motor, cognitive and psychosocial function in people with PD (Hackney et al., 2007, Hackney & Earhart 2009, Hackney & Earhart 2010, McKee & Hackney 2013, McKay et al., 2016), participants use one of two motor training approaches: a) leading, consisting of primarily internally guiding (IG) motor plans, i.e., determining direction, timing and amplitude of steps and b) following, i.e., responding to external tactile guidance (EG). Because Adapted Tango (AT) dancing is improvisational, the step patterns are not choreographed, and therefore are not known beforehand by the follower and often determined in real-time by the leader from a large range of possible steps. As such, the communication via tactile cues is very important for the dance to happen. The leading role differs from the following role in that the neural networks underlying self-initiated IG movement and cued EG movement are distinct and subject to PD-specific pathology (Sen et al., Neuroscience 2010).

The benefits of externally guided movement are known. When following in partnered dance, participants focus on external cues, which may access alternative pathways that assist the basal ganglia. External cues access alternate neural pathways that are relatively intact in individuals with PD, including the cerebellar-thalamo-cortical (CTC) network involving the cerebellum, somatosensory cortex and ventral premotor areas (Sen et al., 2010). In healthy adults, external cueing recruits sensory response networks interposited with motor execution regions operating in a feedback and match to target mode. These include the cerebellum for titration of movement of the lower extremity and cortico-cerebellar pathways to facilitate conscious control. In PD, this CTC system is overly active due to bradykinesia and difficulty in matching response to target as appropriate.

While some evidence has demonstrated that external cues contribute to motor blocks (Bloem Hausdorff et al., Mov Disord 2004), overwhelming evidence demonstrates benefits of external cueing in behavioral studies, (Rocha et al., 2014). Audio-visual cueing strategies have improved stride length, and velocity in people with PD (Mak et al., 2013). Visual EG strategies have improved movement initiation (Jiang et al., 2006) and motor imagery in PD (Heremans et al., 2012). People with PD have faster reaction times to an auditory cue (Ballanger et al., 2006). However, it is unclear which types of cue (auditory, visual, attentional, somatosensory (tactile)) should be delivered and in what combinations.

Coordinating movement with external cues demands continuous state monitoring (postural, visual, positional, auditory, etc.) People with PD have increased pedaling rate under auditory and visual conditions, but the visual cue works only if patients are told to pay attention to the visual cue (Gallagher et al., 2016). People with PD may be able to benefit from attentional or auditory cues, but not necessarily from a combination (Gallagher et al., 2016, Lohnes & Earhart 2011). Freezing of gait can be prevented by auditory cueing during turning, but the cues must always be present to be effective (Spildooren et al., 2012). These findings indicate that further research is necessary to determine which type of cueing is most favorable, in what combinations and for whom.

Tactile cues have received far less attention than auditory or visual cues. Yet, tactile cues (like those conveyed from leader to follower in partnered dance) may be processed faster, with less attentional demand, and more efficiently than visual and auditory cueing. Fortunately, somatosensory integration mechanisms for prioritizing tactile and proprioceptive feedback have been shown to not be disrupted by PD (Rabin et al., 2010). Further, somatosensory cueing can supersede visual distractors (van Wegen et al., 2006). Using haptic speed cues from a moving handrail, people with PD walked faster by spontaneously (ie, without specific instruction) increasing stride length without altering cadence (Rabin et al., 2015. Tactile cues (delivered via a smartphone) have decreased timing errors during a dual task scenario (Ivkovic et al., 2016). Rhythmic somatosensory cues are helpful in increasing turning speed and may be more effective than visual cues (Nieuwboer et al., 2009). Interestingly, research has shown that humans can abstract metric structure (pattern of beats) from tactile rhythms as efficiently as from identical auditory patterns, (Brochard et al., 2008), which followers accomplish in AT, when receiving and responding to the step timing information conveyed with touch cues by the leader. As such, the efficacy for motor outcomes of responding to tactile cues in a partnered dance context should be assessed.

IG movement. Leading involves a movement strategy that demands increased cognitive focus on movement plans, i.e., actual step parameters related to direction, timing and magnitude. Leading requires planning, prioritizing, updating and goal selection, which are executive functions (Lezak et al., 2004). Proper completion of IG movements relies on efficient function of subcortical loops involving the basal ganglia (Alexander G et al., 1986). In healthy individuals, IG behaviors rely on the fact that many aspects of normal movement are automatically performed. However, automaticity is often impaired in individuals with PD. Because of the impairment in IG movement, leading may be especially challenging for people with PD and particularly for individuals with cognitive impairment. Due to dysfunction of the striato-thalamo-cortical (STC) circuit, people with PD have particular difficulty with self-initiated tasks (Wu, et al., 2011). IG movements require timing characteristics to drive motor output. This timing is largely driven by caudate and subcortical interaction with motor planning and execution regions. Given the disruption in dopaminergic communication within the basal ganglia, PD patients have extreme difficulty in maintaining internal timing patterns reliant on basal ganglia function. As a result, PD patients are more likely to engage EG-related circuits to assist in task execution. Indeed, over time, the cerebellar-thalamo-cortical (CTC) circuit is increasingly recruited to perform IG tasks (Sen et al., 2010). In healthy individuals, IG behaviors benefit from normal automaticity of movement. But even in early PD, the loss of dopamine in the dorsal putamen leads to diminished automaticity and requires continually increased cognitive control of motor function (Petzinger et al., 2013). This cognitive control used while planning and selecting movements (an IG strategy) in a motor rehabilitative setting, can provisionally address automaticity loss (Morris et al., 2009). For example, focusing on critical but simple movement aspects (e.g., longer steps, quicker movements) helps individuals with PD to achieve nearly normal speed and amplitude of movement (Fox et al., 2012). Compensatory neural areas are hypothesized to be the CTC as well as frontal areas, including the dorsal-lateral prefrontal cortex (Sen et al., 2010). The relationship between robust function of these compensatory areas and degeneration related to cognitive impairment is largely unknown.

In partnered dances such as AT, leaders use tactile cues to convey movement parameters, and must at least partially, engage in an IG strategy to do so. Ecologically speaking, human movement is rarely, if ever, purely IG or EG, whether in the case of daily activities or in rehabilitative settings. That said, knowledge regarding task specificity of each training will allow us to determine the generalizability of the training, i.e., does IG training translate into enhanced performance on IG tasks and EG tasks, or just IG tasks? Determining the beneficial and most effective qualities and outcomes of IG and EG motor training could inform dance rehabilitation particularly for largely intractable conditions like PD.

Mechanism Two: Aesthetic experience, emotion, and intrinsic networks

The combination of cognition and affect is a therapeutic factor inherent to dance which distinguishes it from other forms of movement such as sports, exercise, or rehabilitation. While there are clear relationships between cognition/affect and motor manifestations of Parkinson's Disease, this has been underappreciated by the scientific community in existing studies involving dance. Dance requires a bidirectional relationship between the cognitive-affective and the motor systems, in which both cognition and affect are expressed through movement, and conversely movement produces impressions that elicit cognitive and affective responses (Koch and Fuchs, 2011). In this (artistic) context, functional limitations are approached with curiosity and interest, rather than with apprehension and concern (Butt, 2017).

The manifestation of motor symptoms in PD has been investigated under both cognitive and emotional load, including postural control, balance, freezing of gait, and bradykinesia. Adkin and colleagues (2003) found that balance in patients with PD could be predicted by fear of falling, postural and gait measures. Importantly, postural and gait assessment alone could not equally predict balance performance. An interaction between postural control and fear of falling was confirmed by a later study (Franchignoni et al., 2005), which reported a positive correlation between PDQ-39 scores, expressing the overall health concerns of individuals with PD, and fear of falling scores, which similarly deal with a self-perceived functional status. Thus, the perception of dysfunction may be linked to self-referential processing including fear and anxiety, which in turn may actively contribute to the motor dysfunction (Martens et al., 2014).

Naugle and colleagues (2012), showed that exposure to emotional stimuli from different categories (i.e., erotica, happy people, mutilation, contamination, attack) had effects on both anticipatory postural adjustments and gait speed in people with PD. Further, gait initiation was evaluated in response to emotional stimuli in patients with or without freezing of gait (FOG) (Lagravinese et al., 2018). Participants were asked to step forward or backward in response to a pleasant or unpleasant visual stimulus, respectively. The task included conditions with different cognitive load (stimulus-response congruence or incongruence), as well as opposite affective valence (positive or negative). Longer reaction times and shorter steps were observed in response to incongruent/unpleasant condition (stepping forward, toward an unpleasant stimulus). Further, the study determined a correlation between reaction times induced by unpleasant stimuli and FOG frequency, underlying the effect of emotional load on step preparation and execution.

These results have been interpreted in relation to approach/avoidance behavior, which is understood as being directed toward life-sustaining, and away from life-threatening, stimuli. Importantly, the basal ganglia play a central role as gatekeepers in both approach motivation (Ikemoto et al., 2015) and avoidance responses (Hormigo et al., 2016). However, the effects of emotional states on motor performance may be mediated by both subcortical and cortical processes. Our current understanding of the functional organization of the brain has moved from assumptions of modularity and topographical distribution of faculties towards an approach that considers cognition as the result of dynamic interactions between brain regions that are intrinsically connected, and operate in large-scale networks (Bressler and Menon, 2010; Barret et al., 2013). Emotions, either manipulated experimentally or occurring spontaneously, can be conceptualized as mental events originated by intrinsic brain networks activities and their interactions (Barret et al., 2013).

Three core functional networks in the human brain have been implied in both higher cognition and emotional processing: the central executive (CEN), salience (SN) and default mode or "mentalizing" networks (DMN) (Bressler and Menon, 2010; Barret et al., 2013). The CEN and DMN appear to have antagonistic responses across different paradigms, as the CEN is involved in mediating attention to external stimuli (i.e., task-related attention and working memory), while the DMN is implicated in attention toward an "internal" world, as in self-related cognitive activity (e.g., autobiographical memory), future-oriented thinking, moral cognition and reasoning (Barret et al., 2013). Notably, the SN is thought to mediate the transition between the DMN and CEN activation, switching attentional resources from "internal" to "external" events, and vice versa (Barret et al., 2013).

In healthy individuals at rest, the DMN is more active than the SN and CEN, as both the SN and CEN appear to activate during cognitively demanding tasks, outlining a positive SN-CEN correlation that has been linked to higher working memory performance (Fang et al., 2016). Individuals with PD exhibit a decreased SN-CEN coupling compared to healthy subjects, with lower activation in limbic structures in the SN (i.e., right fronto-insular cortex), implicated in subjective feeling states and emotional self-awareness, and correlated with higher depression scores (Chang et al., 2018). Further, there is evidence of abnormally higher DMN connectivity in PD (Yao et al., 2014), which positively correlates with rumination tendencies in healthy young adults (Luo et al., 2016). Also, a decreased negative correlation between the DMN and both the CEN and SN (Bressler and Menon, 2010) has been described, and is linked to decreased cognitive performance in PD (e.g., executive functioning, psychomotor speed, and verbal memory) (Putcha et al., 2015; 2016). In summary, individuals with PD exhibit hypoactivity in the SN associated with depression (Chang et al., 2018), hyperactivity in the DMN linked to increased self-referential processing (Yao et al., 2014), and hypoactivity in the CEN, with reduced SN-DMN anti-correlation connected to cognitive dysfunction (Putcha et al., 2016).

Importantly, abnormalities in the SN have been also described in major depression, substance use, and anxiety disorders, as well as schizophrenia, eating disorders (Peters et al., 2016), and post-traumatic stress disorder (Yehuda et al., 2015). Peters and colleagues (2016) suggest that the restoration of SN circuits that involve both cortical and subcortical structures (i.e., striatum and thalamus) may be a key to address pathological feature in these disorders.

Here we speculate about a therapeutic mechanism that is inclusive of both the network abnormalities observed in PD and recently developed concepts in "neuro-aesthetics," a field that investigates experiences ranging from sensation and perception, to action, emotion, self-reflection, knowledge, context and meaning (Chatterjee & Vartanian, 2014). Interestingly, preliminary observations in this field have brought researchers to identify the role of the DMN in aesthetic experience, where the DMN becomes more active while the CEN is switched off (Vessel et al., 2012). This view supports a non-practical mode of experiencing art, in which perceived sensory information and self-referential mentation are strictly connected. However, Brincker (2015) argues that the asymmetric relationship between perceiver and perceived, perhaps experienced when visiting an art museum, is linked to a non-goal-directed attitude, which may not fully account for the sensorimotor experience of literally "being moved" by the artwork. Thus, Brincker outlines an alternative model, called "aesthetic stance," to account for the process of *becoming* a "beholder," which involves motor, contextual and dynamic responses, that overcome the limited view of an executive function halt.

A new framework for creative arts' therapeutic factors has been recently articulated in the context of both art making and experience (Koch, 2017). In the "embodied aesthetics" model (Koch, 2017), impression and expression, perception and action, are part of a dynamic interaction. The moving body and the environment play a central role in determining choices and actions aimed toward creating and, in the case of dance, *becoming* art objects or *extensions* (Koch & Fuchs, 2011). Both these models, *aesthetic stance* and *embodied aesthetics*, invite us to consider salience and emotional features, tightly linked to executive influence, during aesthetic experiences, which is arguably particularly relevant in performing arts, like dance.

In *Dance for PD* (https://danceforparkinsons.org/), a successful program offering classes to the PD community since 2001, participants are referred to as dancers, rather than patients, and are encouraged to move through poetic language, metaphors and evocative music (Butt, 2017). It is crucial to understand the role of the aesthetic experiences, such as moving one's arms "like a swan" (Butt, 2017), not only as passive observes, but as active agents. Here, we speculate that dance may benefit people with PD by activating the otherwise hypoactive SN, "normalizing" the SN activation (Peters et al., 2016), motivating participant to move by increasing activity in the SN, while restoring cognitive control through an strengthened SN-CEN coupling.

Mechanism Three - Motor learning, multisensory networks, and plasticity

Coordinating movement with music, expression, and other dancers requires the use of fine cognitive strategies (Blasing, 2012). The cognitive benefits reported in association with dance programs for PD (Houston & McGill, 2015; Westheimer et. al. 2015) are just one aspect of the growing body of literature investigating the cognitive effects of dance for an aging population (for others, see Alpert et al., 2009; Coubard et al., 2011; Kim et al., 2011; Kimura and Hozumi, 2012; Kattenstroth et al., 2010 & 2013; Hackney et al., 2015; Kshtriya et al. 2015). To better understand the mechanisms involved in these improvements, we turn to the study of expert-level dancers, and suggest how observed neurophysiological differences, such as altered distribution of white and grey matter (Hanggi, Koeneke, Bezzola, & Jancke, 2010; may be linked with the improved outcomes associated with dance interventions for clinical populations. Other differences between dancers and non-dancers include evidence that experts create different mental representations in long-term memory, related to phrasing of movement (Blasing, Tenenbaum & Schack, 2009); these differences may contribute to enhanced motor control and be linked to cognitive improvements. Studies involving experts demonstrate that dance can and does lead to increased/altered structural and functional connectivity, which has important implications for dance-based neurorehabilitation (2). From the study of differences and learning-induced plasticity in experts, we propose a model of how network dynamics may be involved in the improvement of symptoms associated with chronic and neurodegenerative conditions.

Our group (http://www.joeLAB.com) is developing methods to examine how multisensory signals, attention, and practiced motor preparation are used in learning and executing dance. In our fMRI studies, participants learn choreography in the studio and then *visualize* the learned movements while in an MRI accompanied by the associated music, at various stages of learning (before, early, performance, 8-months) (Bar & DeSouza 2016). When investigating questions related to movement, such as dance, subjects are often requested to imagine performing the movements, as it has been determined that visualization uses same/similar brain regions and processes as actual engagement in the activity (Cross, de Hamilton & Grafton, 2006).

To investigate the neural networks involved in learning a ballet choreography associated with a novel piece of music (DeSouza & Bar 2012; DOI: 10.1163/187847612X646677), subjects were scanned up to four times using fMRI over a period of 8 months (to date, we have now scanned 18 professional dancers from the National Ballet of Canada, 12 controls and 10 people with PD). All subjects visualized dancing to a one-minute piece of music during an 8-minute fMRI scan (for more details of the training and performances for the first of 3 cohorts, see Bar & DeSouza, 2016 DOI: 10.1371/journal.pone.0147731). Our published analyses used the general linear model ($p<0.05$, corrected for multiple comparisons) to probe learning across brain regions within supplementary motor area (SMA), auditory cortical regions and dorsal premotor (PMd) regions. Utilising a motor localizer to examine motor regions not activated during dance visualization at the very conservative threshold (Bonf $p<0.05$), we found the SMA region to fit most of the variance for the "inverted U-shape" for learning across time. We show that basal ganglia areas (caudate and putamen) do not show this "inverted U-shape" thus not changing across time (before, early, performance, 8-months). There was a significant increase of BOLD signal across the sessions in a network of brain regions which included bilateral auditory cortex and supplementary motor cortex (SMA) over the first three imaging sessions, but a noted reduction in these areas at the fourth session (34-weeks). This reduction in activity was not observed in basal ganglia (caudate nucleus). This increase and decrease in BOLD signal over learning suggests that as we learn a complex motor sequence in time to music, neuronal activity increases until the movements have been mastered; the activity then decreases by 34-weeks, possibly a result of overlearning and habit formation. Our findings may also highlight the unique role of basal ganglia regions in the learning of motor sequences. We propose these are the neural correlates of "muscle memory" and are examining this dataset using multimodal imaging via The Virtual Brain (http://www.thevirtualbrain.org/); our next aim is to use these functional regions of activation as seed regions to explore structural (DTI) and functional connectivity analysis in this dataset.

Another way we are probing network changes is through resting state electroencephalography (rsEEG). We have measured changes in individual alpha peak power (iAPP) and alpha peak frequency (iAPF) associated with various dance interventions, correlating these with other measures related to quality of life, mental well-being, cognitive function, and motor behavior. We originally used this method to investigate dance for PD, and saw changes pre/post one 50-minute class, including motor (improvements on BERG and TUG) (Levkov et al., 2014) and eventually lower depression scores on GDS (unpublished) and on mood (Simone et al., 2016). We are now extending this model to look at other complex conditions such as chronic pain and depression, which are often comorbid (Barnstaple and DeSouza, 2018). There is growing understanding of the role of maladaptive plasticity in these conditions (Liu et al., 2017), and an emphasis on the role of brain networks (Kucyi & Davis, 2017). Irregular activation and deactivation of the salience and default mode networks is associated with chronic pain (Kucyi & Davis, 2015) and depression (Brakowski, 2017).

Connectomics is an emerging field in which continuous changes in communication among neural networks are considered crucial to cognition. According to the "Dynamic Pain Connectome" model (Kucyi and Davis, 2016) differences in network dynamics characterise pain states; research using EEG and fMRI have shown that the experience of pain engages multiple brain networks which are widely distributed. This model contradicts traditional thinking that pain is constituted by one to one mapping or functions in terms of a simple input/output model. For example, activation and deactivation, respectively, of the SN and DMN cortical areas may reflect the natural tendency of pain to capture attention (Kucyi and Davis, 2015). Crucially the DMN shows less activation during pain-associated states as opposed to no-pain or mind-wandering from pain conditions. As stated in the previous section, the DMN is involved in background activity associated with self- and other-awareness, self-reflection and mind-wandering, and interacts with other networks, such as the CEN, in unique ways that may be related to creativity (Beaty et al., 2015), further suggesting its potential importance in network changes associated with dance.

Neuroimaging studies using fMRI have shown the importance of interregional coordination of activity across networks in chronic pain (Kucyi and Davis, 2015). High temporal variability reflects the dynamic reconfiguration of a brain region into distinct functional modules at different times, which may be indicative of brain flexibility and adaptability**.** In general, primary and unimodal sensory-motor cortices demonstrate low temporal variability, while transmodal areas, including heteromodal association areas and limbic system, demonstrate high variability. Importantly, regions with highest variability such as hippocampus/parahippocampus, inferior and middle temporal gyrus, olfactory gyrus and caudate nucleus are all related to learning; this principle suggests how brain changes related to learning dance may be crucial in altering pain-related conditions. In current and ongoing pilot study, we are collecting rsEEG with people experiencing chronic pain who participate in a weekly 1-hour dance program. Data are analysed using the same data analysis pipeline previously implemented in our group's investigation of dance for people with PD (Levkov et al., 2014). A trend of overall increased alpha synchrony/power in the post-class condition has been detected, with a localized decrease in alpha power over SMA. As alpha power reflects an average of all network activity, the observed global strengthening and increased symmetry may reflect increased variability in network dynamics. Our next step will be to look more closely at specific networks involved in shifting the processing patterns associated with chronic pain states.

Conclusion

Dance is pleasurable, rewarding, challenging, and provides access to unique learning strategies related to neuroplasticity and rehabilitation. In comparison with exercise, dance provides a more enriched environment, offers a greater degree of cognitive challenge, and shows a very high rate of adherence - people have reported that attending a dance is an inherently rewarding experience (Kshtriya et al., 2015; Barnstaple R, 2015; Rabinovich, 2012; Bar and DeSouza, 2016). The inclusion of sensory elements such as touch, affective experiences, and social aspects and may contribute to this enjoyment, and enhance the potential for the acquisition of new, flexible, and adaptive ways of moving in an environment. The use of imagery, memory, narrative, and imagination lift people out of current circumstances and transport them to a realm where they can experience themselves, as bodies, in an entirely new way. While there is a growing body of literature addressing the potential for dance to improve symptoms in neurodegenerative conditions (Bearss, McDonald, Bar and DeSouza, 2017), the integrative, multimodal aspects of dance, which may include improvisational elements (Batson et al., 2016; Olshansky et al., 2014), present various research challenges. The models for mechanisms of effectiveness in dance proposed here are associated with different research methods and strategies; we have presented these as possible avenues for further investigation in the promising new field of research of the benefits associated with dance. Our findings already suggest that there are many more potential mechanisms to explore; we hope more researchers from diverse fields will consider applying their expertise in this exciting area of study.

The following chapter is a preprint of the following manuscript, currently under revision:

Barnstaple R, Hugenschmidt CE, Soriano CT (2020, submitted, under revision). Dance me to the end of love: Enabling cognitively impaired older adults through improvisational dance and movement. *Dancing Across the Lifespan: Age related issues in Dance*. Forthcoming. Editors Doug Risner, Karen Schupp, Pam Musil; Palgrave Macmillan.

Chapter 3: Dance me to the end of love: Enabling cognitively impaired older adults through improvisational dance and movement

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AUTHOR CONTRIBUTIONS

I drafted this manuscript with input from CH on developmental neuroscience and from CS on aspects of the IMPROVment method. This chapter is one output of a 3-month fellowship spent with this team at Wake Forest University, February – April 2019, where I trained in their method and became an interventionist on the study described in this paper, a role I continue to play.

ABSTRACT

Development does not end with childhood; although the early years of life are identified with clear challenges that attend growing and changing bodies and their capacities, aging brings us once again into a shifting relationship with our physicality and its attributes. Growing older can be marked by rapid adjustments to changing conditions as our bodies face challenges associated with illness, loss of mobility, and the need for additional care. There is growing evidence that the skills required to meet these challenges can be learned and facilitated through engaging in a physical and creative practice such as dance, and a growing number of dance-based programs directed towards older adults have emerged globally in recent years. This chapter introduces recent research on the benefits of dance for older adults, particularly those faced with neurodegenerative conditions such as Parkinson's (PD) and Alzheimer's (AD) diseases. We outline how this research aligns with developmental and neuroscience models to suggest how and why dance may support healthy adaptations in aging and possibly slow or counteract neurodegeneration. Finally, we provide an example of a dance-based program developed in conjunction with research that addresses the needs of older adults living with PD and AD - IMPROVment® is an improvisational movement method that aims to support brain and body health throughout the lifespan, and is the subject of a clinical trial investigating the effects of dance on cognition, mobility, affect, and brain dynamics.

Introduction

"Which creature has one voice and yet becomes four-footed and two-footed and three-footed?" ...Oedipus solved the riddle by answering: "Man—who crawls on all fours as a baby, then walks on two feet as an adult, and then uses a walking stick in old age".[10] Apollodorus, Library Apollod. 3.5.8

Capacity for movement accompanies us from prenatal development to the end of our lives. The skills we develop as we learn our bodies, and our worlds, follow us and determine how we experience agency, ability, and the affordances of physical and social environments we inhabit. The later years of life, characterized by both the challenges and rewards of aging, often recentre movement learning in our attention as we are forced to reckon daily with what our bodies can and cannot do. Dance has an important role to play in facilitating motor exploration and supporting creative choices when confronted with impairments related to disease.

As the age of our global population increases, complex diseases such as Parkinson's (PD) and Alzheimer's (AD) disease affect a growing number of individuals, along with their families. These diseases are *neurodegenerative*, meaning they manifest in a broad and wide-ranging array of symptoms affecting movement, cognition, mood, and the capacity to carry out tasks associated with daily living. At this point, there is no cure for these conditions. However, a growing body of research suggests that dance-based programs may be effective in slowing disease progression (DeSouza & Bearss 2018), diminishing symptoms (Bearss et al., 2017; Ciantar et al., 2018) and improving quality of life for those with a diagnosis (Westheimer et al., 2015). While determining the mechanisms underlying these outcomes is a hot topic in current research, the environment provided by dance - which includes motor learning, creative, artistic, and social engagement, and scalable challenges to memory, balance, and coordination - clearly provides a fertile ground for the development of strategies that may assist in coping with physical and mental challenges associated with aging, while supporting brain and body health throughout the lifespan.

Neuroscience of aging and development

Development is a continuous process that proceeds right up until death; changes are a normal feature of aging, in brains and bodies. Neuroscience dogma formerly conceptualized the developmental remodeling of the brain as a rapid gain in synapses and white matter connections while young, followed by continued growth that was increasingly tempered by pruning – loss of synaptic connections - and refinement of synapses as development continued to adulthood. After adulthood was reached, pruning became the dominant process until death. While this overall trajectory of growth and pruning remains, it is now well established that older brains retain the capacity for *plasticity*: the ability to create and strengthen synapses and white matter connections. This plasticity not only results in typical age-related variation; it allows experiences to direct neural changes throughout life. Put another way, you *can* teach an old brain new tricks.

What to expect when you're expecting (to get older)

While the aging brain retains plasticity, at the same time, it is acting within a different physiological milieu than a younger brain; our bodies and response times change with age, and what may be second-nature or automatized when we are younger can become increasingly difficult with age; for instance, walking entails ongoing challenges to balance and attention, requiring additional cognitive and motor resources as we grow older (Van Swearingen & Studenski 2014, review). The growing field of *geroscience* has begun elucidating body-wide changes that occur with aging, including cellular factors that circulate throughout the body (Kennedy, 2014). These may help explain why the risk factors for many chronic diseases increase with age, and other common age-related changes observed across species. Researchers and clinicians in the field of aging are beginning to recognise that dance can be a powerful tool for maintaining integrated brain and body health throughout the lifespan. For dancers and dance educators working with older adults, it is important to recognise that normal aging is accompanied by changes in *body composition, sensory function*, and *cognitive processes*.

Within the body, normal aging is accompanied by patterned changes in *body composition* that include reduced muscle mass and changes in muscle composition, as well as increased fat mass and redistribution of fat away from the limbs and into the torso as well as more intramuscular fat. Personal lifestyle choices, health history, and genetics cause meaningful variability in the onset and trajectory of these changes. However, even extremely fit older adults, like marathon runners or dancers, will have changes in their body composition that ultimately reduce their strength and endurance from their own peak. We all experience changes in the way our bodies feel from day-to-day, and these are exacerbated with aging-related changes. Adapting to our “new” older bodies requires skill and practice; for instance, a flight of stairs that we may have tackled two steps at a time when we were younger may represent ever-increasing challenges to endurance, strength, and balance as we age.

Sensory perception and higher-order *cognitive processes* like attention are also not static experiences in the brain; both evolve over the lifespan of the individual. It is known that even in healthy aging, people experience diminished sensory acuity in all five senses and have subtle alterations in cognitive processes such as attention and memory. Some sensory changes that occur with age take place at the sensory organ - common examples include thickening of the lens of the eye, loss of hair cells in the ear, and some loss of peripheral somatosensory nerve fibers, most commonly in distal regions like the feet and hands. There are also well-documented changes in sensory transduction within the nervous system (Cerf-Ducastel and Murphy 2003; Cienkowski and Carney 2002; Enrietto et al., 1999; Mordi and Ciuffreda 2004; Ostroff et al., 2003; Shmolesky et al., 2000). The speed and fidelity of neural transmission may be altered even in healthy aging through subtle changes in *myelin*, the fatty coating that helps speed neural transmission in large fibers, and the distribution of channels for ions and neurotransmitters that transmit the neural signal at the *synapse*, the juncture where two neurons meet. While the changes themselves are small, when combined with changes in the fidelity of sensory organs, they can lead to a widening of the *temporal and spatial windows of sensory perception*. This means there is a potentially greater gap between events happening in our environment, and our perception of those events.

In addition to changes in each individual sense, older adults experience changes in how their senses interact, a phenomenon referred to as *multisensory integration*. Aging-related changes in the discrimination and detection thresholds mentioned above – the temporal and spatial windows of sensory perception - can alter interactions between the senses (Timiras 2003, review). The overall effects of changes in multisensory interaction in older adults suggest that older adults tend to integrate sensory information coming from different sensory channels to a greater extant than younger adults (Mozolic et al., 2011). Sometimes this can be helpful; for instance, by using visual information from the lips to augment dampened auditory input when someone is speaking. In other situations, though, such as eating in a noisy restaurant, competing attention for multisensory signals can lead to distraction. Dance is inherently a multisensory experience involving visual cues from the instructor, other dancers, and your own body, synced with auditory inputs from music and the instructor, and somatosensory and kinaesthetic and vestibular input from the body as it moves. Thus, dance can leverage the strengths of older adults; however, for these strengths to be optimized, dance instructors have to be mindful of elements within a class that can lead to multisensory distraction, such as the volume of music or other "noisy" elements in the environment. This awareness is particularly pertinent when interacting with older adults with neurological disease, who can be more sensitive to intense stimulation and overwhelmed by background visual or auditory stimulation.

Two main theories of cognitive aging that are well-supported in the literature are those of *generalized slowing* and *inhibitory deficits*. These theories are relevant in the context of dancing with older adults, as they may inform how a teacher chooses to lead a class, along with offering explanations as to why dance can be beneficial in supporting healthy aging. One of the most reliable findings about age-related changes in cognitive processing is that reaction times are *slowed* in a variety of tasks, and this slowing becomes more pronounced with increasing task complexity (Birren et al., 1962; Brinley et al., 1965; Cerella 1985, 1994; Feldman and Reger 1967; Nebes 1978; Pierson and Montoye 1958; Salthouse 1988). The theory of generalized slowing suggests that overall slower responses cause deficits in cognitive performance, as older adults cannot complete cognitive processes in the necessary amount of time, cognitive processes may take so long that information is no longer available when it is needed, and timing between processes is negatively impacted (Salthouse 1996). Another established theory of cognitive aging relevant for dance is that older adults show deficits in inhibitory control that can impact cognitive processes like attention (Hasher and Zacks 1988). Inhibition is important, as it allows us to identify and respond to salient aspects of our environment or circumstances by supressing or "turning down the volume" on less important stimuli. There is evidence that older adults process more unattended background information than younger adults from behavioral studies (Healey et al., 2008; Rowe et al., 2006; Yang and Hasher 2007) and EEG experiments (Alain and Woods 1999; Gaeta et al., 2001; Kok 2000; Tales 2002).

Colloquially, when we talk about 'multitasking' we often suggest this to mean the ability to accomplish multiple tasks simultaneously; the reality is, however, that multitasking involves rapidly shifting *between* the different tasks we are trying to accomplish. Rapid processing speed and effective inhibition are both critical components of being able to rapidly shift between two different tasks, also called a dual task condition or task switching. Dancing, particularly receiving dance instruction in a group, is inherently a dual or multitasking situation. A person is asked to simultaneously attend to and coordinate multiple body parts, often with a partner and/or while attending to instructions and feedback, while also listening to music and incorporating responses to changes in timing and attending to the space around them. They must monitor both their external environment (where they are with reference to the room, their dance partner or dance group, and the instructor) and their internal perceptions (how their body feels and relationships between their body parts as they move). The dance studio provides an excellent environment to strengthen dual tasking skills which may be neuroprotective (Verghese et al., 2003) and offer additional balance and gait benefits (Verghese 2006). A recent perspective article from a group researching neuroprotection and cognitive enhancement in Magdeburg, Germany, proposed dance as an example of motor-cognitive training with incorporated cognitive tasks, hypothesising that this type of dual-tasking may be of greater benefit in stabilizing neuroplasticity effects for older adults with neurodegenerative conditions (Herold et al., 2018).

Movement is extremely important throughout development for many reasons. In older age, movement is vital in promoting health and plasticity. Aerobic exercise is now widely accepted as beneficial throughout the body and throughout the lifespan, as it increases cardiorespiratory fitness, improves vascular health, reduces insulin resistance, and improves mood. In healthy older adults, exercise appears to help maintain brain volumes and white matter health, maintain or improve cognition, and increases levels of brain-derived neurotrophic factor (BDNF). Neurotrophic factors are like 'brain vitamins' that the body self-generates. The effects of exercise are so powerful that they are beginning to be viewed as potentially a means to create a more neuroplastic environment (Cotman & Berchtold 2002), and dance has been proposed as an example of the kind of "enriched environment" shown in animal studies to be associated with neurogenesis (the creation of new neurons) and the preservation synaptic plasticity (Dhami, Moreno & DeSouza 2015). It is interesting to note that in 2002, dance was identified as the only leisure time physical activity associated with decreased risk of dementia in an observational study (Verghese et al., 2003). Recent research on the effects of dance is beginning to show that this finding might not be a fluke. Emerging evidence shows that dance may improve white matter health and increase BDNF levels comparably or even more than aerobic exercise.

In a study specifically investigating the effects of dance versus exercise for older adults, Rehfeld et al., (2018) saw an increase in BDNF that was significant for the dance group, but not for participants in the exercise group. They also found a significant increase in *grey matter volume* – where the cell bodies of neurons in the brain are - in the left precentral gyrus, an area used in the control of voluntary motor functions, along with a significant gray matter volume increase in the right parahippocampal gyrus, a node of the limbic system involved in coding memory, after 18 months (Muller et al., 2017). White matter, the tissue associated with myelin fibres connecting neurons to one another and essential to signal transmission in the brain, has also been shown to be preserved or increased by participation in dance. A recent study randomly assigned healthy older adults into dance, walking, walking plus nutrition, and active control groups (Burzynsky et al., 2017), and found that within the dance group white matter integrity increased, specifically in the fornix, known to play a key role in memory formation. All other groups saw a decline in white matter over the six-month period of the study, an outcome that would be considered normal when studying an aging population. Changes in volume of white matter in the fornix have been linked to the progression from mild cognitive impairment to clinical Alzheimer's (Mielke, 2012), so we can appreciate the importance of these findings when considering the value and content of programs designed to support adults living with the challenges of neurodegenerative conditions.

Dance interventions supporting older adults living with motor and cognitive impairments

Investing in resources that make movement available throughout the lifespan can be an important aspect of the work we are called on to do as dance artists. Many innovative programs have been created to help encourage older adults, even those who never identified as dancers, to *move*, creatively and expressively, in dance studios, clinics, care homes, and more recently in the wake of Covid-19, in our own homes. Movement can belong to everyone if the invitation to move is prompted in a way that creates that opportunity. Improvisation is an important element to include in any dance class focused on older adults, whether it is within a relatively structured social or ballroom dance form, or more central to the focus of the dance practice, as in gaga or creative dance. As discussed in further detail below, both the ethos of improvisation, which stresses non-judgment, and the practice of encouraging multiple correct movement options make dance movement more accessible to people experiencing physical limitations. Improvisational methods may be especially well-suited for people experiencing memory loss because 1) they do not rely heavily on memory; 2) they can be seamlessly adapted to include students sitting, standing, or moving around the room; 3) they are cognitively challenging; and 4) they foster a social, playful atmosphere.

Improvisation also appears to engage brain networks in a different way than many outcome-oriented tasks. The number of functional magnetic resonance studies focused on improvisation are limited, and there are currently none specifically focused on improvisation in dance. However, improvisation appears to lead to temporary widespread decreased neural activity in regions that are often used for planning and effortful thought. This observation is potentially important because of how the brain compensates for aging-related changes in movement. As mentioned above, dual tasking is a cognitive process that is affected negatively by age. For older adults, walking is slowed to a greater degree by talking than is the case for younger adults (Holzter, 2011). Interestingly, one reason for this slowing may be that the brain uses areas usually reserved for effortful tasks while performing tasks that are automatic in younger adults, such as walking (Ibid). Improvisation during dance may create a situation where the brain is turning down the activity in regions devoted to effortful thought while it is moving, promoting the use of less effortful and more automatic brain regions. Improvisation also encourages divergent thinking - the generation of a multiplicity of answers to a question. As we get older, we may need to find new ways to perform old tasks, and improvisation in a dance studio is an explicit way to practice being adaptive and flexible in our responses.

Engaging in creative exploration of movement through improvisational dance opens a window into just how vast, complex and meaningful our movements can be. Movement lives and operates on an ever-expanding scale with flexible and relative parameters that shift as we become more attuned and skilled in our movement choices. From a developmental perspective, all movement - large or small, complex or simple – can be considered successful, whether we are looking at acquiring motor skills in early years or older adults reckoning with diseases that often manifest in what are termed “motor impairments”. In Parkinson’s Disease (PD), these include challenges associated with balance, increased risk of falls, and difficulty with motor initiation; the ability to control and execute a desired movement. While Alzheimer’s Disease (AD) and Mild Cognitive Impairment (MCI – an early stage of dementia) are generally considered to affect cognition and memory, they also come with attendant motor disturbances affecting, gait, balance, and coordination. Many people do not know that people with dementia are at increased risk for hospitalization from falls relative to their non-demented peers (Harvey et al., 2016; van Doorn et al., 2003; Tchalla et al., 2014). The increased risk of falls in people with dementia is likely due to well-documented changes in balance and gait (Bruce-Keller et al., 2012; McGough et al., 2013; Szczepanska-Gieracha 2016). Changes in gait speed are common (Bruce-Keller et al., 2012; Cedervall et al., 2014; Dodge et al., 2012) and can precede dementia onset (Burrachio et al., 2016; Fitzpatrick et al., 2007; Kuo et al., 2007; Nadkarni et al., 2013; Verghese et al., 2014; Verghese et al., 2013; Watson et al., 2010). Changes in gait are detectable early in the course of AD and decline further as dementia advances (Verghese et al., 2007; Ohman et al., 2016).

An inclusive approach that supports any number of movement choices is at the core of many practices that have emerged to support the needs of older adults, such as Dance for PD (https://danceforparkinsons.org/). Founded in New York city by the Mark Morris dance group and the Brooklyn Parkinson's Group, Dance for PD is now in over 25 countries. Their website states that "participants are empowered to explore movement and music in ways that are refreshing, enjoyable, stimulating and creative", and classes are designed to nourish movement creatively, rather than proscribe a specific movement or way to move. Dance for PD is an eminent example of what the International Association for Dance Medicine Science defines as "dance for health": "…holistic, evidence-based alternatives for the individual to manage and adapt to physical, mental and social health challenges. In Dance for Health sessions, trained teaching artists engage people as dancers, rather than patients, in joyful, interactive, artistic activity" (IADMS Dance for Health committee Facebook post, August 7th 2020).

How can we best mobilise our skills as teaching artists to support the diverse needs of aging adults, especially those living with additional challenges from PD, AD, and MCI? Below are some examples from a dance practice engaged in and studied by our team, grounded in the use of improvisational prompts in a supportive environment that encourage movement exploration, creativity and awareness in older adults with neurodegenerative conditions.

Key elements for a dance program aligned with neurodevelopmental theories

Movement prompts – building a score

Improvisational practices rely on prompts to elicit a range of responses rather than a fixed step or pre-determined choreography. Prompts can be part of an elaborate score, just as in music, with layered, or scaffolded cues providing means for engaging with this score and bringing it to life; a well-known example of this is Nancy Stark Smith's *Underscore*, a long-form dance improvisation structure that supports a three to four hour movement practice by providing a map to movement possibilities that are discovered and created through its performance. A score is a way of marking movement in time, with purpose and intention. The delivery of a prompt and its expected lifespan or response can also be short-lived. In our work with older adults, particularly those living with MCI, AD and PD, this is intentional; responses are shared, experienced briefly, and then a new prompt is executed. A typical score might sound like this:

> Make angular shapes with your left arm. *(Five seconds later…)* Now pause and hold that shape. Create this shape with your right arm as you relax your left. Resume the angular shape dance with your right arm, while making a very different angular dance from the one you did on your left. Now have both arms join in an angular dance and interrupt these angular shapes with unique moments of pause that are interesting to you. *(Total time: 30 seconds).*

A score builds and develops through themes, variations, and the body's ability to manipulate the way it uses time, effort, embodied shapes, or the way it takes up space in the room and attention. It is playful yet purposeful; creatively abundant, yet focused and specific. As the adults participating in programs such as ours may be dealing with both cognitive and motor challenges, we set out to create an environment that is supportive while promoting optimal conditions for creativity and exploration as the class, and material to respond to, builds over time. We do this through both temporal and spatial arrangements of the class – for instance, by starting seated in a circle with chairs; this provides an orienting environment conducive to creating community and connection between participants, and the non-hierarchical structure promotes turn-taking and empowerment, as there is no "ideal model" presented as a movement choice – all movements are valued and welcomed. The class moves to standing behind chairs or moves to a ballet barre if it is available, providing opportunities to work on balance and take what the determine to be "reasonable risks" while remaining within reach of a support. Finally, participants are invited to ambulate in space, sometimes as individuals, sometimes with partners, and sometimes in smaller groups, usually with the accompaniment and support of music. With the support of a flexible score, participants are invited to move, move again, and stay curious as they move for an hour.

<u>Multi-tasking</u>

The use of rapid-fire improvisational prompts encourages the practice of multi-tasking. Movement prompts offer a sliding scale of cognitively challenging directives and can build with complexity as class goes on. For instance, movement might become multi-layered in a seated prompt like "Go for a swim. Now change your swimming stroke. Now keep that stroke going with your right arm and do a different stroke with the other arm". These prompts provide an environment that supports the practice of multitasking through encouraging quick changes of attention from one task to another, or focussing on maintaining a response to an earlier prompt while adding detail or other actions from a new prompt.

Prompts are intended to elicit both cognitive and physical creativity. For example, participants may be asked to cross the midline of the body in as many ways as possible. Additional reminders within this prompt are: "Don't forget about the space beside you, or beneath you." Another "prompt within a prompt" may be to simply "Stay curious with what you are doing" or "Don't get bored". Movement, like any language, needs clarifying, encouragement, purpose, and direction. Improvisational movements need additional reminders to keep explorations fresh, new, and nimble. A prompt may evoke a movement response as brief as 2 seconds, or as long as 2 minutes; duration may also be used as a creative partner in developing a dance.

<u>Body composition, memory and attention:</u>

Attention can be systematically directed towards specific body parts, that are then involved in initiating or leading a dance. This helps with formation and updating of "body schema" – our model of where parts of our body are in space, associated with motor control and performance. Body schema in neuroscience refers to a set of fronto-parietal networks that integrate information originating from regions of the body and external space in a way which is functionally relevant to specific actions performed by different body parts (Morasso et al., 2015). This is important for older populations; as outlined earlier, body composition changes with age, and particularly in the context of neurodegeneration, motor control can be severely challenged. When movement prompts are systematically introduced, using the geography of the body to orient explorations, it can facilitate building a clearer model of the body in space while becoming curious about new ways of moving, expanding the movement repertoire. A head and neck dance might be followed by a shoulder dance, elbow dance, wrist dance, and finger dance; the naming of body parts while flexibly manipulating both the body part and attention allows for new movement ideas to emerge. Individual, body-part dances will be unique to every person's own head and neck, shoulder, elbow, wrist and fingers. Multiple body parts can be introduced as a system as class progresses – our ability to hold something in "working memory", an aspect of attention, changes as we age, and can be challenged by neurodegeneration and aging (see Chai, Hamid & Abdullah, 2018 for a recent review). There is also evidence that skills related to this form of attention can be practiced and improved, including pilot data from ongoing research in our group (Hering et al., 2017; see next section on our research). Creating a body-system by "chunking" several body parts together invites an exploratory journey where an understanding of how it might be capable of responding to movement tasks is sought.

Timing, inclusion, and scalability:

As mentioned earlier in this chapter, timing within the nervous system changes with age and generalized slowing in the face of more complex tasks, such as complex movements in dance, is common. Moving quickly through movement prompts, using simple language, provides opportunities to practice responding to increasingly complex tasks eliciting creativity. Reminding people that every movement is a choice, followed by another choice, enhances agency (Batson, Hugenschmidt & Soriano, 2016). Moving on after trying out a movement idea encourages continual exploration, and for adults with cognitive impairments, moving quickly facilitates responding to a prompt. In the context of our classes, we have seen that when a movement cue is difficult to process cognitively or challenging to translate physically, moving swiftly to the next prompt promotes success, experimentation, and a focus on ability.

Regardless of physical ability or movement background, dance-based programs offered for older adults in association with a diagnosed condition should be accessible to everyone in attendance. If someone needs to try an exercise in a chair instead of standing, or at the stationary ballet barre instead of locomoting across the floor with the rest of the class, or with a walker or other support, these adaptations are completely fine, and can be welcomed as aspects of our ongoing creativity and ability to adapt to the changing circumstances or our bodies and worlds. All dance-based explorations can remain scalable with room for interpretation based on every person's individual ability and availability for movement during every session.

Following these basic principles contributes to the creation of a class environment that fosters creativity and skillfulness, essential aspects of dance, and key ingredients of living fully.

INSET: testimonial from long-time community class participant, Carol Roan.

> What if you could release your body, your mind, and your spirit from the limitations you've come to believe in? What if you could dance your way into a new, more vibrant self?
>
> The community dance class can open that door for you. Whatever physical diagnosis you've been given, your body can respond to the rhythms you feel and hear. Whatever your age, you can improvise little dances. Maybe a dance for your right elbow, maybe a dance for your left ankle. Sometimes a drummer or a violinist will be there to inspire, and to be inspired by, your improvisations; sometimes you'll dance to recorded music, blues or country, jazz or classical.
>
> You'll begin each class in your chair, part of a dancing circle. The leader will call out suggestions, such as "Let your fingers be raindrops down your arms." How you respond to any suggestion is up to you—maybe your fingers will want to be a rainstorm that day, maybe a gentle spring shower. You'll be guided through bends —"Enjoy the fold"—and twists, angular movements and circular movements and poses, until you've re-acquainted yourself with every part of your body, from skin to spine, and explored all the space you can reach from your chair.
>
> The energy in the studio builds until you're on your feet, finding more space to explore—first from the safety of the barre, then claiming the entire room, sometimes dancing alone, sometimes improvising with a partner.
>
> That energy will stay with you long after you've gathered your shoes and your jacket, and moved on into your day with more confidence, more flexibility and grace than you thought possible when you woke up that morning. - Carol Roan

<u>How do we measure success?</u>

There are many ways of measuring success in a class designed for older adults living with cognitive impairments. Like prompts, success can be scaled, adapted, and interpreted in numerous ways. For some participants, simply showing up for class can be considered an achievement – the task of getting to a studio, particularly for people living with a motor or cognitive disorder, is no small feat. Another aspect of success that is difficult to measure, but should not be understated, are the ways people in classes such as these inspire one another. While some of our former class participants have specifically expressed their appreciation for the cognitive challenges that class provides, others have noted increases in self-confidence, body awareness, and self efficacy. In addition, community building and ongoing social support are facilitated through classes developed to support older adults living with a diagnosis, which can be otherwise scary and isolating. Neuropsychiatric symptoms like apathy and depression, linked to PD and MCI, have been shown to decrease in our pilot study (Barnstaple et al., in prep). The next section outlines new research associated with our specific practice, and the physical, social, and psychological impacts of an improvisational dance-based movement intervention.

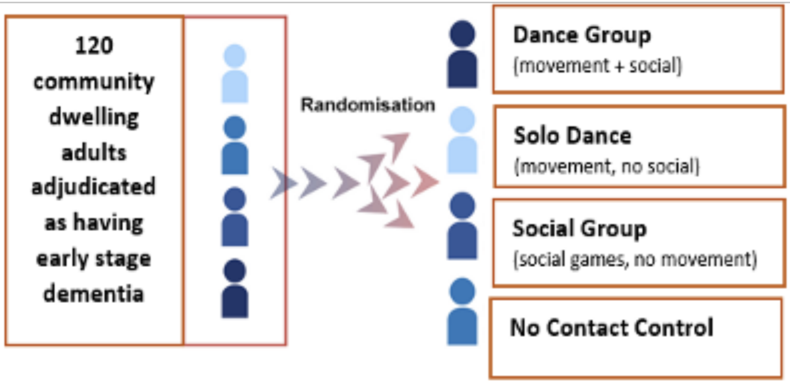
Research Study: IMPROVment

As the potential for dance to counter the effects of neurodegeneration is increasingly evident, researchers are starting to ask questions with the aim of determining exactly *how* dance-based programs support adults living with cognitive impairments – what are the key ingredients or "active components" that might reduce symptoms or improve quality of life? Does it matter whether movements are choreographed or improvised, performed alone or in a group, learned from an instructor, led by a partner, or copied from a computer? How important is creativity? Over the last 8 years, faculty and students from Wake Forest University and Wake Forest School of Medicine, with community and academic partners, have initiated an investigation into the potential for a dance-based improvisational movement practice to improve outcomes for people living with neurodegenerative diseases and their care partners. The initial phase of this study, funded by Blue Cross Blue Shield of NC (BCBS), resulted in pilot data that led to a multi-year randomized control trial (RCT) funded by the National Institute for Health (NIH), currently underway. This ground breaking study assesses changes in motor, cognitive, and neuropsychiatric domains along with measures of neural connectivity in a community of participants living with Mild Cognitive Impairment (MCI) and their care partners as they engage in a specific improvisational protocol developed specifically for older adults facing PD/AD, referred to as IMPROVment®. Research questions include determining if, how, and to what extent a program such as this could address fall-risk, a secondary symptom of MCI, change networks in the brain, and impact social and affective dimensions of MCI.

To determine the separate and combined effects of movement and social dimensions, the study features a 2x2 factorial design; this means essentially that subjects (the person with disease – PWD, and their care partner - CP) are randomized to one of three groups where improvisation, as a mechanism, is assessed for its impact through different domains, with the exception of the control group, who do not participate in the intervention:

1) Group 1- the dance group. Hypothesised physical, social and cognitive challenges are provided through traditional IMPROVment® classes delivered in group format
2) Group 2 - the solo dancer: IMPROVment® classes are delivered through audio prompts only to solitary individuals who participate without group influence or video instruction from the instructor
3) Group 3 - the social group: Participants play structured and modified party games that require improvisation (such as Balderdash, Apples to Apples, Mad libs) in group format.
4) Group 4 - the no contact control group.

This graph shows the randomization of the four groups as well as the number of subjects required to qualify as a fully powered randomized control trial. At the time of writing, 7 waves of participants had completed the study with approximately 50% participation of the necessary recruited subjects. With the onset of Covid-19, the study team has pivoted to explore online delivery of the intervention and is currently in a new phase of data collection for feasibility.



This NIH-funded study builds on an initial pilot study, which recruited couples (dyads) of older adults with MCI (n=10) and their caregivers (n=10). The first 5 dyads recruited were assigned to our improvised dance intervention meeting twice weekly for eight weeks at a local dance studio. The last 5 dyads were assigned to the control group. Physical function, mindfulness, and quality of life were measured before and after the intervention. Resting state brain images were collected before and after the intervention as well. We hypothesized that the dance class, which provided both movement and social engagement opportunities, would increase balance, decrease mood and behavioral symptoms like apathy and depression, and increase quality of life in our study population. We measured these changes through fMRI brain scans and self-reporting surveys. While the data from that study is still under review, below are some of the quality of life changes from an included survey, with significant responses to questions about both physical and psychosocial changes highlighted in red.

	Not at all/ A little (1-2)	Somewhat (3)	A lot/ Very much (4-5)
1. After class, do you feel more energized or motivated?	10%	30%	60%
2. Do you think of class acitvities and/or practice them outside of class?	30%	20%	50%
3. Do you feel you have increased your skills as a mover?	10%	30%	60%
4. Has your empathy for fellow class members increased?	-	-	100%
5. Do you feel this class has increased your flexibility?	10%	30%	60%
6. Has this class improved your problem solving skills?	10%	30%	60%
7. Has your balance improved after taking this class?	11%	-	88%
8. Has your creativity improved after taking this class?	10%	-	90%
9. Before you began taking this class, did you feel concern about falling or losing your balance?	70%	-	30%
10. Before you began taking this class, did you ever change your behavior to lower the risk of falling or losing your balance?	50%	20%	30%
11. Do you feel that taking this class increased your confidence in your ability to keep your balance?	10%	20%	70%
12. Has your fear of falling or losing your balance changed after taking this class?	20%	20%	60%
13. Would you take this class again?	-	10%	90%
14. Did you enjoy taking this class with your spouse?	-	-	100%
15. Has this class changed your relationship with your spouse?	22%	55%	22%

Understanding how improvisational movement can contribute to “movement confidence” is key question for both the researchers on our team and the movement interventionists. 100% of the participants in the pilot acknowledged an increased confidence in their ability to keep their balance, suggesting there are crucial aspects of the dance program that may contribute to this outcome. Better understanding the specifics of how a program such as this can impact physical, social, emotional, and cognitive dimensions along with quality of life for adults living with neurodegenerative conditions is of prime interest in our ongoing research, as questions such as these may influence health outcomes and choices people make when receiving a diagnosis such as PD/AD/MCI. In addition, clarifying the specific contributions of choices made in the design and delivery of the dance program will help in the creation of optimal programs in the future.

Conclusion – Don’t stop dancing!

Growing older can be a time of great resilience and discovery. People who have not yet aged may have negative views of aging that result from stereotypes, fear, or observations of increased risk of disease. However, while depression can accompany aging and may be an early sign of some age-related neurological diseases, older adults on the whole report being happier than younger adults. Some of these fears stem from imagining that aging is attended by an unavoidable loss of independence and skill. Dance, and especially improvisational movement, reinforce autonomy and embracing the changes that come with new developmental stages. Highlighting creativity, adaptation, and providing people with an environment to “practice change” is a powerful contribution that can be made by dancers and dance educators through programs that support older adults as they live through the challenges and rewards of later years.

The following Chapter is the peer-reviewed preprint version of the following published article:

Barnstaple R, Protzak J, DeSouza JFX, Gramann K. (2020). Mobile Brain/body Imaging (MoBI) in dance: A dynamic transdisciplinary field for applied research. *European Journal of Neuroscience, special issue – Time to move: Brain dynamics underlying natural action and cognition* which has been published in final form at https://onlinelibrary.wiley.com/doi/abs/10.1111/ejn.14866

Chapter 4: Mobile Brain/body Imaging (MoBI) in dance: A dynamic transdisciplinary field for applied research

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AUTHOR CONTRIBUTIONS

I conceived and designed the original study and collected all data with input from KG and JFXD; I also proposed, conceived of, prepared and drafted this paper. Data analysis plan and pipeline were contributed to by JP, with input from KG and JFXD.

Keywords: Mobile EEG, motor learning, neuroplasticity, dance therapy

Abstract

Neuroscience of dance is an emerging field with important applications related to health and well-being, as dance has shown potential to foster adaptive neuroplasticity and is increasingly popular as a therapeutic activity or adjunct therapy for people living with conditions such as Parkinson's and Alzheimer's Diseases. However, the multimodal nature of dance presents challenges to researchers aiming to identify mechanisms involved when dance is used to combat neurodegeneration or support healthy aging. Requiring simultaneous engagement of motor and cognitive domains, dancing includes coordination of systems involved in timing, memory, and spatial learning. Studies on dance to this point rely primarily on assessments of brain dynamics and structure through pre/post tests or studies on expertise, as traditional brain imaging modalities restrict participant movement to avoid movement-related artifacts. In this paper, we describe the process of designing and implementing a study that uses Mobile Brain/body Imaging (MoBI) to investigate real-time changes in brain dynamics and behaviour during the process of learning and performing a novel dance choreography. We show the potential for new insights to emerge from the coordinated collection of movement and brain-based data, and the implications of these in an emerging field whose medium is motion.

Mobile Brain/body Imaging (MoBI) in dance:
A dynamic transdisciplinary field for applied research

Complex, situated human behaviours challenge scientific methods and measure; they resist reduction, and efforts to isolate variables can destroy ecological validity along with the authenticity of the phenomenon in question. Techniques such as Mobile Brain/Body Imaging (MoBI; Makeig et al., 2009; Gramann et al., 2011; 2014) are opening new frontiers in the study of complex naturalistic behaviour, a prime example of which is in the field of dance. Ranging in expression from spontaneous head-bopping along with a beat to forms as diverse and demanding as ballet, butoh, folk, Krump, and tango, dance marries creativity with technique and has been observed in every known human culture (Pusnick, 2010)[10]. Dance has performative, cultural, and individual dimensions, and traditional associations with health and healing, a role currently being revived in emerging therapeutic applications of dance for aging, development, and the treatment of conditions such as Parkinson's, Alzheimer's, and Cerebral Palsy.

Neuroscience of dance investigates how engagement in and with dance affects brain structure and function, as dance provides unique access to processes involved in action and perception, visuo-motor transformations, learning and expertise. Dance involves the production of complex motor sequences synchronized with external cues such as music, other people and the environment or studio, and probing these processes can provide rich data related to broader questions in neuroscience such as how memory, timing, and spatial orientation are realized by

[10] And in some animals, particularly birds, elephants, and cetaceans; a recent study featuring Snowball the dancing cockatoo is notable for its observance of spontaneity and diversity of movement in a bird (Keehn et al., 2019).

the brain. As a rehabilitative activity, dance demonstrates potential to slow neurodegeneration (DeSouza & Bearss, 2018) and foster neuroplasticity (Burzynska et al., 2018; Rehfeld et al., 2018). Over the past four decades, scientific interest in dance has steadily increased, with the number of published articles involving "dance" increasing exponentially over last two decades from 34 articles in 1979 to 648 last year, while those addressing "dance and health" have increased over the same period from 3 articles to 140 in 2019 (PubMed, accessed 2020-02-20).

While some studies have shown anatomical differences that seem attributable to dance (Hänggi et al., 2010; Burzynska et al., 2017; Karpati et al., 2017) and others have demonstrated that dance learning is associated with functional differences suggestive of learning dependent plasticity (Bar & DeSouza, 2016), this research has been conducted while people were not in the process of actually moving. Considering the centrality of motion in dance, there is huge potential for new insights to emerge from investigation of mechanisms involved as people move in real time and space. What we know so far in the field of dance neuroscience has been inferred from comparative studies involving expert versus novice groups (Burzynska et al., 2017) or contrasting types of expertise as in dancers and musicians (Karpati et al., 2017; Giacosa et al., 2018; Poikonen et al., 2018); there have also been anatomical studies that look at structural differences associated with training, mental rehearsal or imagery, and reactions to video stimuli. Most of these study designs relied on traditional neuroimaging methods, which restrict movement in order to limit motion artifacts, rather than emerging from the best means of studying the phenomena if technical constraints were not a factor. Previous investigation of changes in EEG (electroencephalography) related to dance therapy with specific conditions such as schizophrenia (Margariti et al., 2012; Ventoura et al., 2015), traumatic brain injury (Kullberg-Turtiainen et al., 2019), and seniors (Zildou et al., 2018), have analysed resting state pre/post conditions using a variety of analysis methods and shown measurable changes in frequency bands that may be associated with alterations in network engagement or organisation. Cruz-Garza et al., (2014) used MoBI to investigate the neural basis of expressive human movements, such as those found in dance, and found it feasible to identify and distinguish these by decoding EEG signals post-hoc, demonstrating an identifiable change in neural signals associated with different manners of moving.

The field of scientific research on dance has shown clear potential to elucidate how brain structure and function may be shaped by expertise and the biological effects of dancing. However, the question of how specific elements of dance may be involved in these processes has been difficult to isolate. Mobile brain imaging technologies have opened up this field of inquiry, and in the next section we describe the process of designing and implementing an experimental protocol using MoBI to investigate the brain dynamics underlying dance as an archetype of a common but highly complex human activity. Dance is composed of rich dynamic blending of motor and cognitive processes as well as neural dynamics, interacting to allow synchronization with externally provided rhythms and taking place in a specific spatial and social context. The following protocol demonstrates how MoBI studies can provide significant insights into the processes involved in learning, performing, imagining and watching dance.

The Dance Project

Our goal was to investigate the potential for using MoBI to investigate real-time changes in brain dynamics and behaviour during the process of learning and performing a novel dance choreography. The project built on studies from members of our group that showed dance-based learning over 8-months produced blood-oxygen-level-dependent (BOLD) signal changes in supplementary motor areas (SMA) as measured with functional magnetic resonance imaging (fMRI; Bar & DeSouza, 2016) and resting state alpha power increases in frontal cortex post-dance in people with Parkinson's disease compared to controls (Levkov et al., 2014; DeSouza & Bearss, 2018). The process of investigation in this new project was distinctly transdisciplinary, drawing on our individual areas of expertise in dance and movement studies, systems and cognitive neuroscience, and mobile imaging techniques.

Dance is a complex phenomenon; isolating variables can be extremely demanding if not impossible – almost every instance of dancing includes music or rhythm, social and cultural elements, specific uses of space and time that must be imitated, intuited, or invented, and relational dynamics between dancers, dancer and teacher, or dancer and audience. We made a concerted effort to constrain or identify the influence of these elements and focus our study on the process of learning a dance over time, a question that seemed ideal for MoBI. To achieve this, we created five brief (~30-second) choreographies comprised of elements common to many dance forms, but not belonging to any one in particular, and used novel synth-generated music to reduce affective responses associated with music. The entire experiment's data collection lasted approximately one hour, and behaviour and data recording were continuous throughout.

Sessions were recorded at the Berlin Mobile Brain/Body Imaging lab (BeMoBIL), with a dedicated 150 m^2 lab space allowing for acquisition of motion capture data synchronized with wireless mobile EEG (ActiCap; 128 electrodes, Brain Products, Gilching, Germany). Movements were captured using the HTC Lighthouse tracking system (High Tech Computer Corporation, Taoyuan City, Taiwan) with five trackers each on the dancer and five on the teacher (left/right wrist, left/right ankle, and centre of back). EEG data, motion capturing data and event marker data were synchronized streamed and recorded using the open source software Lab Streaming Layer (Kothe, 2014).

The session was organised to resemble, to the greatest extent possible, an actual dance class or dance intervention (Bearss et al., 2017). Trials included warm-up, watching the choreography to be learned and an alternate choreography that would not be learned, to allow for eventual comparison pre/post of EEG for known versus novel movement sequences (VIDEO, 2 times each), watching live performances of the choreography to be learned (WATCH, 6 times), moving with the teacher (LEARN 3 to 20 times, as per each participant's requirements to reach our criterion of 80% accuracy in repeating the movement sequence, assessed by a trained rater), imagining performing from a first-person perspective (IMAGINE, 6 times), and finally performing the choreography in space (PERFORM, 6 times). We also collected pre/post resting EEG data from the participant while standing, with eyes open and eyes closed (rsEEG) and included a pre/post activity of walking a predetermined path through the space twice, plus an additional trial of imagining walking this path pre and post dance learning phases (Space Walk; see **Figure 1** for an overview of all phases of the study design)**.** The Space Walk had a dual function of providing additional warm-up and cool-down time along with the opportunity to collect data relating to spatial coding as the subject explored the room before and after learning the dance sequence.

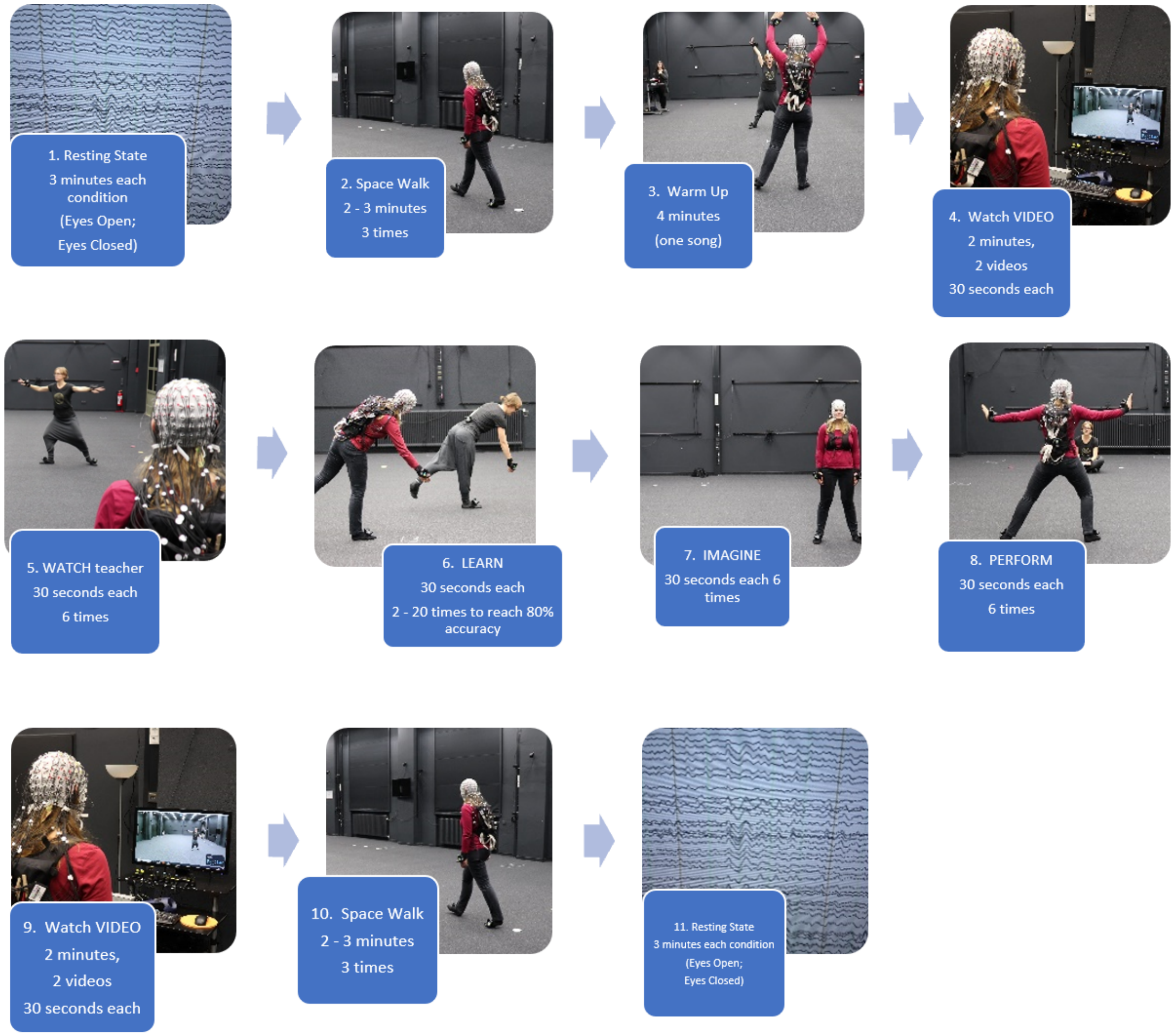

FIGURE 1 Elements of study design and time required for each segment

We hypothesised that brain-based changes observed in previous imaging studies of dance could result specifically from challenges involved in learning and reproducing motor sequences; dance, as opposed to most forms of exercise, is spatially oriented and temporally cued. For this reason, we developed choreographies designed to address this question, while remaining within the technical constraints of conducting scientific research in a lab environment. The choreographies used in this protocol were both 30 seconds in length and included elements of extension, one-support balance, weight shift, rotation, and coordinated movements of arms and legs **(Figure 2).** We limited movements with high acceleration or jerk that could lead to movement of the electrodes or cable sway but included other potentially challenging aspects of dance that were still accessible to a novice participant, such as fast rotation. We used novel synth-generated music that was rated for valence pre/post the experiment and was unfamiliar to all subjects and thus lacking in emotional associations.

Figure 2: LEARN trial with the teacher; subject is wearing an ActiCap with 128 active electrodes (Brain Products); both subject and teacher are wearing 5 Vive Motion capture pucks (HTC Vive): 2 each on wrists and ankles, and 1 on the centre of the back. Pictures courtesy Benjamin Paulisch.

Study Design

Implementing MoBI with dance offers unique means of investigating different aspects of movement and brain dynamics, along with their combined range and interactions. The power of the protocol developed here is in the vast possibilities for analysis and comparison of different kinds of data, including movement, EEG, combined motion and EEG data, participant experiences, video materials, and correlations or interactions between these. In Figure 1, we gave an overview of elements in our experimental design; the entire protocol was completed in approximately one hour per subject, and allowed for continuous collection of EEG, motion capture, video, participant feedback through open-ended questionnaires and brief interviews, and experimenter observation. The following section will provide an overview of how the data will be processed and provides examples for concrete analyses that will be conducted to test specific hypotheses associated with the Dance Project.

Data Recordings and Analyses

For the EEG-recordings, a 128-channel mobile EEG System (ActiCap; Brain Products, Gilching, Germany) with a customized channel arrangement was used, including two frontal electrodes relocated under the eyes for the recording of ocular activity. In this project, we decided against the use of additional neck electrodes to record dorsal neck muscle activity, as extensive data analyses provided evidence that the use of such neck electrodes increases noise and reduces the number of brain sources that can be identified (Klug & Gramann, submitted to this special issue), Data preprocessing was conducted using Matlab 2019b (MATLAB, The MathWorks Inc., Natick, MA, USA) and standard routines from the EEGLAB plugin (Delorme & Makeig, 2004) as well as customized scripts based on the BeMoBIL pipeline (Klug, 2019). Further details can be found in publications with similar processing approaches (e.g., Gramann et al., 2019) that are based on channel cleaning and interpolation, filtering and downsampling as well as subsequent independent component analysis using adaptive mixture independent component analysis (AMICA; Palmer, Makeig, Kreutz-Delgado & Rao, 2008). The advantages of independent component analysis (ICA) and subsequent equivalent dipole modelling of independent components (ICs) are the dissociation of brain and non-brain activity such as eye movement and muscle activity that contribute to the volume conducted signals recorded at the sensor level (particularly for studies that include active movement, as in the Dance Project), an increased signal to noise ratio for data analyses when moving from the sensor to the source space, as well as additional neuroanatomical information gained from the approximation of the cortical origins of the recorded data. Independent components across participants will be clustered using repetitive k-means clustering (Gramann et al., 2018) to allow for group level analyses of cortical activity associated with different aspects of dance.

Motion capture data were recorded as x,y,z as well as quaternion orientations of the ten rigid bodies from each Vive tracker and preprocessed using adapted functions from the MoBILab toolbox (Ojeda, Bigdely-Shamlo, & Makeig, 2014). Processing steps included low pass filtering, transformation from quaternion data to Euler angles and computation of the first two derivates of position data for subsequent analyses of velocity and acceleration of each rigid body.

For answering our main research questions on real-time changes in brain dynamics and behaviour during the process of learning and performing dance, we intend to analyse sensor level as well as source level data. Here, we give a brief overview of some of our primary hypotheses and examples of planned analysis.

Dance impacts resting state alpha activity. Previous studies from our group showed modulation of baseline resting state alpha power in frontal cortex after participation in a one-hour dance class (Levkov et al., 2014; Barnstaple & DeSouza, 2018). The MoBI protocol developed for this study allows for robust comparison of baseline alpha and any frequency domains pre/post observing and learning a specific dance, with minimal interference as subjects remain in the same experimental environment for the duration of the study. To this end, EEG spectral power in the alpha (8-12 Hz) frequency band will be compared for pre and post resting state sessions for the sensor level using frontal electrodes as well as the source level identifying clusters of ICs located in or near the lateral and central prefrontal cortical regions. Aiming at a replication of previous results indicating changes in the frequency domain (Levkov et al., 2014), tonic power spectrum density estimates will be calculated for each three minute pre/post-dance resting state condition over a frontal electrode cluster (e.g. using Welch's method on windows of 256 points length, zero padded to 512 points) and statistically assessed by a repeated measure analysis of variance (ANOVA) with factors resting state condition (eyes open, eyes closed) and timing (pre-, post-dance).

Dance and Spatial Orienting. Along with resting-state data (rsEEG) including eyes open and eyes closed conditions, we collected pre/post sessions of walking a predetermined path through the space, along with *imagining* performing this same task once the path was learned (Space Walk). This activity provided subjects with a simple warm-up and cool-down exercise, along with furnishing a rich data set pertaining to spatial coding before and after participants interact with the environment in the spatially constrained and oriented activity of learning specific movements comprising the dance. Assuming that participants learn the boundaries of the space they move through while learning the choreography, we will specifically contrast event-related spectral perturbations in the theta, alpha, and beta frequency bands of clusters of ICs with their centroid located in or near the restrosplenial complex as well as the parietal cortex. These areas are implicated in computing heading representations and transformation of egocentric sensory information sampled from the senses into an allocentric representation of space stored in the medial temporal cortex (Vann et al., 2009; Gramann et al., 2010; Lin et al., 2012).

Dance Impacts Action Representation. Pre/post VIDEO segments provide further EEG data for analysis related to viewing unfamiliar versus familiar motor sequences, and the possibility of detecting error signals in the case of the learned dance. The advantage of analysing EEG data during watching of video segments lies in the direct comparison of videos presenting an unfamiliar motor sequence *before* participants learn the choreography, with identical videos *after* dance learning; at this point, one of the videos now shows a choreography that has been directly experienced while the second video shows a still unknown motor sequence. We will focus the analyses again on the frequency domain at the sensor as well as source level, concentrating on electrodes and clusters with their centroids located in or near motor cortices to investigate mu desynchronization using repeated measures ANOVA with factors of timing (pre dance, post dance) and familiarity (learned vs. novel choreography).

Perception of Live versus Recorded Dance. The protocol also includes watching video versus live performances of a dance, in the same setting and with the same dancer, potentially addressing gaps in the literature as to any difference between these kinds of viewing. Given the growing research on the effects of watching dance (Cross et al., 2009; Di Nota et al., 2017), and the dependency on video material in standard neuroimaging protocols using fMRI or EEG, this data has potential to be highly informative. Increasing ecological validity of stimulus material leads to higher variance in eye movements and information selected for attentive processing (Dorr et al., 2010). Here, we will focus on analysing specific periods of the choreography that contain easy versus difficult movements to investigate whether video material and live performed movements elicit comparable activations in motor and parietal brain regions of observers. Frequency domain parameters can be further investigated using regression models with subsequent performance of participants during the learning stage (number of necessary repetitions) as the dependent variable of frequency modulations during viewing of the choreography.

Dance Imagery versus Dance Performance. Our design also provides data on processes involved in imagining performing the dance, which can be directly compared with watching, learning, and performing it in space; we can probe for changes in the frequency domain during learning and performance by comparing across trials as the subject becomes more proficient and comfortable in reproducing the movements of the dance. The study design also includes data where there are no physical movements, and behaviour remains the same while the task changes, as in the trials of imaging the dance, imagining the space walk, and resting state.

Movement and Brain Synchronization. The inclusion of five Vive trackers each on the subject and teacher provides ample opportunities for various kinds of motion analysis from the behavioural data. We can mathematically model speed, acceleration, and path for each tracker or sets of trackers; we can look at the level of synchronisation between the subject and teacher over LEARN trials; we can correlate movement dynamics from LEARN to PERFORM; we can compare the movement trajectories of different subjects with different learning curves and between subjects and teacher; and we can model evolution or decay in reproducing the motor sequence across trials. This data is further enriched by the inclusion of video recordings, along with teacher/experimenter observation and phenomenological data as subjects are asked to rate the extent to which they felt as though they are “fully dancing” on each PERFORM trial and reflect on any changes. Motion data, correlated in this way with experiential aspects of dancing, can enhance understanding of essential elements that may have been overlooked in existing clinical and scientific research, by providing “hard data” on aspects of dance experience that can be difficult to quantify but may be of high importance. Additionally, investigating frequency domain changes, specifically in frontal cingulate and motor cortex, and correlating these with the level of movement synchrony between teacher and participants over learning trials (and across participants) may provide insights into action-perception coupling, and how variations in performance impact brain dynamics and vice versa.

Moving Beyond Entrainment. Previous research on dance for therapeutic purposes has focussed on elements such as entrainment (Thaut 2015; Grahn & Brett, 2007), suggesting that beat-locking or moving to regular rhythmic stimulation is the primary driver of physiological changes. While entrainment certainly appears to contribute to observed effects, focussing solely on rhythmic stimulation is not an ecologically valid representation of dance, which can involve “groove” (off-beat or syncopated rhythms), live music, and a significant degree of personal expression. Entrainment is an easy target for researchers, as it is relatively simple to assess, even in a stationary set-up. An analysis of more complex aspects of dance, correlated with participants’ percepts while they are dancing, may provide new evidence for the importance/inclusion of aspects such as dynamic movement, imagery, sequence learning, and individual motor expression in therapeutic dance programs. Neuroimaging data can be added to the analysis of motion capture to increase our understanding of systems and strategies mobilised through dance, in the fullest realisation of the potential inherent in MoBI: combined motion capture (MoCap) and EEG Analysis (Gehrke et al., 2018; Gehrke et al., 2019).

General Analyses Perspectives. Studies have shown long-term plasticity associated with dance learning in elderly populations (Zildou et al., 2018, Muller et al., 2017). MoBI offers the possibility for us to investigate short-term plasticity within a brief window of time, by correlating behavioural/motion data associated with learning and changes in cortical network organisation through network analysis (for an example of this in a longitudinal EEG study, see Zildou et al., 2018). We can also look at more granular distinctions in the frequency domain and assess their dependence on movement, motor preparation, or learning processes such as trial and error. There is potential to investigate how changes in frequency bands may depend on velocity profiles of specific trackers, or the level of challenge involved in producing the movement. And finally, in relation to existing literature on entrainment, we can assess the degree of synchronization between frequency domains, the music, and actual movements in space and time.

This study demonstrates the huge potential for insights to emerge by bringing new technologies such as MoBI into an ecologically valid setting. Dance is one of the oldest aspects of human culture, depicted in ancient cave drawings[11] and early manuscripts; MoBI offers the possibility of investigating brain dynamics involved in this highly complex activity, how these change over time, and how aspects of expertise and learning can affect and be affected by the acquisition of new movement repertoire including artistic elements and dynamic range. Extending current scientific literature on dance, our study includes pre/post data enriched by the additional insight available from data collected *while* people are dancing - learning, making mistakes, and improving performance - in each trial. All participants (n= 19) reached our target criteria of 80% or higher accuracy in reproducing the movement sequence within 20 LEARN trials; however, previous dance training was associated with significantly fewer trials required to reach criteria. In just one of the many possible avenues of exploration within this rich data set, we can investigate whether experience is associated with different learning strategies that

[11] Figures in the Magura Cave drawings and Bhimbekta rock shelters from the Mesolithic period are interpreted as dancing; for an overview of the cultural history of dance, see Royce 1977.

correlate with alternate brain activation patterns, an important distinction as therapeutic applications of dance most often involve non-expert populations who may benefit from the degree of novelty or difficulty involved in dance-based learning. We can probe this by comparing trials of watching live and recorded performances of the choreography with data collected during each subject's process of performing the dance, correlating this analysis with previous dance experience.

Applications

Dancing is intensively multimodal and complex, involving physical and cognitive coordination, uniting motor control with memory, attention, and artistry. This may explain why dance provides a potent environment for health and healing; it mobilises all our faculties while challenging us on many levels. As the age of our global population increases, conditions such as Parkinson's and Alzheimer's affect a growing number of individuals, along with their families and loved ones. Neurodegenerative ailments manifest in a broad and wide-ranging array of symptoms affecting movement, mood, cognition, and the capacity to carry out tasks associated with daily living. At this point, there is no cure for either of these conditions; however, there is a growing body of research suggesting that dance-based programs and therapies can be effective in slowing disease progression (DeSouza & Bearss, 2018; Ciantar et al., 2018). Collecting EEG can provide putative biomarkers needed for early neurodegenerative detection once a ground truth of the neural mechanisms can be discovered and then implemented with diagnostics and modelling (Leger et al., 2020).

The multimodal nature of dance is both a challenge and an opportunity – while it presents obstacles and a high level of complexity for researchers, as it is hard to exclude or isolate variables, there is a rich opportunity to develop novel study designs using new technologies.

Using MoBI in dance research is a perfect example of how emerging capacity in neuroimaging can be leveraged to explore some of the most vital and humanistic aspects of our experience. The impact of this research is far-reaching and important; as dance is increasingly brought into the therapeutic realm, a clearer understanding of why and how elements involved in dance contribute to resilience or recovery will allow for the development of evidence-based programs with the highest possible efficacy. Dance has long played a central role in societies that recognise holistic dimensions of health; the integrity of a phenomena such as dance, with its power to move us and support quality of life, invites the engagement of our best faculties and tools. This study only scratches the surface of what is possible in using MoBI with dance; we hope other researchers will join us in the pursuit of knowledge that dissolves the boundaries of arts and sciences, revealing new dimensions of the human condition.

ABBREVIATIONS

AMICA - adaptive mixture independent component analysis
ANOVA - analysis of variance
BeMoBIL- Berlin Mobile Brain/Body Imaging lab
BOLD signal - blood-oxygen-level-dependent signal
EEG - electroencephalography
fMRI - functional magnetic resonance imaging
HTC - High Tech Computer Corporation
IC - independent component
ICA - independent component analysis
MoBI – Mobile Brain/Body Imaging
MoCap - motion capture   SMA - supplementary motor area

This Manuscript is to be published in the Springer series *«Advances in Experimental Medicine and Biology»* (keynote at GeNeDis 2020 conference on 10.10.2020).

Chapter five: Multinetwork motor learning as a model for dance in neurorehabilitation

With expanding applications for dance in geriatrics, including rehabilitation and pre-habilitation of neurodegenerative conditions, an examination of how elements of dance may contribute to specific improvements is called for. "Dance" can refer to a vast number of diverse practices; dancing may be rehearsed or improvised; performed with or without music, and may include a wide variety of styles of movement and accompanying sounds; some dances, such as tango and other social dance forms, rely on a partner, while many folk and cultural forms are group-based; artistic and contemporary forms may consist of solo exploration/performance. Research on the impacts of dance-based interventions has spanned many different varieties of dance, and often the specifics of dance interventions involved are sparsely provided. This paper offers a brief review of elements central to many dance forms that may contribute to rehabilitation, suggesting hypotheses for future research and training examining how elements of dance may foster adaptive plasticity. Primary topics include motor learning, motor control, spatial navigation, action observation and entrainment, with suggested future considerations as to how imagery, imagination, multisensory integration, mental rehearsal, volitional movement, and creativity in non-expert populations contribute to a multinetwork toolbox that may be neuroprotective.

For the emerging field of neurobiological research on dance to achieve maximal effectiveness in applications for aging, it is essential to identify core elements and competencies activated or trained through dance participation, particularly for novices. While dance has commonalities with therapeutic modalities involving exercise and music, the practice of learning and participating in dance combines and extends these (Dhami et al., 2015; Kshtriya et al., 2015). Dance forms require the production and (often) repetition of motor sequences, which may be triggered by music, spatial location(s), or interactions with other dancers; dance also requires advanced motor training, as movements can be highly nuanced and expressive, demanding spatial and temporal precision and/or attending and responding to somatic signals. Reflecting this complexity, emerging research suggests that along with motor improvements (di Natale et al., 2017), there are cognitive and affective benefits associated with dance for elderly populations, such as better performance on memory tasks (Hashimoto et al., 2015) and reduction in depressive symptoms (Ciantar et al., 2018; Bears & DeSouza, 2017). Some of the most promising research to date has pointed to evidence for neuroplasticity associated with dance, including increases in brain-derived neurotrophic factor (BDNF; Rehfeld et al., 2017), improvements in overall brain connections and white matter health (Burzynska et al., 2017), resting state EEG modulation (Bears & DeSouza, 2017) and adaptive network modulation assessed through graph-based analysis (Zildou et al., 2018). Understanding how and why this occurs requires a consideration of core elements of dance.

Dance and neuroplasticity – review of dance elements

Dance in neurorehabilitation as a field of research is still in its infancy. As an analogy, in the late 1990's the fields of neuroscience and economics joined forces to develop a new field of neuroeconomics (Glimcher 2004), which despite growing pains had an intrinsic utility; as a representation of the state of current research on dance, I will refer to a recent systematic review which identified eight publications presenting evidence of neuroplasticity associated with dance (Teixeira-Machado et al., 2019). Three studies involve the same dance method (Baniqued et al., 2017; Burzynska et al., 2017; Ehlers et al., 2017), three are associated with another (Muller et al., 2017; Rehfeld et al., 2017; Rehfeld et al., 2018), and two use one specific method each (= four methods in total). These studies seem to share a hypothesis as to what must be included for a dance intervention to promote neuroplasticity; specifically, the learning of motor sequences from a trained teacher (expert model), with increasing levels of complexity and challenge. I offer an overview of the dance methods described in each study, followed by discussion of how these pertain to core elements of dance.

Three of the papers reported on an intervention built around American and English folk dancing, during which participants learned three to five dances at the start of each month, with the speed and complexity of dances increasing over the course of each month and across the intervention. Dances were led by an experienced "caller," who provided instruction on upcoming figures and reduced instruction over the course of each month (Ehlers et al., 2017). The dance form and manner of instruction were selected to maximise physical and cognitive engagement, through the learning of increasingly complex sequences in a social environment; the dance combinations became progressively more challenging over the course of the 6-months program, and participants moved between partners during each dance. Each participant learned and alternated between lead and follow roles for each dance, increasing the cognitive challenge. (Baniqued et al., 2017; Burzynska et al., 2017). The studies by Rehfeld and Muller et al. (2017; 2018) compared dance and exercise interventions; similarly, the dance aspect of their study involved participants learning new movement sequences requiring the coordination of different body parts in space under increasing strain conditions (physical strain, precision, situation and time pressure). There were additional memory challenges, as subjects had to learn the choreographies by heart. Five different genres of music and movement were used: line dance, jazz dance, rock 'n' roll, Latin-American dance and square dance; these were switched after every fourth session. Over the course of the intervention, demands on coordination and timing were increased by the introduction of more complex movements and increasing the beats per minute in the music (Muller et al., 2017). Doi et al.,'s study (2017) also involved learning sequences, in this case from ballroom dance forms (salsa, rumba, waltz, cha-cha, blues, jitterbug, and tango), taught by professional dance instructors. Participants practiced sequences demonstrated by instructors until they achieved mastery, at which point they were taught a new set of dance steps. At the end of each session, participants, who were randomly paired into couples, were given "homework" of dancing the sequence learned in that session. For the study described by Kattentstroth et al. (2013), dance aspects involved learning step sequences of increasing complexity as part of a dance program developed specifically for elderly people called Agilando™, supervised and demonstrated by a trained dancing master.

All these studies rely on mastering a skill common to many dance forms – the acquisition, refinement, repetition and production of increasingly complex motor sequences, involving coordinated movement of body parts in relation to spatial and temporal demands imposed by the form and music. This skill puts demands on, and exercises, some of the most fundamental parameters of the nervous system – observation, replication and assessment of behaviour, including core aspects of motor learning such as improved motor control, observing an expert model, synchronising motor responses, and entrainment with music or a partner. The next section provides an overview of these and suggests why each may contribute to an explanation for how dance promotes resilience in the nervous system and healthy aging.

Motor Learning in the real world

Dance involves many aspects of motor learning, as it is fundamentally an activity where experience and practice improve performance of skilled actions. Participating in dance requires both implicit and explicit adaptation to a multisensory environment, which may include music, other people moving through the room, and spatial patterns; error-driven feedback learning, in comparison to a skilled model or temporal constraint; sensory prediction, efference copy and multisensory integration, particularly in live and social dance forms; and continuous sequential actions and refinements in motor acuity.

Once a dance is learned, it remains within the nervous system, potentially forever. A recent example of this is a widely-shared video (1.8-million on November 13, 2020) of former ballerina Marta González from non-profit organisation Música para Despertar, in which hearing the music associated with a dance elicits a moving performance, even though the elderly dancer is now suffering from Alzheimer's and confined to a wheelchair (https://youtu.be/owb1uWDg3QM). An fMRI study has shown that expert dancers exhibit different activation patterns in supplementary motor area and auditory brain regions over the course of learning a specific dance choreography; blood oxygen related level dependent (BOLD) signal in SMA increased after the rehearsal period, and once mastery had been achieved, BOLD signal dropped suggesting a role for neuroplasticity and altered network connections with motor learning rehearsal associated with dance (Bar & DeSouza 2016). While dance forms aimed at performance may rely on choreography, folk and cultural forms have similar requirements in the memorisation and reproduction of movement patterns. Almost all dance forms involve complex sequences fitted to specific spatial and temporal constraints; information is “chunked” to enhance performance and recall. As sequences are often strung together in logical, expressive, or narrative patterns, there may also be examples of co-articulation (Sosnik et al., 2004) as participants learn how to successfully connect movements in a sequence. All of these involve different forms of memory – procedural, implicit, and explicit, thus motor learning training associated with dance could conceivably support memory function and build resilience into the nervous system through enhancing the cognitive reserve network (Muller et al., 2017).

Motor control training

During the process of dance learning and training, achieving proficiency requires advanced motor control training – refinements in one’s ability to initiate, direct, and titrate motor behaviour; in dance this may relate to an aesthetic output or interaction with a partner. Achieving this requires enhanced vestibular and kinesthetic awareness, as dancers must track where their limbs are in space and complex relationships between body parts as balance and timing are called into play. Dancing also demands a high degree of multisensory integration, as visual, auditory, and somatosensory information are integrated with specified motor outputs. Blasing et al., (2012) report on many studies the have shown enhanced motor control in expert dancers.

While this means that expert dancers are more efficient at learning and accurately performing motor sequences, novices may have greater neurobiological benefits associated with learning dance as it presents a more novel and stimulating environment, fostering adaptive neuroplasticity. Initial results from people with PD learning a dance choreography showed the same learning curve and changes in SMA and auditory cortex activity as professional dancers, with a greater degree of improvement in motor symptoms in people with PD as dancers have a ceiling effect (Harrar, Bar & DeSouza, 2016; DeSouza & Bearss 2018).

Spatial orienting

Dance is spatially oriented - in a performative sense, this may be in relation with an audience; in folk forms it can refer to following specific patterns through the room in response to other dancers; movements often need to "arrive" at a particular location in space, whether that is extrinsic (the room) or intrinsic (in relation to the body). This is a fundamental distinction between dance and exercise. While dance is an embodied form, it is not *only* about body movement; dancing connects body with environment, as movements are spatially located and often relational. Dance thus engages crucial brain areas and neural activity associated with spatial navigation, memory, and executive function, including the hippocampal network and medial temporal lobes, which may be involved in larger network dynamics (Brown and Chrastil, 2019). Spatial navigation tasks have been shown to be neuroprotective, reducing age-related changes in hippocampal integrity during early and late adulthood (Lövdén et al., 2012). Rehfeld et al. (2017) specifically investigated hippocampal volume changes in their dance study and saw a statistically significant change in left hippocampal volumes for the dance group, and in the right subiculum.

Timing and Entrainment

In scientific research, dance has often been defined as "movement to music", and numerous studies have investigated dimensions of dance such as our ability to entrain with a rhythmic beat (Merchant et al., 2015) or other dancers (Washburn et al., 2014). In the studies listed by Teixeira-Machado et al., (2019), pushing time constraints by increasing beats-per-minute is used to increase the level of challenge involved in producing the movement repertoire. While many dance forms interact with music, it is not always the case that this occurs in a strict metered tempo; "playing" with the music is an important aspect of dance. Tango and other forms include elements such as *rubato* – a deliberate speeding or slowing in the tempo of the music, stretching of a metre or phrase. Fitch proposes that an ecologically valid study of music should include dance, as most musical forms have been attended by movement over the course of human history; a focus on movements accompanying music may advance our understanding of the origins of meter and rhythmic cognition in humans more generally (2016).

Action observation

Learning dance in many cases involves observing and following an expert demonstration – in the studies described above, a teacher or "dancing master" provided a model and description of the movements to be mastered. Motor learning studies have shown that time spent observing an expert model can induce skilled motor coordination patterns in a single session of intermittent practice (Friedman & Korman, 2018). Researchers have proposed a network comprised of sensorimotor regions including bilateral premotor and parietal cortices during action observation, referred to as the "Action Observation Network" (AON); physical rehearsal and observational learning have been shown to share common neural substrates within the AON, (Cross et al., 2009). This network has been implicated in studies of observed action sequences, which are shown to be modeled by distinct patterns of activity in frontoparietal cortex, and these representations generalize to similar, but untrained, sequences (Apšvalka, Cross & Ramsey 2018). Studies of expert dancers have shown altered functional connectivity of the AON and general motor learning network, relating to dance skill, balance, and training-induced structural characteristics (Burzynska et al., 2017).

Future topics – more than movement training

While aspects of dance associated with motor learning are crucial to its performance, dance is also a creative and cultural phenomenon that involves more than reproducing movement. Dance can be highly imaginative, and many dance forms involve imagery – analogies may be used in training, rehearsal or performance; in dance, movement often has meaning, including cultural and historic references, narrative structures or poetic elements. While learning choreography requires memory, practice, and repetition of motor sequences, for movement to be fully "danced" it often requires an additional layer of image, affect, or intent. It should also be noted that while motor sequences and choreography are central to many performances, not all dance forms are choreographed. Improvisation is key for many practices, including social forms like tango (Barnstaple 2017), and may be used in studio exploration or as a method in and of itself (Batson, Hugenschmidt and Soriano, 2016). Improvisation is a skill that can be practiced and improved upon, challenging the nervous system through training attention, multisensory integration, response times, and creativity. Dance can be, and often is, inherently playful; through movement exploration, we practice and expand our vast motor repertoire with its almost limitless degrees of freedom, blending movement with mind in bringing meaning to behaviour.

For the emerging field of dance-based neurorehabilitation to reach its full potential in scope and application, these and other subtle elements of dancing must be included in rigorous clinical research and clinical trials that demonstrate efficacy. Currently there are 85 total clinicals trials running (not yet recruiting; recruiting; enrolling by invitation; active, not recruiting). We attempted to address the nuances of what contributes to a "felt sense" of dancing in a recent mobile EEG study which followed participants through the process of watching, learning, mentally rehearsing, and performing a novel dance choreography (Barnstaple et al., 2020). Participants were asked to what extent they felt like they were "fully dancing" at the end of each performance trial; scores consistently increased, correlating with sense of self-expression or fully "inhabiting" the movement. This is a crucial, not to be overlooked aspect of what distinguishes dance from exercise – movements, even when choreographed, can be highly individualised and are primarily volitional – dance in most cases is not functional, object- or goal-directed; dance and dancer are synonymous and inseparable. In dance, it is not so much *what* a movement is, but *how* it is performed, that provides the sense of dancing. Arms can be raised with a quality of lightness or strength - as if lifting a window or throwing confetti in the wind. Elements such as these are described by Laban Movement Analysis (LMA), a system for observing and codifying movement that is widely used in dance but has yet to be fully adopted by scientific studies. Moving beyond the "what" to the "how", and even the "why", is a crucial next step for dance in neurorehabilitation. Further collaboration between arts and sciences with a focus on the details of dance and elements of dance-based literacy will greatly enhance this project.

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