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A Neuroscience of Dance: Potential for Therapeutics in Neurology

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A Neuroscience of Dance and Exercise

Many individuals dance either professionally or recreationally. Dance, in fact, has such favorable effects on the brain and its ability to form connections as well as in its ability to stimulate substances that support neuroplasticity that it is now being used to treat individuals with many forms of neurodegenerative conditions such as Parkinson's disease, a progressive neurological movement disorder that, in part, concerns the integratory function of movement and cognition (Leisman, 2012; 2016).

Researchers have given little thought to the neurological effects of dance until relatively recently, when studies of the complex coordinated movement in dance and its attendant cognitive components began to be examined. Brown and Parsons (2008), in an article in *Scientific American*, indicated that the synchronization of music and movement (the dance), fundamentally creates "double pleasure" as music stimulates the brain's reward centers, while dance activates its sensory and motor circuits.

PET imaging has identified brain regions that support the learning of dance moves (Cross, 2006). These regions obviously comprise the motor cortex as well as the somatosensory cortex, basal ganglia, and cerebellum. The motor cortex is involved plans, controls and executes voluntary movements. The somatosensory cortex is concerned with motor control and similarly provides control of eye-hand coordination. The basal ganglia together with supplementary brain regions endeavors to control the smoothness of movement, while the cerebellum combines input from the brain and spinal cord and helps in the planning of fine and complex motor actions (Israely et al. 2018; Melillo and Leisman 2010). While some imaging studies have illustrated the nature of dance activated brain regions (Cross 2006), others have investigated how the expressive and physical aspects of dance modify brain function. For example, much of the research on the benefits of the physical activity associated with dance links with those gained from physical exercise benefits (Hillman et al., 2009; Mualem et al., 2018), benefits that range from memory improvement to strengthened neuronal connections.

Numerous complex sensorimotor behaviors involve the combination of spatial pattern, rhythm, and synchronization to external stimuli and coordination of the whole body. Such activities include primordial adaptations such as hunting, fighting and play, as well as more contemporary adaptations such as marching, group physical labor, group musical performance and sport.

Neuroimaging studies have examined some constituents of these multifaceted actions, such as the entrainment of movement

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to external timekeepers or spatial patterning of limb movement. However, this research has typically studied fundamental processes as finger tapping or ankle rotation (Penhune et al., 1998; Jäncke et al., 2000; Ehrsson et al., 2003; Sahyoun et al., 2004). A central issue is whether the neural systems implicated in these elementary processes “scale up” and “scale out” to complex ecological activities. Are the means that regulate complex sensorimotor processes the same as those that trigger elementary processes such as finger tapping or ankle or are new and different mechanisms recruited?

Dance is a universal human behavior related to group rituals (Sachs, 1937; Farnell, 1999). Although portrayed in cave art dating back over 20,000 years (Appenzeller, 1998), dance may actually be much older. Dance may actually be as old as human capacities for bipedal walking and running, dating back 2-5 million years (Ward, 2002; Bramble and Lieberman, 2004; Melillo and Leisman, 2010). A major aspect of dance is that body movements are structured into spatial patterns. This patterning of movement incorporates a map of the trajectories of the body in exocentric space (Longstaff, 2000) as well as visual and kinesthetic maps of body schema in egocentric space (Haggard and Wolpert, 2005). The displacement configurations of dance can involve any body part; every dance can be categorized by the identity and number of its contributing movement-units. Furthermore, dances tend to possess a modular organization, comprised of distinct sections that are interwoven with one another cyclically. Due to this combinatory organization, dances are amenable to grammatical analysis and description (Hutchinson-Guest, 1997).

Another aspect of the dance involves movement synchronization that in turn is based on metronomic or musical beats, a capacity nominally specific to human beings. Essentially all dancing is performed to musical rhythms, thus allowing temporal synchronization between dancers. Dance movement generally emulates the graded arrangement of strong and weak beats evident in musical rhythm patterns. In the waltz, the first beat is emphasized with weaker second and third beats; in parallel in waltz movements, the first step is the most emphasized with shorter and weaker second and third steps. Therefore, the music and dance entrainment involves both synchronization in time and a spatial component related to the equating of hierarchies in the motor pattern with those in the musical rhythm.

Positron emission tomography (PET) studies were performed with amateur dancers executing small-scale, bipedal dance steps on an inclined surface, as compared to auditory, motor and rhythmic control tasks (Brown et al., 2006). Brown and colleagues attempted to develop a systems-level view of complex sensorimotor processes involved in dance, by attempting to

isolate and identify the brain areas involved in the voluntary control of metric movements, (i.e. dance steps occurring in an equal-time-interval rhythm).

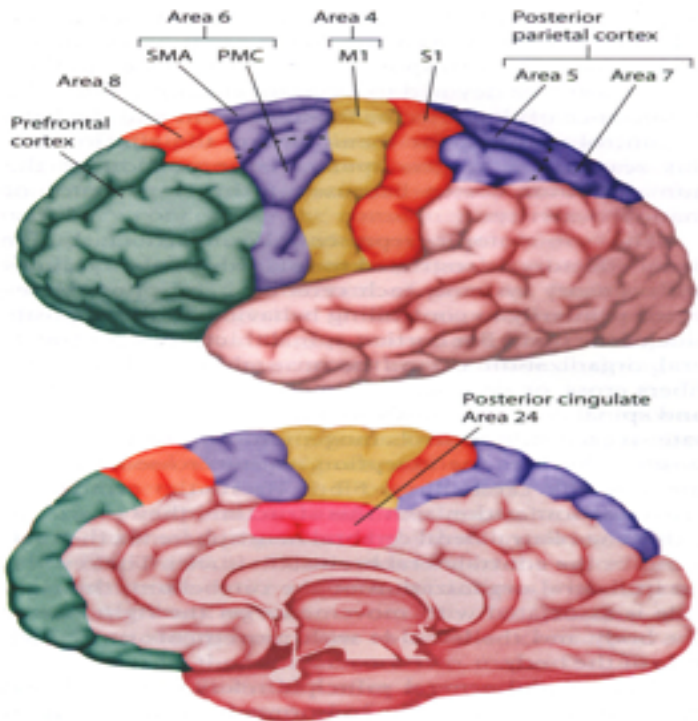
Brown et al.'s (2006) findings exemplify the coordination of distributed neural systems associated with reiterated dance steps entrained musical rhythm. Elements of both discrete and rhythmic movements (Schaal et al., 2004) are present in dance, itself a gestural system. Activation patterns are largely consistent with subcortical system activation involved in the timing and coordination of discontinuous movements, whereas the specific cortical systems activated support the control of the continuous movements (Miall and Ivry, 2004).

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The operative neural subsystems that Brown and colleagues (2006) found included: the superior temporal gyrus and superior temporal pole associated with the melodic aspects of the music. The medial geniculate nucleus was reported to direct input, through brainstem nuclei that project to the anterior cerebellar vermis and lobules V and VI, relating to beat information supporting the entrainment of movement to musical beats. The basal ganglia, and putamen control the selection and organization of action segments in particular for movements with strong probability and constancy, such as metronomic or timed movements. The thalamus was reportedly involved in linking somatosensory and motor parameters together and is singularly significant for the performance of novel or non-metric rhythms.

Brown and associates have found that somatotopic areas for the lower extremity in SMA, premotor, and motor regions of the cortex are associated with parameters related to contractile forces, muscle groups, initial and final limb position and direction of movement. A representation of involved brain regions may be found in Figure 1. The SMA, cingulate motor area and the cerebellum support interhemispheric coordination of the two limbs during cyclically repeated, bipedal motion (Brown et al. 2006; Leisman et al., 2013; 2014) Involved in motor sequencing is the right frontal operculum and the right cingulate motor region is associated with movement intention. Brown and colleagues (2006) reported that the medial superior parietal lobule subserved kinesthetically mediated spatial guidance of leg movement during navigation in dance.

Figure 1: The motor areas of the cerebral cortex, among them the premotor cortex (PMC), supplementary motor areas (SMA), primary motor cortex (M1), posterior parietal. Also, primary sensory area (S1) and the limbic lobe including the cingulate gyrus (lower image). (Adapted from Gazzaniga et al., 1998, with permission Adapted from Gazzaniga et al., 1998, with permission)



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Brown and colleagues distinguished in their 2006 study between different aspects of the dance. They analyzed: audio-motor entrainment, meter and movement patterning. In audio-motor entrainment two matched dance patterns were performed at the same rate with one necessitating entrainment to a rhythmic beat and the other one, self-paced. Entrainment processing was reportedly related to the anterior cerebellar vermis exclusively. In their metronomic and non-metronomic support for Brown et al.'s (2006) findings, Debaere et al.'s (2001) functional magnetic resonance imaging (fMRI) studies of right-foot flexion/extension timed to metronomic auditory cues demonstrated similar findings in the anterior cerebellar vermis. Additional support of the involvement of the anterior cerebellar vermis in an fMRI study by Sahyoun and colleagues (2004) demonstrated that with right-foot flexion/extension timed to a metronomic visual rather than auditory cues the anterior cerebellar vermis was also involved.

This region was also activated by rhythmic self-paced walking (Fukuyama et al., 1997) as well as by finger tapping without ongoing external stimuli (Penhune et al., 1998). These similarities between self-paced walking as well as metronomic-based dance patterns evidenced on fMRI imply that common mechanisms are involved in entrainment, indicating the importance of the anterior cerebellar vermis (III) for the entrainment of movement to external timing cues.

Brown and colleagues (2006) noted in their analysis of functional activation of metronomic dance minus passive music listening, activity in cortical auditory areas was eliminated, with significant residual signal in the right medial geniculate nucleus as well as well as in posterior cerebellar lobules V and VI. These investigators did not find these regions to be activated during self-paced dance steps without music (in contradistinction to rest to rest).

There exist significant reciprocal projections between the cerebellum and the thalamic nuclei via relays in the brainstem (cf. Schmahmann, 1997). Furthermore, cerebellar lobules V and VI have been explicitly associated in neuroimaging studies of pitch and melody discrimination, and are disconnected from motor coordination or cortical motor activity (Parsons, 2003a; Petacchi et al., 2005). It is conceivable then that the sensory input to the anterior cerebellar vermis for entrainment processing involves auditory processed information from subcortical sites.

It appears then that entrainment in dance has no requirement for musical content necessarily but rather is contingent on low-level information about beat, facilitated by subcortical pathways. This hypothesis may in part account for the similarities of entrainment mechanisms between dance and simple sensorimotor behaviors like finger tapping and ankle rotation.

There is much argument concerning the role of the cerebellum, which has been understood as a mechanism in motor-control and coordination but not so much concerned with non-motor processes (Ivry and Fiez, 2000; Bower and Parsons, 2003; Melillo and Leisman, 2010; Leisman et al., 2013; 2014). Cerebellar function has been viewed differently of late by various authors. It was Wolpert et al. (1998) who contended that the cerebellum possesses “internal forward-inverse model pairs.” Alternatively, Ivry (1997) focused on the cerebellum’s role as involved in timing in both movement preparation and motor response coordination (in the anterior and

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vermal regions) and the sensory perception of duration on the order of hundreds of milliseconds (in lateral cerebellum).

In yet another view of the function of the cerebellum in the present context proposed by Bower and Parsons (2003) was that the cerebellum functions to optimize the acquisition and control of sensory data. In the present application related to the dance, the cerebellum would function to support cortical, subcortical and peripheral neural structures in assembling optimal auditory and somatosensory information in order to effect the cortical motor system to synchronize the execution of movement with the auditory rhythm.

Metronomic vs. Non-metronomic Movement

Brown and colleagues (2006) also found that metronomically timed dance movement was associated with robust bilateral activity in the putamen in general, and the right putamen in particular. Non-metronomic movement associated with dancing dance demonstrated no activity in the putamen but rather significant increases in signal strength in the right ventral thalamus. Much prior and later research confirms the basal ganglia’s role in the controlling metronomic movement in rhythmic tapping tasks (e.g. Rao et al., 1997; Penhune et al., 1998; Melillo and Leisman, 2010; Leisman et al., 2014) and in piano performance of memorized musical pieces (Parsons et al., 2005; Leisman et al., 2010). The putamen’s contribution in metronomic movement is supported by Sahyoun and colleagues’ (2004) fMRI investigation of visually cued, metronomic right-foot flexion/extension where the thalamus was significantly less active. Similarly, in a PET study of the same task (Ehrsson et al., 2000), activity in the putamen, but not the thalamus, was reported. The involvement of the ventral thalamus in non-metric rhythms

agrees with similar findings from an fMRI study (Jäncke et al., 2000) of tapping the right index finger to a non-metric, randomly timed visual cue.

Generally, the feedback activity occurring between putamen and ventral thalamus here described proposes that for both dance and elementary movements, the basal ganglia are preferentially triggered in the execution of motor activities that have predictable and regular rhythm and that unpredictable unfamiliar temporal configurations employ alternative pathways.

This is also consistent with Dhamala et al.'s (2003) findings indicating that in fMRI, self-paced finger tapping produces activity in the basal ganglia for simple rhythms and activity decrease was noted with greater rhythmic complexity. In the thalamus and anterior cerebellar vermis, on the other hand, increased activation was produced with increasing complexity.

Brown and associates (2006), investigation demonstrated moderate activity levels in both the central thalamus and putamen for self-paced dancing without music and for the performance of isometric leg-muscle contractions to metronomic tango music. Therefore, basal ganglia activity appears to be moderated by limb displacement and entrainment and by the presence or absence of metronomic regularity.

This composite functionality implies that the basal ganglia may be one part of the brain sensitive to the interactions between entrainment, spatial patterning and meter, the constituent elements of dance.

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Dance, Somatotopy and Control of Lower Limbs

An additional aspect of Brown et al.'s (2006) fundamental study of the dance emphasizes the lower extremity's topographic representation in the sensory-motor cortex and in the superior parietal lobule, cingulate motor area, cerebellum, and putamen.

Activation of a mesial strip encompassing the leg representation in the primary motor cortex, somatosensory cortex, SMA and premotor cortex was reportedly existent for tasks involving motor activity. Activation in similar somatotopic cortical regions for the lower extremity have been found in a number of reports of SPECT studies of upright walking (Fukuyama et al., 1997); results of a study of near-infrared spectroscopy of bipedal walking on a treadmill (Miyai et al., 2001); an fMRI study of right-foot flexion/extension timed to a metric auditory cue (Debaere et al., 2001); a PET study of this same task (Ehrsson et al., 2000); an fMRI study of metronomic, visually cued right-foot flexion/extension (Sahyoun et al., 2004); an fMRI study of unipedal flexion/extension of either the left or right knee joint (Luft et al., 2002); an fMRI study of the placement of either foot into visually presented foot postures (Chaminade et al., 2005); and an fMRI study of imagined and executed flexion/extension of the toes timed to a metronomic auditory cue (Ehrsson et al., 2003).

The SMA, premotor and motor regions of the cortex probably encode parameters associated with muscle group, contractile force, initial and final position, and movement direction (Graziano et

al., 2002; Israely et al., 2018). The SMA, the cingulate motor area and possibly the cerebellum (Ivry, 1997; Wolpert et al., 1998; Kajal et al., 2017) are likely involved in interhemispheric coupling associated with repetitive synchronization of the two homologous limbs, as suggested by studies of bimanual coordination (e.g. Jäncke et al., 2000; Manca et al., 2018). Similar activations have been reported for coordinated unilateral movements of the hand and foot (Ehrsson et al., 2000; Debaere et al., 2001; Kang and Cauraugh, 2017).

The right frontal operculum (represented in Figure 2) is reportedly triggered by motor production but not by music listening, indicating that the region possesses a role in motor sequencing rather than in spatial patterning and metronomic entrainment (Ehrsson et al., 2003; Karpati et al., 2017). Responses in the frontal operculum have been noted in an fMRI study of flexion/extension of the toe timed to a metronomic auditory cue (Ehrsson et al., 2003) both during mental imagery of movement and actual movement. Analogous activity was also reported in an fMRI study of visually cued metric right-foot flexion/extension (Sahyoun et al., 2004). In a PET study of finger tapping timed to imitate the rhythm of brief sequences of visual stimuli with long or short elements (Penhune et al., 1998), the right frontal operculum was also triggered. The same region shows activations for motor mental imagery, perception, and imitation tasks involving the hands (Parsons et al., 1995; Grafton et al., 1996; Heiser et al., 2003; Kilintari and Papanicolaou, 2017). Correspondingly, an area anterior to the right frontal operculum was activated in ballet dancers viewing ballet movements and in capoeira dancers while observing capoeira movements (Calvo- Merino et al., 2005). This report supports a role for this region in both elementary motor sequencing and in dance, during both perception and production.

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Figure 2: coronal section of the human parietal operculum (green), temporal operculum (blue), and insular cortex (brown). The red inset show the position of the brain slice. (Adapted from: John A Beal, Dept. of Cellular Biology & Anatomy, Louisiana State University, 2005, with permission.)

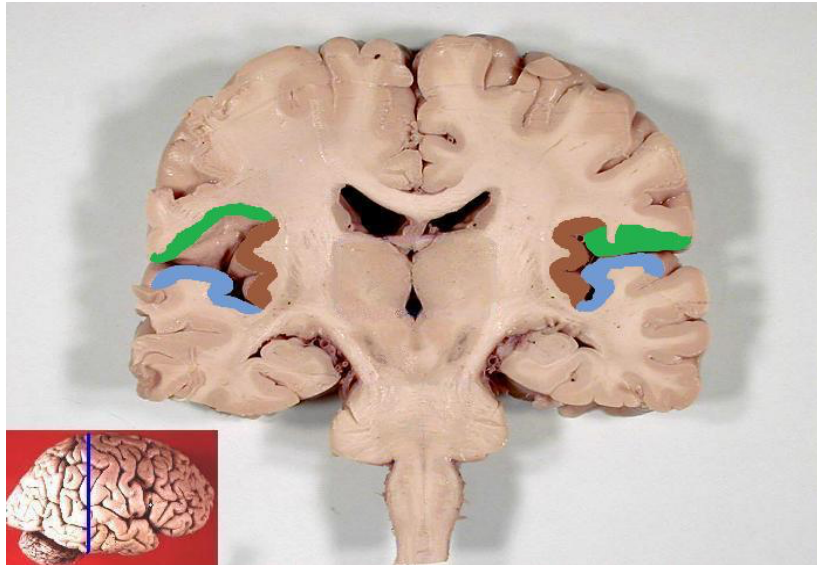
Dance and Spatial Cognition

Brown et al., (2006) found that the medial superior parietal lobule is involved in the kinesthetic control of leg movement during navigation in dance, interacting with the somatosensory, timing, sequencing and obviously motor areas of the cortex. In older fMRI studies (Debaere et al., 2001), activation in the medial superior parietal lobule was also note for right-foot flexion/extension timed to metric auditory cues as well as in a similar PET studies (Ehrsson et al., 2000). More recent studies have conformed these effects (Chauvignú et al. 2017; Bears and DeSouza, 2017).

The posterior parietal cortex is associated with involvement in numerous cognitive- spatial functions (Colby and Goldberg, 1999; Parsons, 2003b; Hwang et al., 2017) including those related to body schema (Berlucchi and Aglioti, 1997; Halligan et al., 2003; Hwang et al., 2017; Wood et al., 2017). The inferior and superior parietal lobules receive both somatosensory and visual inputs. The posterior regions of both lobules process visual information, the anterior superior parietal lobule somatosensory, and the anterior inferior parietal lobule integrates the somatosensory and visual information (Colby and Olsen, 2003; Elliot, 2017; Burzynska et al., 2017). Dancing with the eyes closed was reported by Brown and associates (2008) by some of their participants to be accompanied by mental imagery of their body. They assumed that the

parietal activation was probably involved in spatial cognitive functions based on proprioceptive processing of leg position and joint angle and on somatosensory contact of the feet with the surface (Parsons, 1987; Burzynska et al., 2017).

While not much is known about leg representations in posterior parietal cortex of either humans, somesthetic guidance of navigation is crucial to dance, where vision provides a support role indicating whether there is ample area to carry out particular movements. The fact that superior parietal lobule is activated in some of the studies of elementary ankle and wrist rotation suggests that, unlike isometric muscle



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contraction, these simple movements still have a basic element of spatial patterning. This suggests that activity in superior parietal lobule increases as the spatial and navigational demands of the movement increase.

The numerous brain areas activated for dance are the same as those recruited in non- dance sensorimotor activities. It is likely that learning or refinement of natural complex tasks would entail changes in functional and effective connectivity, and in the reorganization and redistribution of processes basic to the process of rehabilitation (Garraux et al., 2005; Kelly and Garavan, 2005; Melillo and Leisman, 2010).

Dancers, for example, must learn complex movement sequences by efficiently reproducing movements they observe that incorporates the translation of visual and verbal information into motor action. Dancers modify movements with respect to direction in space, speed, rhythm, and amplitude, and express them precisely as observed from the choreographer's instructions, adding the dancer's refinement of the movements for aesthetic purposes.

When dancing individuals must remain attentive to their partner so as to be in synchrony. Dance, therefore, requires observing, generating, executing and coordinating complex movement patterns through cognitive–movement interaction.

Dance and Equilibrium, Posture and Motor Control

Dancers show enhanced abilities in posture control and equilibrium maintenance as a vital part of their expertise (Daprati et al., 2009). A number of studies have investigated the cognitive control mechanisms fundamental for dancers' exceptional motor skills, concentrating on the acquisitions mechanisms and their maintenance and how the acquisition mechanisms may affect other sensorimotor processes.

Dance training heightens sensorimotor control functions underlying static as well as dynamic equilibrium. For example, classically trained dancers exhibit better postural control (Rein et al., 2011), can maintain given postures for longer durations (Crotts et al., 1996), and show more vertical alignment during stepping than non-dancers (Chatfield et al., 2007). Numerous studies have demonstrated that dancers possess better balance skills in dancers than do non-dancers (Golomer et al., 1997a; 1997b; Golomer et al., 1999a), in adult dancers compared to younger and less experienced dancers (Bruyneel et al., 2010), and in female compared to male dancers in equilibrium reactions (Golomer et al., 1997b). Even short episodes of breakdance training have been found to increase balance skills in young amateurs (Ricotti and Ravaschio, 2011).

We know that with greater skill acquisition in dance, there is a complimentary increase in somatosensory functional ability with physical training. For example, enhanced proprioceptive skills associated with dancers' heightened posture control have been suggested to interfere with other sensory processes such as vision (Golomer et al., 1999a; Jola et al., 2011). Dance training has been claimed to increase the relative effect of somatosensory function with a shift of sensorimotor dominance to proprioception from vision (Golomer and Dupui, 2000; Boucher, 2017). Therefore, skilled dancers demonstrate a greater position sense based on proprioceptive information, and should rely more on proprioception than on vision compared to non-

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dancers. Evidence for this hypothesis has been found for dynamic equilibrium tasks among professional ballet dancers (Golomer and Dupui, 2000), and for position- matching tasks involving matching the hand location in space (Jola et al, 2011; Ramsay and Riddoch, 2001). Dancers even appeared to be more reliant on proprioception even when vision was available, leading to a tendency toward higher error rates in the vision-only condition, in which controls are generally more accurate.

On the other hand, static equilibrium in dancers demonstrate that their balance strategies for motion rely more on visual rather than to somatosensory information (Hugel et al., 1999; Golomer et al., 1999b; Boucher, 2017; Ponzo et al., 2018). Nonetheless, dancers' dynamic patterns of postural sway are regulated by visual input in different ways compared to non-dancers. While dancers often demonstrate lesser pitch sway oscillations than do non-dancers, roll

sway and pitch were increased in dancers standing on one leg with the left hemifield occluded, whereas only pitch sway was increased in untrained controls (Golomer et al., 2010).

These findings suggest that sensory control strategies are likely task-specific, and that dance training enhances the relative influence of somatosensation, specifically proprioception, on multimodal assimilation for position-matching and for dynamic equilibrium tasks, but not for static tasks.

One can therefore conclude that the essential functions fundamental to the dance include the control of equilibrium, posture, and sway are sensitive to training effects, and that, therefore dance training has the potential to stabilize and align dancers' performance via these functions. The roles of individual sensory modalities in multimodal integration, especially relative influences of vision and somatosensation deserve further study. The intimation here is that there is potential therapeutic benefit for those with developmental delays, developmental coordination disorders, individuals post-stroke and those suffering from a plethora of neurodegenerative conditions.

Dance and the Control of Complex Movements

The seemingly effortless performance of challenging moves is a characteristic of skilled dance. Dancers realize this by optimizing motor synergies reducing energy costs of force and muscle tension as a consequence (Israely et al., 2018). Overall, classical dancers have the ability to efficiently combine movements of related joints into single motor synergies, thus reducing the number of degrees of freedom required for neuronal control, resulting in a highly accurate reproduction of the orientation and shape of the required trajectories (Thullier and Moufti, 2004; Wilson et al., 2004).

On the basis of our current understanding of the effects of dance training, on neurocognitive control functions and its capability of modifying physical abilities, such as facilitating the optimization of muscle activation, and coordination of novel movements, we learn that dance training has the potential to influence basic functions underlying motor control, including multimodal integration as well as posture and equilibrium control, facilitating the performance of complex movements in body alignment and balance tasks. On this basis the employment of dance as a therapeutic intervention tool in neuromuscular and developmental disorders allows the individual

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to develop strategies such as the optimization of motor synergies when executing complicated movement combinations.

As dancers develop and apply strategies in ways that requires attentional processes and higher cognitive processes, such as the use of imagery, and adaptable to external acoustic or visual cues, therefore, even though dancers' movement expertise can be examined and described via biomechanical measures (Krasnow et al., 2011), physical skills in dance cannot be separated

from the cognitive functions and strategies that enable dancers to make use of them in a way that makes dance an art form.

Dance and Motor Learning: Imitation, high-level cognition and improvisation

Motor learning is the modification of the behavior following experience (Leonard 1988). In this section we concentrate on the motor learning phase of the of dance, summarizing briefly the experimental findings on the brain regions involved in motor learning in dance. It also assesses some possible implementation of different motor learning methods for movement therapy.

When discussing the various motor learning procedures of dance, we focus on acquiring and improving dance skills using three main methods: learning dance by imitation, learning dance via a high cognitive component instructions and learning through improvisation. We will show that each of these different ways of learning dance utilizes somewhat different neural pathways and, therefore, is eligible to different purposes of dance and therapy practices.

Learning Dance Moves by Imitation

Learning movements by imitation is a common and useful method for learning dance. It is a fascinating phenomenon whereby while observing another person moving one can instruct one's own motor system to produce the same movement with his/her own body, simultaneously (Brass and Heyes, 2005). There is considerable evidence regarding the role of mirror neurons system in motor learning and movement imitation, in animals as well as in humans. For the observer, the mirror neurons system mediates the transition between visual response to movement and motor responses that mimics that performed by the dancer (Rizzolatti and Craighero, 2004). The human action observation network (i.e., the mirror neurons system) is thought to involve premotor and parietal cortices, possibly involved in action simulation, as well as the supplementary motor area (SMA), superior temporal sulcus, and primary motor cortex (Cross et al., 2006; Karpati et al., 2015; Kruger et al., 2014). Another brain area engaged during imitation is the superior parietal lobule, activated in the case of specific instruction to imitate a movement (Buccino et al., 2001). Studying imitation of movement by musicians, Buccino and associates (Buccino et al., 2004) showed that the basic circuit underlying imitation learning consists of the inferior parietal lobule, the posterior part of the inferior frontal gyrus, and the adjacent premotor cortex (mirror neuron circuit). This circuit was shown to be involved in action understanding. Experimental results also indicate that the basic circuit underlying imitation coincides with those which are active during action observation, and that the posterior part of IFG is involved in direct mapping of the observed action and its motor representation (Rizzolatti and Craighero, 2004).

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The correlation of brain activity with imitation in dance has been studied mostly indirectly, as part of measuring brain activity while watching dance. During this research two basic conditions were employed: observation of dance with no physical movement and observation of dance with some physical execution of dance. The studies under the first condition are summarized by Karpati and colleagues (2015) as follows: “neuroimaging studies of action observation in dance have shown that (1) dancers show activation of the action observation and simulation networks,

particularly the premotor cortex, when observing dance, likely because they have an enhanced motor representation of an observed movement; (2) functional differences in the action observation system of dancers are related to the degree of dance training; (3) short-term dance training is correlated with brain functional plasticity in non-dancers; and (4) observation of recorded versus live dance performance results in differential brain activity. However, the studies reviewed in this section are limited by the fact that they only address observation of dance” (Karpati et al., 2015).

Brain activity during observation of dance together with physical execution of the dance is very hard to achieve. Thus, only a few studies perused this direction so far. These works indicated

Karpati et al.

action observation network, which also considered participating in understanding of social behavior and empathy. This form of dance learning is so natural that practically every

one, from early childhood, uses it onwards.

Learning Dance by the Use of Higher Cognitive Functions

At times, motor learning of dance is based on a highly cognitive comprehension of the task. Such types of tasks can include, for example, learning a dance score from movement notation, which is a challenging cognitive task in terms of the transformation from one language (dance notation) to physical execution (dance) and in terms of the cognitive demand of understanding and analyzing the notated movements (cf. Warburton, 2005). Additionally, working with dance notation may induce a heavy load on the memory systems (both the explicit and the implicit systems) and may challenge coordination system (cf. Al-Dor, 2015). Another example of high cognitive components of learning dance is simply the performance of complex dance demands, in terms of learning the physical sequence of the movements, timings, directions, dimensions, simultaneous movements of different body parts and learning the subtle qualities of the dance movements (such as “flow”).

This form of a highly cognitive learning is characterized by comprehension of concepts, knowing and memorizing facts and events, conscious and verbal communication – all referred as declarative learning. It is contrasted with the procedural learning, also referred as “learning by doing”, which can be acquired without conscious awareness of the rules being learned but rather by motor practice

the involvement of some brain regions in various aspects of

execution of dance, such as the superior temporal gyrus, superior parietal lobule,

fronto-polar cortex, and middle temporal gyrus (Brown et al., 2006; 2015; Tachibana et al., 2011).

Taken together, imitation in dance is composed from several processes including the intention to imitate, observation of someone else moving and the execution of the

movements in real time. The phenomenon of imitation involves the

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(Cohen and Squire, 1980; Leonard, 1998; Willingham et al., 2002). It is common to think about procedural memory as independent neurally of declarative memory, and that these two systems operate independently during learning (Brown and Roberson, 2007; Cohen and Squire 1980; Squire 1992). Some studies have shown that during sequence learning, declarative and procedural systems operate in parallel whereas these memory systems may interact following learning (Brown and Roberson, 2007). There has been some evidence that manipulation of practice procedure influences cognitive processes during the encoding phase. For example, random-order practice of motor sequence (compared to blocked-order practice) engages the learner in deeper cognitive processing of information. This deeper cognitive processing leads to a stronger motor memory representation, which improves learning and retention (Kantak, and Winstein, 2012). Even though there is some evidence in several studies for overlap between various brain areas activated in these two procedures (such as left prefrontal cortex, left inferior parietal cortex and right putamen), some studies found also that SMA, caudate nucleus and somatosensory cortex were activated during procedural learning. A clear difference in the activity of several brain areas (such as left prefrontal cortex, dorsal prefrontal cortex, superior parietal cortex) has been found during declarative motor learning in comparison with procedural learning (Cohen and Squire, 1980; Willingham et al. 2002).

All this indicates that manipulation of practice structure using a high cognitive component motor learning, provides an opportunity to influence brain activity and physical behavior, via manipulation of the memory systems (declarative and procedural)

Learning Dance Movement by Improvisation

Improvising is an important form of learning and performing dance, being used among professional dancers and novices. Improvisation is studied and practiced in order to look for and

develop new movement materials for the dance. Also it is intended to convey emotional and conceptual ideas through the body. Improvisation in dance introduces a set of movements, which are composed and performed in real time. There are no stylistic rules to improvisation or fixed movements. Yet, there are some general rules for improvisation. For example, the technique might be generic in the sense that it can be applied to different body parts and specific in the sense that it chooses a particular set of movements (or avoids particular movements) (Hagendoorn, 2003). According to Hagendoorn, improvisation in dance is distinguished from pure motor learning of motor skills by the need of understanding of the concept behind a technique, so study and practice improvisation improves both – the motor performance and the cognitive aspects of dance (Hagendoorn, 2003). Improvisation is based on the generation of a variety of alternative motor patterns in order to create a divergent production. Its relationship to creative thinking has been demonstrated. Particularly, the relation of contact improvisation (sharing of a constantly moving point of contact with a partner, so the movements arise from a reflexive relationship with the partner) enhances the divergent of responses, thus stimulating motor creativity (Torrents, 2010). The study by Fink and colleagues (2009), one of the very few works on the connection of brain activity to dance improvisation, has shown that a task of improvisation in dance (namely imagery of free associative dance task, recorded by EEG) has elicited more alpha activity than a Waltz dance (by imagery of a known structured sequence of movements). Enhanced

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alpha brain wave activity was most pronounced in frontal, fronto-central and centro-temporal regions of the brain. This phenomenon was found in both professional dancers as well as in novices. This research demonstrates that improvisation task recruited brain regions which are active during creative thinking in general and more so than in learning a structured dance, such as Waltz.

Imitation in dance can be associated with procedural learning, which can be acquired without conscious awareness of the structure or the rules of the sequence being learned. Highly cognitive dance learning, which is, by nature, part of declarative learning, involves conscious awareness of the facts and events of the dance being learned. Improvisation in dance involves creative thinking and comprehension of principles.

Therapeutic Applications of Dance

In a 2003 study in the *New England Journal of Medicine* by researchers at the Albert Einstein College of Medicine Verghese and colleagues (2003) discovered that dance could decidedly improve brain health. The study investigated the effect that leisure activities had on the risk of dementia in the elderly. The researchers looked at the effects of 11 different types of physical activity, including cycling, golf, swimming, and tennis, but found that only one of the activities studied—dance—lowered participants' risk of dementia. According to the researchers, dancing involves both a mental effort and social interaction and that this type of stimulation helped reduce the risk of dementia. Numerous studies show that dance helps reduce stress (Hanna, 2017) increases levels of serotonin (Christensen et al., 2017), and helps develop new neural

connections (Brown et al., 2006), especially in regions involved in executive function, long-term memory, and spatial recognition.

The Parkinson's Disease Foundation reports that over a million people in the USA live with Parkinson's disease with 60,000 new cases reported yearly in the USA. (Parkinson's Disease Foundation, 2018) Parkinson's disease belongs to a group of conditions called motor-system disorders, which develop when the dopamine- producing cells in the brain are lost (Forno, 1996). Dopamine is an essential component of the brain's system for controlling movement and coordination. As Parkinson's disease progresses, cells of the basal ganglia increasingly die, significantly reducing the amount of dopamine available in the brain. The primary

We have learned that there are three main methods for learning a dance; learning via imitation, learning via higher cognitive processes and learning via improvisations.

These different methods activate some overlapping brain regions and some

non-overlapping brain regions. One implication of these findings is that implementation of all three teaching methods is important in order to stimulate the brain and body of a dancing person to various conditions of brain activity and motor learning. It is more so with regards to people who have impaired motor system, or

people who uses dance therapy for various other reasons.

Given the forgoing indicating how dance and dance instruction can affect the brain and how motor learning serves to effectively integrate brain function, one can therefore wonder whether there exists significant therapeutic benefit in dance training for individuals in various states of neurological compromise either developmentally or as a result of neurodegenerative conditions such as Parkinson's disease, as well as

post-trauma or stroke?

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motor symptoms of Parkinson's disease include *bradykinesia* (slowed movement), stiffness of the limbs and trunk, tremors, and impaired balance and coordination. Dance may help alleviate these symptoms, as the dance is a form of rhythmic auditory stimulation (RAS). In this technique, a series of fixed rhythms are presented to patients, and the patients are asked to move to the rhythms. Studies of the effects that this technique has on patients with movement disorders have found significant improvements in gait and upper extremity function among participants. (Hausdorff et al., 2007; Thaut and Abiru, 2010; Sohliya and Thomas, 2018). Although there have been no scientific comparisons of RAS with dance or music therapy, individuals with Parkinson's "speak and walk better if they have a steady rhythmic cue" (Sandrini et al., 2018).

At the Osher Center for Integrative Medicine at Brigham and Women's Hospital, Peter Wayne and colleagues (2017), have conducted clinical trials designed to evaluate the safety and efficacy of tai chi for patients with Parkinson's and other balance disorders. Tai chi, now performed as exercise, is a self-defense Chinese martial art. Wayne considers tai chi to be a more ritualized, structured form of dance. Tai chi is an exercise that benefits for both balance and mental function. Wayne and colleagues contend that the increased susceptibility to falls occurring among the aged, who also suffer from movement impairments including Parkinson's, can be mitigated by tai chi as it improves flexibility and strength as well as cognitive performance (Wayne et al., 2017)

A study appearing in the New England Journal of Medicine in 2012 (Li et al., 2012) found that tai chi helped improve balance and prevent falls among people with mild to moderate Parkinson's disease. Those who practiced tai chi twice weekly had better balance and were physically stronger compared with those who did either weight training or stretching after six months. Participants performing tai chi achieved balance measures that were twice as good compared with weightlifters and four times better than those participants who stretched. Those people who practiced tai chi also fell less and had slower rates of decline in overall motor control.

Animal research suggests that an amalgam of sensory enrichment and physical activity has a significant and sustaining effect on adult neuroplasticity. Dancing has been suggested as a vehicle for intervention in neurological compromise as the dance poses demands on physical, motor and cognitive functions. Rehfeld and colleagues (2018) reported the results of the effects of a challenging dance program in which elderly participants were required to learn novel and increasingly difficult choreographies. This six-month-long program was compared to conventional fitness training matched for intensity. The pre/post-assessment measured general cognition, attention, memory, postural and cardio-respiratory performance and neurotrophic factors along with an examination of changes in MRIs. These investigators found differences in the effects on brain volumes. When dancing interventions were compared to conventional fitness activity led to larger volume increases in more brain areas, including the cingulate cortex, insula, corpus callosum and sensorimotor cortex (represented in Figures 3 A and B). Only dancing was associated with an increase in plasma BDNF levels (brain derived neurotrophic factors highly associated with fomenting neuroplasticity). Both groups improved in attention and spatial memory manifesting no significant group differences.

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Figure 3.

Compared to typical fitness programs, Rehfeld et al.'s, (2018) six-month dancing program

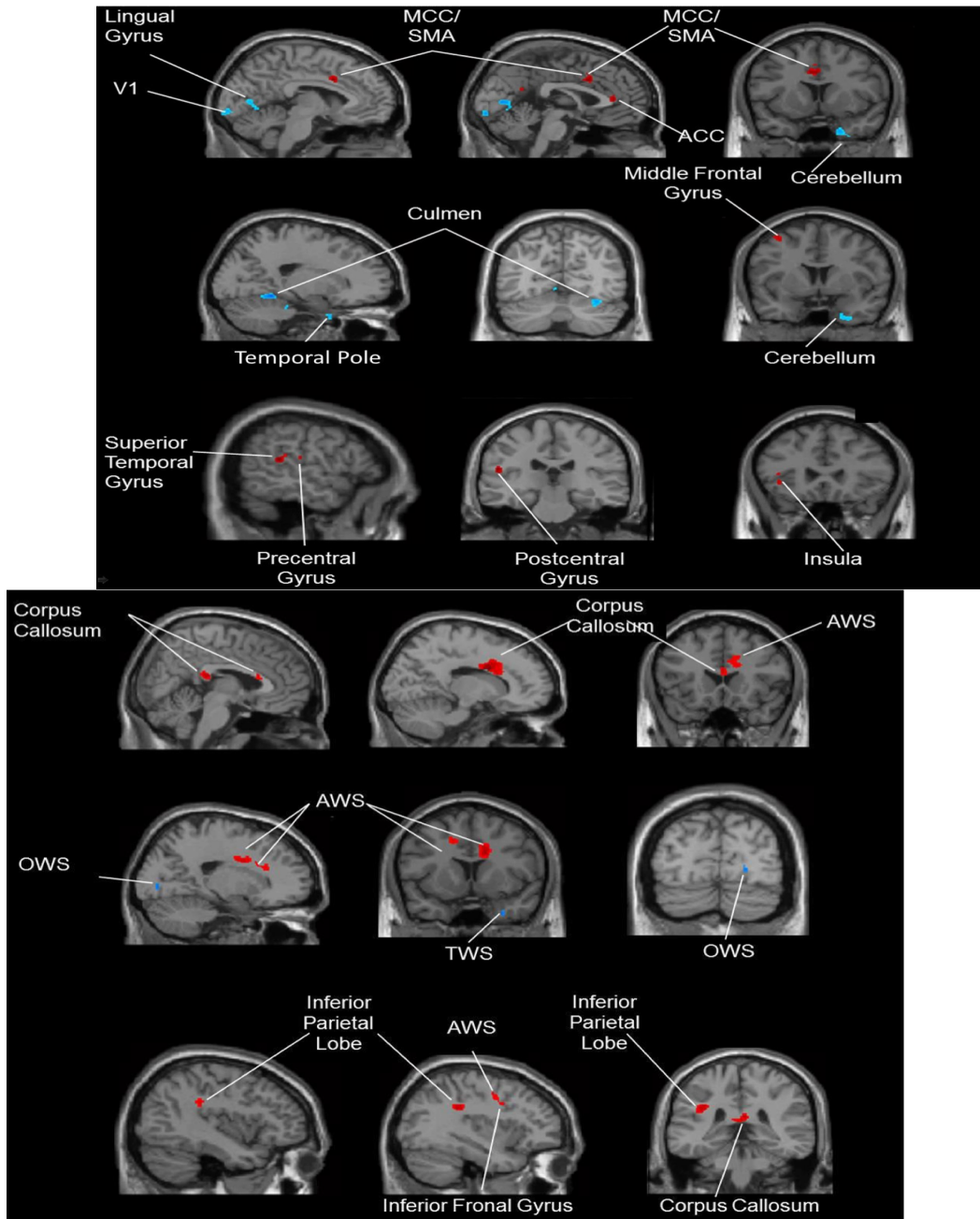
increased volumes in regions which relate to higher cognitive processes such as working memory and attention that are specifically affected by age-related deterioration. Dancing stimulates simultaneous processes of spatial orientation, movement coordination, balance, endurance, interaction and communication all associated with age-related declines and structured partnered dancing can provide

a potentially therapeutic effect. Here

presented are (A) Gray matter volume increases for the contrast dance > sport (red-colored) and for the contrast sport > dance (blue-colored). Annotation. ACC: anterior cingulate cortex, MCC: medial cingulate cortex, SMA: supplementary motor area, V1: primary visual cortex. (from <https://doi.org/10.1371/journal.pone.0196636.g002>) (B) Comparison of white matter volume increases for the contrast dance > sport (red-colored) and for the contrast sport > dance (blue-colored). Annotation. AWS: anterior white matter, OWS: occipital white matter, TWS: temporal white matter. (from <https://doi.org/10.1371/journal.pone.0196636.g003>)

(A)

(B)



Kim and associates (2011) performed a study of the effects of dance on the cognitive function in elderly individuals with metabolic syndrome. Metabolic syndrome is highly associated with an increased risk of cognitive impairment (Komulainen et al., 2007; Solfrizzi et al., 2009; Yaffe et al., 2004). The purpose of their investigation was to examine the effects of dance exercise on cognitive function in elderly patients with metabolic syndrome. Their participants included 38 elderly metabolic syndrome patients with normal cognitive function. Their dance-exercise group performed dance exercise twice a week for 6 months. Cognitive function was assessed in all participants. Compared with the control group, the exercise group significantly improved in verbal fluency, word list delayed recall, and word list recognition. Their results indicated that six months of dance exercise improved cognitive function in older adults with metabolic syndrome.

Hackney and Earhart (2010) had examined the effects of dance on gait and balance in Parkinson's disease. They found that tango dancing with partner has a significant effect on gait and balance. Partnered tango dance can improve balance and gait in individuals with Parkinson disease (PD). They compared the effects of partnered to non-partnered dance on balance and mobility in individuals with mild-moderate PD. Balance and gait were compared after 20 lessons within 10 weeks. Both groups the partnered and non-partnered groups reportedly demonstrated improvement as rated by the Berg Balance scale, with no significant differences noted between the partnered and non-partnered groups.

In yet another recent study by de Natale and colleagues (2017), these investigators explored the outcomes of Dance Therapy (DT) and Traditional Rehabilitation (TR) on both motor and cognitive domains in Parkinson's disease patients (PD) with postural instability. Sixteen PD patients with recent history of falls were divided into Dance Therapy (DT), and Traditional Rehabilitation (TR) groups. Motor (Berg Balance Scale, Gait Dynamic Index, Timed Up and Go Test, 4 Square-Step Test, 6- Minute Walking Test) and cognitive measures (Frontal Assessment Battery, Trail Making Test A and B and Stroop Tests) were tested at baseline, after the treatment completion and after 8-week follow-up. Motor and cognitive outcomes significantly improved after treatment and were retained after follow-up in the DT but not in the TR group. Their findings support the notion that DT is an intervention for PD patients, which effectively impacts on motor (endurance and risk of falls) and on executive functioning.

physical inactivity and low resting heart rate variability (HRV) are associated with an increased cardiovascular deconditioning, risk of secondary stroke and mortality. Dance offers the possibility of multidimensional physical activity and recent research supports its application as a valid alternative

cardiovascular training (Al-Qudah et al., 2015; Sampaio et al., 2016).

Individuals having suffered a stroke may have done so for numerous reasons. Whether dysfunction of the autonomic nervous system is a cause or an effect, post-stroke it is certainly an issue to be examined and treated, prophylactically or

otherwise. We know that

Sampaio and colleagues evaluated cardiac autonomic modulation in individuals with chronic stroke post-training using a virtual reality – based aerobic dance training paradigm of 6 weeks duration. HRV analysis pre- and post-intervention consisted of HRV for ten minutes in the supine and quiet standing positions. High-frequency (HF)

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power measures as indicators of cardiac parasympathetic activity, low-frequency (LF) power of parasympathetic-sympathetic balance and LF/HF of sympatho-vagal balance were calculated. YMCA submaximal cycle Ergometer test was used to acquire VO_2 max pre- and post-intervention. After training, participants demonstrated a significant improvement in autonomic modulation. Post-training the participants had significantly higher VO_{2max} , thereby justifying dance as an adjunct therapy in stroke rehabilitation.

Patterson et al., (2018) produced a systematic review of papers studying or purporting to have studied the value of dance as a rehabilitation tool in numerous conditions.

Their systematic review supported the use of dance in adults with a variety of neurological conditions, not only those suffering from PD. Their results suggested that dance is a useful interventional tool for adults with neurological conditions that can affect gait and balance such as stroke, multiple sclerosis, and Huntington's chorea with no adverse events reported. While the types of dance varied across studies as did the frequency and duration of classes. These findings contrasted with a systematic review of dance in PD, which included studies focused primarily on tango (Shanahan et al., 2015).

Patterson and colleague's (2018) review found that gains in gait, balance and functional mobility could be made with diverse forms of dance with numerous neurological conditions. The current review revealed that intensity of the program was rarely reported when describing the dance intervention. It should be noted, however, that the majority of studies analyzed in Patterson et al.'s (2018) analysis were randomized controlled trials and the quality of 5 of the 9 studies reviewed were rated poor or fair and therefore definitive conclusions about the effects of dance cannot be made at this time.

However, all 6 studies that measured functional mobility reported improvement with dance and 3 of those were rated good quality. The findings for the effects of dance on spatiotemporal

parameters of gait differed between studies; for example, velocity declined in some studies and did not change in others, whereas double support time was improved in another study.

The effects of dance on gait as measured by a clinical scale were more consistent; both studies that used the Dynamic Gait Index were rated as good quality and both reported improvement. Finally, some of the changes reported on gait velocity and Berg Balance Scale scores for individuals with stroke exceeded published MID cut-off s suggesting that some changes made with dance are likely to have an impact on participants' function. Given the indication of positive changes with dance in some studies with better quality ratings, further investigation of the effects of dance on balance, gait and functional mobility of people with neurological conditions other than PD is warranted.

In conclusion, the use of dance for neurological conditions other than PD has received very little attention. Like PD, many adult neurological conditions involve damage to central nervous system structures and feature motor impairments resulting in gait, balance and mobility dysfunction (admittedly due to different underlying pathologies) that could be improved with a dance program. It can be concluded that dance holds promise as an intervention to improve gait, balance and mobility in a

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variety of neurological as well as address the often seen attendant dysautonomias. The neurophysiological justification for such intervention reflected in the current literature is self-evident.

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