Dance and Parkinson's: A review and exploration of the role of cognitive representations of action

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Abstract

Parkinson's disease (PD) is a neurodegenerative disease causing both sensorimotor and non-motor impairments, and there is a clear need for non-medical approaches to improve quality of life. Dance is an increasingly popular activity among people with PD, which demonstrates potential therapeutic benefits. However, findings to date have been inconsistent, and little is known about the mechanisms underlying benefits of dance in PD. In this review, we provide an overview of research into dance for people with PD. The majority of evidence is in the sensorimotor domain, but cognitive, psychological and social effects have also been reported. We consider the role of cognitive representations of action within dance through observation, imitation and imagery, which may contribute to both sensorimotor and non-motor outcomes for people with PD. Moreover, we discuss how these processes may be enhanced through dance to provide further benefits in everyday life. Finally, we propose avenues for future research to increase understanding of action representation in dance for PD, which has the potential to inform practice and maximize benefits.

Keywords Parkinson's disease; quality of life; symptoms; dance; intervention; action representation; motor imagery; imitation; action observation; music; simulation; embodiment.

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Suggested reviewers	Daniel Eaves, Peter Lovatt, Bettina Blasing, Will Young

Submission Files Included in this PDF

File Name [File Type]

Dance and action representation in PD Bek et al resubmission 2 Cover Letter.docx [Cover Letter]

Dance and action representation in PD Bek et al resubmission_2 Response.docx [Response to Reviewers]

Dance and action representation in PD Bek et al Highlights.docx [Highlights]

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Research Data Related to this Submission

There are no linked research data sets for this submission. The following reason is given:
No data was used for the research described in the article

Dear Dr Cirulli,

Thank you for the opportunity to further revise our manuscript, "*Dance and Parkinson's: A review and exploration of the role of cognitive representations of action*", following the reviewers' latest comments. We have responded to these comments in the attached document, explaining the changes we have made.

The reviewers' suggestions have been very helpful in enabling us to further enhance the manuscript and provide additional clarification and consistency throughout the paper. We are grateful to the reviewers for taking the time and care to give such useful and comprehensive feedback.

Yours sincerely,

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Reviewer 1

The revised manuscript has improved in particular through the provision of relevant supporting evidences. While it does have the potential for a strong and coherent theoretical review paper; there are a number of shortcomings. I highly recommend the authors to address these carefully by considering the manuscript as a whole in their revision.

Overall, the changes were done in a piecemeal fashion, which reduced the coherence of the manuscript.

- We thank the reviewer for these suggestions. We have carefully considered the flow and coherence of the manuscript, and have made changes to the sections highlighted below as well as in other places (for example, restructuring Section 4).

To provide some examples: On page 8, the authors refer to a single case study as supporting evidence for functional brain changes through dance training in PD. Yet on page 14, the authors appropriately refer to the large controlled trial study by Myers et al. 2018 that did not identify advantages for neuronal changes in response to dance compared to exercise. The two references need to consideration within the same realm to provide an objective picture of existing evidence.

- The Myers et al. (2018) study is now introduced within the discussion of neuroimaging evidence on p8 and we have rephrased the citation on p13 within the discussion of effects of dance on motor imagery:

  [P8] *"In a larger-scale trial using fMRI to investigate effects of Tango, treadmill training and stretching (Myers et al., 2018), no change was found in activity of the somatomotor network after 12 weeks; however, separate results were not reported for each intervention. Further evidence is clearly needed to elucidate neuroplastic changes and mechanisms of neuroprotection in relation to dance in people with PD."*

  [P13] *"Another study (Myers et al., 2018) found no change in neural activity during motor imagery of gait but, as noted above, the results were combined for participants receiving three different interventions (Tango, treadmill training, and stretching), which may have masked any dance-specific effects."*

Similarly, in a number of paragraphs, the authors jump between topics, thus lacking coherence. For example, on page 21, the authors discuss live-vs-digital representation before discussing eye movement measures, to continue elaborating virtual or augmented reality studies.

- We have restructured Section 4.3 (now 4.2) to improve the flow between paragraphs.

Also, on page 19, it is not quite clear why dance styles and individual differences are discussed in the same section since the first and second paragraph are unrelated.

- Subsections 4.1. and 4.2. have been combined under the broader subheading "4.1. Investigating action representation in dance for Parkinson's", which encompasses proposed research into effects of action representation within dance across domains, and considers the influence of different dance styles and individual differences in relation to this.

Table 1 is extremely useful for further research and theoretical considerations; and I appreciate the authors work on this. However, it does in fact contradict the authors' focus on Tango as a dance intervention style. For example, on page 9, one reads: "To date, few published studies have investigated styles other than tango". Looking at the number of studies in table 1, while there are indeed more studies cited that employed tango as the dance intervention style overall, this is not the case for certain measures. Notably, the number of studies that found evidence for improvement through Tango practice across the measures is not significant. The text does require further clarification on this point. Further, in my view, providing actual numbers of studies would be a useful addition and clarification of the relevance of Tango as a dance style in consideration of its evidence for enhancement in PDs.

- Our aim is not to propose that Tango confers greater benefits than other dance styles, but to emphasise the need for further research across a range of different dance forms, since Tango has been investigated more than other styles. We have edited the manuscript to ensure that our point comes across as clearly as possible:

  [P9] *"Of the studies included in this review, the majority focused on Tango (n = 18), with others investigating effects of modern dance (n = 4), Irish set dance (n = 3), ballet (n = 1), Waltz/Foxtrot (n = 1), DMT (n = 1), or mixed styles including Dance for PD (n = 8)."*

  [P21] *"Another consideration for future research is that different dance styles may vary in the extent to which imagery and observation are used, or the explicitness of action representation processes. For example, improvisational dance may rely less on action observation but may have a stronger emphasis on imagery, while partnered dance may involve a greater influence of touch rather than observation during learning. These differences and their relationships to physical, social and emotional outcomes of dance could therefore be investigated."*

Other points:

- Page 8 first sentence "The majority…", is not evident from the preceding text

  - We have corrected this statement to read "*The majority of quantitative evidence to date showing potential benefits of dance for PD is in the sensorimotor domain, focusing on aspects of balance and gait, general severity of motor impairment, and functional mobility*"

- Page 8 last sentence in first paragraph "Additionally, …" is repetitive

  - We were not able to identify where the repetition is in this sentence; however, if the reviewer is able to clarify this point we would be happy to address it.

- Page 8 3rd paragraph is not clear in relation to the manuscript as a whole

  - We acknowledge that this point is peripheral to the key aims of the manuscript, and the need for further research into long-term outcomes is also noted on p22 ("*The relationship between action representation, music and movement in people with PD should also be explored, as well as longer-term outcomes in terms of neural changes in sensorimotor areas associated with action representation and transfer of skills to everyday tasks.*"); we have therefore removed this paragraph.

- 2nd paragraph page 15 is too vague.

  - We have added further detail to this paragraph to clarify the effects reported in the cited research:

    [P14] *"In healthy individuals, physiological responses (skin conductance) and subjective ratings of emotion when observing expressive movements have been found to be influenced by experience of dancing (Christensen et al., 2016), such that trained dancers were more sensitive than non-dancers to differences between movements expressing happiness and sadness. Moreover, dancers showed a closer correspondence between physiological measures and affective ratings. These findings indicate that dance* *training can enhance embodiment of observed actions, and has the potential to improve emotional and social processing in people with PD."*

- It would be of interest to understand "how" the authors understand that group or partner work is proposed to enhance inhibitory control.

  - This point has been elaborated upon to explain the rationale behind our suggestion, and we have inserted relevant references:

    [P15] *"However, inhibitory processes can be improved with practice (e.g., Spierer et al., 2013). Group or partner work in dance may therefore contribute to not only increased social imitation (e.g., Heyes, 2013), but also improved inhibitory control and coordinative action (e.g., via turn-taking, leading and following), resulting in enhanced interaction and communication."*

- Page 18: "Music could also provide a cue outside of classes" The authors could expand on this with empirical evidence

  - We have added a reference to support this point:

    [P19] "Music could also provide a cue outside of classes, evoking representations of associated actions or qualities of motion (e.g., Eitan and Granot, 2006) to facilitate movement."

- 4.1. is interesting, but the paragraph does not follow up on the notions.

  - As noted above, we have now restructured Section 4, incorporating proposed research into both motor and non-motor effects of dance in relation to action representation in Section 4.1.

- There are a number of repetitions in the manuscript that should be corrected, for example, page 19: "To date, the majority of studies of dance in relation to PD have involved forms of Tango." By that point, this statement has appeared a number of times.

  - Although we felt it appropriate to re-emphasise certain points in different sections of the manuscript, we appreciate that this may appear repetitive to the reader, and have removed or rephrased repeated statements accordingly.

- Page 21: "Nonetheless, as discussed above, video-based…" The studies provided in the section above did not support that evidence (as they were video-supported; not video-based training sessions).

  - We realise that this statement may not have been entirely clear, as it referred to the prior discussion of action observation therapies in PD (Section 3.1), rather than the studies immediately preceding this paragraph. This has been rewritten for clarification and we have also incorporated the point about social interaction in participatory dance from later in the section:

    [P20-21] *"It should be noted that live observation – both for dance and other actions – has been found to increase sensorimotor activity compared with digital observation (Jola and Grosbras, 2013). Additionally, the social element of dance is important to people with PD (Houston & McGill, 2013; Kunkel et al., 2018), and the group setting likely promotes greater use of imitation, coordination, and communicative and expressive action. Nonetheless, as discussed in Section 3.1, video-based action observation therapies have shown positive effects in people with PD."*

- Page 20: The definition of kinaesthetic empathy is misleading. Reason and Reynolds described it as the ability to experience empathy merely by observing movements of another human being. To my knowledge, it has not been investigated if they spectators had the same ‘feeling’ (spectators have muscle-specific motor resonance; which does not imply the same ‘feeling’)

- We have rephrased this point:

  [P20] *“The term “kinaesthetic empathy” has been used in relation to dance and neuroaesthetics (Jola et al., 2012b; Reason and Reynolds, 2010), to describe a process of embodiment in which audiences may internally simulate the dancers’ movements when watching a performance.”*

- “participation” in the following sentence is wrong (or misleading in this context as ‘dance participation in the studies’) and should be corrected with ‘expertise’ or ‘training’

- This has now been rephrased:

  [P20] *“Neuroimaging evidence has indicated the involvement of sensorimotor processes when watching dance (Calvo-Merino et al., 2008, 2005; Cross et al., 2009, 2006); moreover, experience in observing dance even without physical training can increase corticomotor responses to familiar dance movements (Jola et al., 2012a).”*

- Page 22: do the authors mean iii: dance can enhance motor imagery and embodiment in PD?

- The aim of this paragraph is to explain that we are bringing together evidence from different literatures (both on PD and non-PD research) and drawing on this to hypothesise roles of action representation in dance for PD. We have rephrased this for clarification:

  [P22] *“Evidence from various lines of investigation indicates that (i) action observation, imitation and motor imagery can facilitate movement in people with PD; (ii) dance can enhance motor imagery and embodiment in healthy participants; and (iii) action observation and imagery may contribute to physical and emotional effects of dance.”*

- Overall in-text citations need correction (use of brackets)

- We thank the reviewer for pointing out this formatting issue, which we have corrected throughout the manuscript.

Reviewer 2

- The authors have replied to all my comments and they did a great job in improving the paper.

- We thank the reviewer for their previous comments, which have contributed to the improvement and clarification of the manuscript.

Dance and Parkinson's: A review and exploration of the role of cognitive representations of action

Highlights

- Dance can provide both motor and non-motor benefits in Parkinson's disease (PD)
- Dance utilises internal action representations through observation and imagery
- Music promotes and supports action representation in dance
- Action representation may contribute to positive effects of dance for PD
- Future research should explore mechanisms of action representation in dance for PD

Dance and Parkinson's: A review and exploration of the role of cognitive representations of action

Abstract

Parkinson's disease (PD) is a neurodegenerative disease causing both sensorimotor and non-motor impairments, and there is a clear need for non-medical approaches to improve quality of life. Dance is an increasingly popular activity among people with PD, which demonstrates potential therapeutic benefits. However, findings to date have been inconsistent, and little is known about the mechanisms underlying benefits of dance in PD.

In this review, we provide an overview of research into dance for people with PD. The majority of evidence is in the sensorimotor domain, but cognitive, psychological and social effects have also been reported. We consider the role of cognitive representations of action within dance through observation, imitation and imagery, which may contribute to both sensorimotor and non-motor outcomes for people with PD. Moreover, we discuss how these processes may be enhanced through dance to provide further benefits in everyday life. Finally, we propose avenues for future research to increase understanding of action representation in dance for PD, which has the potential to inform practice and maximize benefits.

Dance and Parkinson's: A review and exploration of the role of cognitive representations of action

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Dance and Parkinson's: A review and exploration of the role of cognitive representations of action

Keywords

Parkinson's disease; quality of life; symptoms; dance; intervention; action representation; motor imagery; imitation; action observation; music; simulation; embodiment.

1. Introduction

Parkinson's disease (PD) is a neurodegenerative condition affecting more than 1 in 100 people aged over 60, in which depletion of dopamine in the substantia nigra alters the functioning of basal ganglia circuitry. This results in multiple sensorimotor impairments, including reduced speed and amplitude of movement, rigidity, tremor and balance and gait disturbances. The internal generation of movement, which relies upon cortical-subcortical networks, is particularly affected (Brown and Marsden, 1988); indeed, it has been proposed that the loss of dopamine in the basal ganglia selectively impairs automatic or habitual movement rather than goal-directed actions (Redgrave et al., 2010).

Additionally, PD involves non-motor features including mood disturbances, cognitive impairments and apathy (Chaudhuri et al., 2006). Although recent genetic and pharmacotherapuetic advancements are promising (see Foltynie and Langston, 2018), no disease-modifying treatment for PD is currently available. While symptoms may be controlled to a degree by medications or neurosurgery, there is a clear need for non-medical approaches that can improve everyday functioning and quality of life (e.g., Bek et al., 2016a; Kleiner-Fisman et al., 2013).

Dance is becoming increasingly popular as a therapeutic activity for people living with PD. Combining physical, rhythmic, cognitive, emotional and social elements, dance is complex and multidimensional, with the potential to impact upon multiple domains of functioning in PD (Dhami et al., 2015; Houston and McGill, 2013; Kshtriya et al., 2015). Physical activity promotes dopamine release and may offer neuroprotection (Hou et al., 2017), but levels of activity are reduced among people with PD (Nimwegen et al., 2011), and participation can be affected by loss of motivation, low mood and fatigue (Afshari et al., 2017). However, motivation levels and adherence rates among people with PD participating in dance are high (Sharp and Hewitt, 2014), suggesting that long-term participation may be more feasible for dance than other forms of physical or cognitive activity.

This article briefly reviews the current evidence on benefits of dance for people with PD across sensorimotor and non-motor domains. We then discuss a set of mechanisms, based on the internal representation of action, which may underlie some of these effects. In particular, we consider the roles of observation, imitation and imagery in contributing to sensorimotor and non-motor outcomes of dance. Finally, we suggest future directions for research to increase understanding of these mechanisms, in order to further extend the benefits of dance for people living with PD.

2. Dance and Parkinson's: the existing evidence

Several review articles on the topic of dance for people with PD have been published in recent years. These include PD-specific meta-analyses (dos Santos Delabary et al., 2018; Kalyani et al., 2019; Lotzke et al., 2015; Shanahan, 2015a; Sharp and Hewitt, 2014) and systematic reviews (Aguiar et al., 2016; Mandelbaum and Lo, 2014), as well as a review of non-motor outcomes of dance in both PD and healthy ageing (McNeely et al., 2015a) and a broader review on dance and ageing (Kshtriya et al., 2015). The above meta-analyses, which included between 5 and 13 studies, reported evidence of short-term benefits to people with PD in terms of general motor impairment severity, gait, freezing, balance and functional mobility, as well as some cognitive improvements. Limitations in the existing literature were highlighted, such as the scarcity of randomised controlled trials, the fact that many studies were conducted by the same research groups, small sample sizes, poor quality and risk of bias. It was suggested that future research should examine the optimal dosage and long-term benefits of dance, the effects on social interaction and quality of life, and the effects of different dance styles, as well as comparisons with other therapeutic activities..

In the following sections we provide an overview of the current evidence, rather than a comprehensive account of the literature, summarising the effects of dance found in sensorimotor and non-motor domains in people with PD. Table 1 outlines findings in relation to quantitative outcome measures; more detailed summaries of study characteristics and outcomes are provided in the supplementary material.

2.1. Sensorimotor outcomes

In the sensorimotor domain, the most commonly reported improvements were in severity of motor impairment based on the Unified Parkinson's Disease Rating Scale (UPDRS or MDS-UPDRS; e.g., Goetz et al., 2008), and balance, assessed using a variety of clinical measures.

Participation in Tango has been associated with reduced motor impairment in uncontrolled studies (Hackney and Earhart, 2009a; Rabinovich et al., 2017), and compared with a no-intervention (Duncan and Earhart, 2012; 2014) or education (McKee and Hackney, 2013) control group.

Motor signs have also been reported to be improved with Irish set dancing in an uncontrolled study (Shanahan et al., 2015b) and when compared to an exercise-based intervention (Volpe et al., 2013), as well as in uncontrolled studies of mixed dance styles (Heiberger et al., 2011; Westheimer et al., 2015) and modern dance (Marchant et al., 2010).

Improvements in balance have been reported following participation in Tango, in 4 uncontrolled studies (see Table 1), and when compared with no-intervention control groups (Duncan and Earhart, 2012; 2014), an education control group (McKee and Hackney, 2013), or exercise or physiotherapy based interventions (Hackney et al., 2007a; Hackney et al., 2007b; Rios Romenets, Anang, Fereshtehnejad, Pelletier, and Postuma, 2015). Modern dance has been associated with improved balance in uncontrolled studies (Batson, 2010; Batson, Migliarese, Soriano, Burdette, and Laurienti, 2014; Marchant et al., 2010) and compared with an exercise intervention (Hashimoto et al., 2015). One study of Irish set dancing (Volpe et al., 2013) found an advantage of dance for balance measures compared with individual physiotherapy. Uncontrolled studies of ballet (Houston and McGill, 2013) and "Dance for PD" - an approach specifically developed for people with PD - (Bearss et al., 2017) have also reported improvements in balance.

Findings in relation to aspects of walking and gait (e.g., velocity) and functional mobility have been less consistently found. Improvements in gait were noted for Tango in 4 uncontrolled studies (see Table 1) and when compared with a no-intervention group (Duncan and Earhart, 2012). Functional mobility was found to improve in participants taking Tango classes compared with a no-intervention control group (Duncan and Earhart, 2014), and compared to self-directed exercise (Rios Romenets et al., 2015), traditional rehabilitation (De Natale et al., 2017) or treadmill and stretching programmes (Rawson et al., 2019). Gait was also reported to improve following a mixed-style dance programme compared with a social support control group (Ventura et al., 2016). Irish set dancing was associated with a reduction in freezing of gait and increased functional mobility compared to individual physiotherapy (Volpe et al., 2013), and gait speed was noted to improve in a cross-over control group study of dance/movement therapy (DMT) (Westbrook and McKibben, 1989). Uncontrolled studies have found increased functional mobility following Dance for PD (Bearss et al., 2017), improved self-reported mobility with a mixed dance programme (Heiberger et al., 2011), and improved gait with modern dance (Marchant et al., 2010).

A small number of studies have examined other sensorimotor outcomes. Tango has been associated with improvements in activities of daily living (Duncan and Earhart, 2014) and dexterity (Duncan and Earhart, 2012) compared with a no-intervention control group. An uncontrolled study of "Zumba Gold" for PD using wearable accelerometers during classes found an increase in activity levels over 6 weeks (Delextrat et al., 2016), although this could reflect differences in movement complexity or speed as teaching progressed. Studies using qualitative approaches (e.g., observations, diaries or interviews) have also reported sensorimotor outcomes such as improvements in movement quality, body awareness and rigidity in participants taking ballet (Houston and McGill, 2013) and Dance for PD (Westheimer et al., 2015).

Few studies have compared the effects of different dance styles. Hackney and Earhart (2009b) found similar improvements in balance and gait with Tango or American ballroom (Waltz/Foxtrot) classes compared with a no-intervention control group. Comparing outcomes of Tango and Dance for PD, McNeely et al. (2015b) found similar improvements in both groups on repeated sit-to-stand, balance and walking endurance after 12 weeks, although the Tango group showed greater gains for motor signs and functional mobility. The authors note that the movements practiced in Tango overlap more with those assessed by the outcome measures, highlighting the importance of selecting appropriate assessment tools. However, these findings must be interpreted with caution as the Dance for PD programme was compared with an existing Tango programme within another ongoing study.

[Table 1: Outcomes of dance in people with PD]

2.1. Non-motor outcomes

Non-motor effects of dance have been investigated in people with PD using approaches such as questionnaires, neuropsychological assessments and qualitative methods. Despite the obvious cognitive demands of dance, only a small number of studies have examined outcomes in this domain for people with PD. Mixed effects on tests of spatial cognition were found following Tango classes when compared with a health education control group (McKee and Hackney, 2013) and on executive function when compared to traditional rehabilitation (De Natale et al., 2017). Using a brief measure of general cognitive function, one study found a trend towards improvement in a Tango group compared with a self-directed exercise group (Rios Romenets et al., 2015), while McKee and

Hackney (2013) found improvements in both Tango and education groups. Comparing participants of a mixed-style dance programme to a social support group, Ventura et al. (2016) found improvements in verbal working memory and attentional switching but not on measures of executive function, while improved executive function was found following a modern dance intervention compared with exercise or no intervention (Hashimoto et al., 2015).

Dance has also been found to improve mood and affect in PD, although again findings are inconsistent. In uncontrolled studies, a reduction in depression scores was found following participation in Tango (Blandy et al., 2015), and an overall improvement in mood, as well as a specific reduction in anger, was found in people with PD taking part in a mixed dance programme (Lewis et al., 2016). Lower depression scores were found in Dance for PD participants compared with a social support group (Ventura et al., 2016), and for DMT compared with exercise in a cross-over study (Westbrook and McKibben, 1989). Reductions in apathy and depression were also reported for modern dance compared with exercise and no-intervention control groups (Hashimoto et al., 2015). However, other studies did not find improvements in mood and apathy following participation in various dance styles (see Table 1).

Few studies have examined the effects of dance on other non-motor symptoms of PD such as sleep disturbances, pain and fatigue. One study reported improvement in the UPDRS non-motor examination after two years of Tango classes compared with a no-intervention control group (Duncan and Earhart, 2014), and a trend towards a reduction in fatigue was found with Tango compared to self-directed exercise (Rios Romenets et al., 2015).

Self-reported quality of life, encompassing well-being across domains including mood, cognition, mobility and daily activities, has been assessed in several studies of dance for PD. Increased quality of life was found following participation in Tango compared to Tai Chi and a no-intervention control group (Hackney and Earhart, 2009c), as well as in uncontrolled studies of mixed dance styles (Bearss et al., 2017; Bognar et al., 2017; Heiberger et al., 2011; Westheimer, 2008) and Irish set dancing

(Shanahan et al., 2015b). However, others found no improvement in quality of life with Tango in an uncontrolled study (Blandy et al., 2015) or when compared to an educational control group (McKee & Hackney, 2013). Self-reported social participation was enhanced in participants of a Tango programme compared with a no-intervention control group, including participation in new activities (Foster et al., 2013). Two further studies without control groups also reported increased social participation in people with PD following Tango (Zafar et al., 2017) or dance for Parkinson's (Bognar et al., 2017) programmes. Additionally, qualitative studies of various dance styles have highlighted further psychosocial outcomes such as increased confidence and motivation (Bognar et al., 2017; Houston and McGill, 2013; Rocha et al., 2017; Westheimer, 2008; Westheimer et al., 2015).

As in the sensorimotor domain, few studies have compared non-motor outcomes between different dance styles. Hackney and Earhart (2009c) reported improved quality of life with Tango but not American ballroom dance, while McNeely et al. (2015b) found no improvement with either Tango or Dance for PD.

When considering non-motor outcomes, it is important to note that participants value the social environment of dance classes (e.g., Houston and McGill, 2013; Kunkel et al., 2018), and partnered dance has been associated with greater enjoyment and motivation to continue compared with non-partnered dance (Hackney and Earhart, 2010), indicating the importance of social contact in improving well-being. Loss of confidence, apathy and social isolation are likely to impact significantly on quality of life in people with PD (Karlsen et al., 2000); the above findings suggest that dance may address these issues, also leading to engagement in other social activities that could further improve quality of life.

2.3. Summary of findings

The majority of quantitative evidence to date showing potential benefits of dance for PD is in the sensorimotor domain, focusing on aspects of balance and gait, general severity of motor impairment, and functional mobility. However, improvements have not consistently been found, and many studies are limited by small sample sizes or the absence of control groups, as noted in previous reviews. Additionally, few studies have examined other sensorimotor outcomes, such as fine motor tasks relating to dexterity and activities of daily living.

Some improvements in non-motor domains such as cognition, mood and quality of life have been reported, although other than the most widely-used measure (Parkinson's Disease Questionnaire; PDQ-39; Peto et al., 1995), there is little overlap between studies to allow comparisons to be made. Despite the involvement of emotional and social cognitive processes in dance, these have not been tested quantitatively. Nonetheless, given the importance of non-motor outcomes for the well-being of people with PD, it is important to try to elucidate and understand these effects.

Neurophysiological effects of dance are also poorly understood, having been investigated in only a few studies. A single-case fMRI study found increased functional connectivity between the basal ganglia and premotor cortex following 5 days of intensive modern dance training (Batson et al., 2014), and EEG studies involving small numbers of participants found evidence of changes in muscle synergy during walking and balance tests after 3 weeks of Tango classes (Allen et al., 2017; McKay et al., 2016). In a larger-scale trial using fMRI to investigate effects of Tango, treadmill training and stretching (Myers et al., 2018), no change was found in activity of the somatomotor network after 12 weeks; however, separate results were not reported for each intervention. Further evidence is clearly needed to elucidate neuroplastic changes and mechanisms of neuroprotection in relation to dance in people with PD.

The heterogeneity among previous studies in terms of participant characteristics, intervention duration and intensity, trial design and outcome measures, makes it difficult to identify consistent effects across the literature. In the studies summarized in this review (see supplementary material), interventions have varied in intensity from 45 to 450 minutes per week, with investigations ranging from a single session up to 5 years. Ten studies compared dance with an alternative intervention (e.g., exercise programme), 9 compared dance with an inactive control group, and 17 did not include any control or comparison group, while three studies compared different dance styles. Sample sizes ranged from 5 to 26 per group, including participants at various levels of disease progression, from asymptomatic to severe. There were also gender imbalances within and between groups, as well as across studies. Participants were tested on their usual medications in some studies while medication was withheld in others, and several studies did not report medication status. Quantitative and qualitative outcome measures have been used, as well as mixed approaches. Additionally, differences between dance styles mean that some will be more closely aligned with commonly-used clinical assessment tools, whereas others may produce effects best captured by alternative measures. Of the studies included in this review, the majority focused on Tango (n = 18), with others investigating effects of modern dance (n = 4), Irish set dance (n = 3), ballet (n = 1), Waltz/Foxtrot (n = 1), DMT (n = 1), or mixed styles including Dance for PD (n = 8).

In order to advance knowledge of how the benefits of dance for people with PD are achieved, future research should explore the underlying mechanisms of its effects. A better understanding of elements and processes in dance that are particularly effective could inform evidence-based approaches to optimize the benefits of dance across domains and provide a framework for selecting suitable outcome measures for future studies.

Given the complexity of dance as a physical, emotional, cognitive and social activity (Dhami et al., 2015), its efficacy cannot easily be distilled down to a small number of components. Nonetheless, in the following section we discuss one candidate set of processes, based on internal representations of action, which may contribute broadly to both motor and non-motor effects of dance in PD, and could be targeted within dance programmes to further enhance outcomes.

3. Dance, action representation and Parkinson's

Observation of others' movement primes action by engaging a network of brain areas, located primarily in fronto-parietal sensorimotor regions, which overlap with those involved in motor execution (Caspers et al., 2010; Rizzolatti and Sinigaglia, 2010). Movement may be imitated either deliberately - by watching and copying actions - or more spontaneously, such as by inadvertently moving in a similar manner to those around us. Observation and imitation can thus facilitate movement and learning through shared motor representations (Buccino et al., 2004; Lagravinese et al., 2017; Stefan et al., 2008). In dance, these processes of action representation occur naturally: students learn by watching and replicating the instructor's movements, and group or partner work often involves imitating or "mirroring" other dancers.

Motor imagery - sometimes referred to as "mental practice" - shares neural substrates with both observation and execution of actions (Hardwick et al., 2018), and includes visual (imagining what a movement looks like) as well as kinaesthetic (imagining what a movement feels like) components (e.g., Guillot et al., 2009). Widely utilized in sports training and rehabilitation (Schuster et al., 2011), motor imagery is used by dancers to aid learning and enhance movement quality (Blasing et al., 2012; Nordin and Cumming, 2008). Dance experience has been associated with qualitative differences in imagery, including a greater reliance on kinaesthetic representations (Golomer et al., 2008; Jola et al., 2011; Nordin and Cumming, 2006).

Action observation, imitation and imagery therefore provide potentially powerful tools to prime movement within dance for people with PD via motor simulation, enabling access to known movement patterns or enhancing motor learning. This facilitation can be considered within the context of the relative preservation of associative networks in the basal ganglia, which underlie goal-directed movement control and may compensate for the diminished production of automatic movements (Redgrave et al., 2010). This is also evident in the facilitatory effects of external visual and auditory cues in people with PD (Spaulding et al., 2013; van Wegen et al., 2014).

People with PD have shown the ability to imitate actions (for review, see Poliakoff, 2013), as well as exhibiting motor resonance for incidentally-observed (task-irrelevant) movements (Bek et al., 2018). They are also able to engage in motor imagery, reporting similar vividness to age-matched controls (Bek et al., 2019; Heremans et al., 2011). Several studies have demonstrated promising effects of interventions based on either observation or imagery in PD (see Abbruzzese et al., 2015; Caligiore et al., 2017). Combining observation and imagery has been shown to increase behavioural and neural effects in healthy individuals (Eaves et al., 2016), and there is some evidence that this combined approach may be effective in people with PD (Bek et al., 2019), but therapeutic benefits have not yet been tested.

Action observation, imagery and imitation are already frequently incorporated within dance programmes for people with PD. Indeed, several of the studies reviewed in this article refer explicitly to action representation processes, using terms such as “imagery”, “mirroring”, “visualization” or “mental rehearsal”. In the sections below, we consider the involvement of imagery and visually-evoked actions in sensorimotor, social and emotional effects of dance for people with PD. We then discuss the role of music and rhythm in dance and action representation.

Although other forms of exercise and creative activities also utilise action representations, in the present article we focus on dance as an emerging therapeutic approach for people with PD that has the potential to provide sustainable long-term benefits across multiple physical and non-physical domains.

3.1. Sensorimotor effects of action observation and motor imagery

Consistent with the broader literature on action observation, watching dance has been shown to activate sensorimotor cortical areas in the observer’s brain, and the strength of this response is mediated by experience (Calvo-Merino et al., 2005; Cross et al., 2009, 2006). In healthy participants, increased neural activations have been found when actions are observed with the intention to imitate than with passive viewing (Grèzes et al., 1999). Therefore, when dance is observed in an active learning context (i.e., within a class), movement should be primed to a greater extent.

As noted above, external sensory cues can facilitate movement in people with PD. Seeing other people's movement provides another type of stimulus that may prime a broader range of actions than afforded by simple cueing, and a small number of studies have indicated effects of action observation in PD. People with PD have been found to exhibit motor resonance for simple hand actions – that is, their movements are automatically influenced by observing those of another person (Bek et al., 2018). They are also able to imitate the timing (Pelosin et al., 2010; Robles-Garcia et al., 2013) and amplitude (Bek et al., 2019) of observed actions. Thus, watching and imitating actions within dance is also likely to be effective in enhancing the timing and quality of movement in people with PD.

Moreover, action observation has been used in other therapeutic interventions for people with PD, demonstrating improvements in motor symptoms, balance and gait (Agosta et al., 2017; Pelosin et al., 2010), as well as increased functional independence (Buccino et al., 2011). There is also preliminary evidence that training with action observation can increase fronto-parietal brain activity in people with PD (Agosta et al., 2017). These findings suggest that, beyond the immediate facilitation of movement, action observation within dance may also confer therapeutic benefits over time.

Motor imagery is sometimes used explicitly in dance, but may also be evoked indirectly through the use of narrative or analogy, providing an implicit context in which to imagine visual and kinaesthetic properties of a movement. This could include the mechanics or qualities involved in a particular manner of moving (e.g., "move your arm like a swan"; Butt, 2017), or those afforded by an imagined object (e.g., weaving a thread; putting on a pair of boots). Evidence from healthy participants indicates that motor imagery may be enhanced by dance training: studies involving both novices (Sacco et al., 2006) and expert ballet dancers (Bar and DeSouza, 2016) have reported increased sensorimotor cortical activations during imagined movement following dance training combined with imagery practice.

People with PD are able to perform motor imagery of basic actions (e.g., Bek et al., 2019; Heremans et al., 2011), and motor imagery practice has shown positive effects within therapeutic interventions for PD (Kikuchi et al., 2014; Tamir et al., 2007). However, the processes underlying motor imagery may be compromised in PD, with neurophysiological evidence suggesting a greater reliance on compensatory networks involving visual processing areas (van Nuenen et al., 2012). Additionally, people with PD have shown a tendency to depict actions from a third-person (external) perspective rather than a first-person (internal) perspective when producing communicative gestures (Humphries et al., 2016), further indicating that they may be less likely to engage spontaneously in kinaesthetic imagery.

As noted above, observation and imagery are found to have stronger effects on movement when combined (Bek et al., 2016b; 2019; Eaves et al., 2016), and dance may promote the use of kinaesthetic imagery in people with PD by providing visual input through action observation, thereby reducing reliance on internally-generated action representations (Bek et al., 2019). References to imagined characters, objects or scenes within dance may also evoke both visual and kinaesthetic imagery, reducing the need for spontaneous generation of motor images.

To date, very few studies have examined effects of dance on imagery in people with PD, and findings are inconclusive. Improved performance on a task requiring mental rotation of body parts was found following participation in modern dance (Hashimoto et al., 2015), but an exercise group also showed improvement, so the effect cannot be specifically attributed to dance. Another study (Myers et al., 2018) found no change in neural activity during motor imagery of gait but, as noted above, the results were combined for participants receiving three different interventions (Tango, treadmill training, and stretching), which may have masked any dance-specific effects.

If dance can improve motor imagery ability in people with PD, this could provide a strategy to facilitate movement in everyday life, thereby producing effects beyond dance classes. Indeed, qualitative evidence indicates that some individuals with PD use observation and imagery spontaneously for daily tasks (Bek et al., 2016a), and dance could encourage people with PD to apply these skills more broadly. Further to improving motor imagery ability in general, dance training may specifically increase the use of kinaesthetic imagery, as well as the utilisation of visual information provided by action observation to facilitate this.

3.2 Emotional, social and psychological effects of action observation and motor imagery

So far we have considered the influence of observation, imitation and imagery on movement, but the action observation system has also been proposed to have a role in social understanding and empathy (Chartrand and Bargh, 1999; Iacoboni, 2005). For example, when we witness another person expressing a particular emotion, the same emotion may be embodied through our own neural and physiological response (Decety and Jackson, 2006). People with PD can have difficulty in recognizing emotions (Argaud et al., 2018), which may result from their own reduced facial expressiveness impacting on the ability to simulate others' emotions (e.g., Ricciardi et al., 2017). Additionally, communicative co-speech gestures may be altered in people with PD (Cleary et al., 2011; Humphries et al., 2016). Together, these issues can limit the ability to understand, empathise and communicate with others. Indeed, social cognition has been widely reported to be affected in PD (e.g., Narme et al., 2013), and difficulties with communication can impact significantly on well-being for people with PD (Wootton et al., 2018).

In healthy individuals, physiological responses (skin conductance) and subjective ratings of emotion when observing expressive movements have been found to be influenced by experience of dancing (Christensen et al., 2016), such that trained dancers were more sensitive than non-dancers to differences between movements expressing happiness and sadness. Moreover, dancers showed a closer correspondence between physiological measures and affective ratings. These findings demonstrate that dance training can enhance embodiment of observed actions, indicating the potential to improve emotional and social processing in people with PD.

Links to action representation, empathy and communication may be provided by aesthetic aspects of dance for people with PD, such as the use of story-telling and expression through movement (Westheimer, 2008). As noted above, themes and narratives within dance may encourage and facilitate the use of motor imagery. Additionally, practicing expressive gestures and facial movements in a group setting may enhance communicative action as well as increasing empathy through embodiment of emotions.

Dance often involves coordinating with others' movements and producing joint action, which relies on the ability to internally represent others' actions and either imitate or inhibit those movements as appropriate (Sebanz et al., 2006). This imitative control is also suggested to be important in social interaction (Spengler et al., 2010). Inhibitory control of action can be impaired in PD (Wylie et al., 2012), and the ability to inhibit imitation of observed actions may increase with disease severity (Bek et al., 2018). However, inhibitory processes can be improved with practice (e.g., Spierer et al., 2013). Group or partner work in dance may therefore contribute to not only increased social imitation (e.g., Heyes, 2013), but also improved inhibitory control and coordinative action (e.g., via turn-taking, leading and following), resulting in enhanced interaction and communication.

Dance has also been reported to provide psychological benefits for people with PD, such as improving confidence and motivation. Studies with older adults have highlighted the role of imagery in increasing self-efficacy and motivation in relation to physical activity (Kosteli et al., 2019; Wesch et al., 2006), suggesting another route by which imagery may contribute to functional outcomes of dance, as well as improving general well-being.

3.3. Music, rhythm, and action representation

In addition to visual cues, external auditory cues such as music and rhythmic stimuli can aid motor control in PD. Music and rhythm are key components of many forms of dance, and also provide links to internal representations of action.

Music and rhythmic cues have been found to facilitate movement and timing in people with PD (for review see Ghai, Ghai, Schmitz, and Effenberg, 2018; Spaulding et al., 2013). For example, rhythmic auditory stimulation - a form of cueing that involves walking to music or a metronome beat - has been found to improve gait parameters as well as perceptual and motor timing in PD (Ashoori et al., 2015). The beneficial effects of music and rhythm are suggested to result from the activation of neural structures involved in movement and timing (Chen et al., 2008; Ghai et al., 2018), which may be accessed via alternative pathways associated with externally cued or goal-driven movement that bypass the affected basal ganglia circuitry, particularly premotor cortical areas (e.g., Hanakawa et al., 1999). However, beneficial effects are not consistently found, and it is likely that rhythm-based interventions need to be tailored to the individual (Ghai et al., 2018). Enhanced effects have been found when music was used to deliver rhythmic cueing, both in people with and without PD (Ghai et al., 2018; Rodger and Craig, 2016; Rose et al., 2019). Music provides a richer stimulus to elicit movement than simple rhythmic cues that rely more on intact timing mechanisms, and has been found to promote dopamine release in the basal ganglia (Salimpoor et al., 2011), activating neural networks involved in emotion and motivation (Ferreri et al., 2019). This process may contribute further to facilitatory effects on movement in people with PD (Pacchetti et al., 2000).

It has also been found that a population of "audiovisual" neurons in the brain are activated by action-relevant auditory stimuli (Kohler et al., 2002). Indeed, neuroimaging studies have shown that the motor system is engaged by music perception (Zatorre et al., 2007), and motor facilitation has been found in response to action-related sounds (Aziz-Zadeh et al., 2004). These findings suggest a route by which music and auditory cues may influence movement and emotion in a similar way to action observation (e.g., Overy and Molnar-Szakacs, 2009; Zatorre et al., 2007).

In the context of dance, music is therefore likely to boost the effects of action observation and imagery by providing an additional input into sensorimotor networks. For example, activity in the extrastriate body area, which is involved in action observation (e.g., Hardwick et al., 2018) has been found to be enhanced when dance movements were observed with accompanying music (Jola et al., 2013).

The effects of ecological action-sound cues have also been investigated in people with PD (Young et al., 2014). Walking to recorded footstep sounds reduced both temporal and spatial variability of gait, and step length variability improved more with this naturalistic stimulus than with metronome cueing. Moreover, participants demonstrated the ability to use motor imagery to regulate their step length after listening to the footstep cue, suggesting that this type of stimulus might be particularly effective by facilitating access to motor representations. Research in healthy participants has also shown that action-relevant auditory cues (footstep sounds) can influence the perception of one's own body (Tajadura-Jiménez et al., 2015), further indicating that movement characteristics may be altered via changes in imagined movement.

Westheimer (2008) notes that music and imagery in dance are intimately linked, and music has been used to support imagery of trained dance sequences in the absence of physical performance (e.g., Bar and DeSouza, 2016). Music may influence imagined movement and subsequent action execution in a number of ways. For example, a piece of music could be associated with a learned sequence (e.g., Rocha et al., 2017) or recall a particular movement pattern such as marching or swaying. Music may also evoke the imagined movement of an animal, object or natural substance (e.g., a gliding bird, a falling leaf, waves on the ocean), and it has been proposed that the motor system may be involved in representing these non-human movements (Schubotz, 2007). Music also supports storytelling and themes, and the combined use of storytelling and music in dance provides a particularly rich context to promote motor imagery.

4. Future directions

In this section we suggest directions for future research to increase understanding of action representation within dance for people with PD, and to identify how further benefits may be obtained within dance training or even through watching dance.

4.1. Investigating action representation in dance for Parkinson's

As noted above, studies in healthy participants have indicated effects of dance training on motor imagery (Bar and DeSouza, 2016; Sacco et al., 2006) and on physiological and neural responses to observed actions (Calvo-Merino et al., 2005; Christensen et al., 2016; Cross et al., 2006), but effects of dance on action representation have not yet been objectively demonstrated in people with PD. The investigation of changes relating to action observation, imitation and motor imagery in people with PD participating in dance therefore offers a promising avenue for future research. For example, motor imagery ability may be enhanced, or participants may learn to apply observation and imagery more effectively as strategies to facilitate movement for everyday tasks. These outcomes should be explored using both quantitative (e.g., neuroimaging) and qualitative (e.g., subjective reports of imagery use) measures, and could also be studied in relation to the explicit use of action representation processes within or alongside dance programmes. The relationship of sensorimotor and non-motor effects of dance in people with PD to changes in neural (e.g., sensorimotor activations during imagined movement) and behavioral (e.g., body rotation tasks) measures of motor imagery and action simulation could also be examined.

Previous reviews have highlighted the need for further research into outcomes relating to social interaction (e.g., Lotzke et al., 2015). In particular, social-cognitive processes involving action representation could be assessed, such as emotion recognition, empathy and communicative gestures. Improvements in these processes could help people with PD to regain confidence and maintain social participation and interaction, but have received little attention in previous studies of dance and PD.

While the effects of music and rhythmic cues have been studied more broadly in people with PD, the influence of music on outcomes of dance for PD should also be explored, such as investigating the relationship between music, imagery and movement. In particular, music may enhance the effects of action observation, and promote and enhance motor imagery within dance classes. Music could also provide a cue outside of classes, evoking representations of associated actions or qualities of motion (e.g., Eitan and Granot, 2006) to facilitate movement.

Another consideration for future research is that different dance styles may vary in the extent to which imagery and observation are used, or the explicitness of action representation processes. For example, improvisational dance may rely less on action observation but may have a stronger emphasis on imagery, while partnered dance may involve a greater influence of touch rather than observation during learning. These differences and their relationships to physical, social and emotional outcomes of dance could therefore be investigated.

Effects of dance may also be mediated by individual differences in motor imagery ability, which are found both within the general population and among people with PD (Heremans et al., 2011; McAvinue and Robertson, 2008). Moreover, older people or those with neurological conditions may have greater difficulty in understanding and engaging with imagery tasks, because of cognitive impairments or reduced access to action representations (e.g., Emerson et al., 2018). These potential barriers could be addressed, respectively, by employing imagery more implicitly within dance programmes (e.g., through story-telling), or by providing additional education and instruction on imagery techniques.

Individual differences in motor experience and ability can also influence the effects of action observation. Cortical excitability and activation of sensorimotor neural networks are greater for observed movements that are more similar to those within the observer's own motor repertoire (e.g., Avanzino et al., 2015; Calvo-Merino et al., 2005); however, there is evidence that observational training can alter this neural response as new movements are learned, thus expanding the motor repertoire (Cross et al., 2009; Jola et al., 2012a; Lagravinese et al., 2017). To maximise potential benefits, individual motor abilities could therefore be taken into consideration when observation and imagery based exercises are practiced within dance.

4.2. Watching dance: a potential investigative and therapeutic approach

In this review we have discussed the role of action representation within dance and how observation, imitation and imagery may contribute to both motor and non-motor outcomes. A further suggestion is that, even without active participation, simply watching dance could offer therapeutic effects for people with PD. The term "kinaesthetic empathy" has been used in relation to dance and neuroaesthetics (Jola et al., 2012b; Reason and Reynolds, 2010), to describe a process of embodiment in which audiences may internally simulate the dancers' movements when watching a performance. Neuroimaging evidence has indicated the involvement of sensorimotor processes when watching dance (Calvo-Merino et al., 2008, 2005; Cross et al., 2009, 2006); moreover, experience in observing dance even without physical training can increase corticomotor responses to familiar dance movements (Jola et al., 2012a).

It should be noted that live observation – both for dance and other actions – has been found to increase sensorimotor activity compared with digital observation (Jola and Grosbras, 2013). Additionally, the social element of dance is important to people with PD (Houston & McGill, 2013;

Kunkel et al., 2018), and the group setting likely promotes greater use of imitation, coordination, and communicative and expressive action. Nonetheless, as discussed in Section 3.1, video-based action observation therapies have shown positive effects in people with PD. Training with observation and imagery of dance (i.e., watching videos while engaging in kinaesthetic imagery of the observed movements) may therefore provide a safe option for people with PD who are unable to attend classes, or could be used to supplement classes. In studies of Irish set dancing for people with PD, participants were asked to watch videos of the dance movements at home between classes (Shanahan et al., 2017; Volpe et al., 2013), and in the former study participants were asked to engage in "mental rehearsal" during home practice. However, in the absence of a comparison group taking dance classes without home practice, the influence of this additional training is unclear. Another potential avenue for further investigation is the use of virtual or augmented reality as a method of delivering dance training using observation and imitation (Abbasi, 2017; Lee et al., 2015). To date, one study has provided initial data suggesting sensorimotor and non-motor benefits of virtual reality imitation-based dance in a small number of people with PD (Lee et al., 2015), but further work is needed to determine the feasibility and efficacy of home-based training using digital and immersive technologies.

Investigating dance observation also allows for the use of techniques that would be difficult to apply during physical participation, such as neuroimaging and eye tracking, which may offer further insights into the effects of dance. Some of these approaches have already been used in research with healthy participants, and could also be explored in people with PD. As noted above, dance experience has been associated with increased cortical activations and emotional responses when observing dance and expressive movements (Calvo-Merino et al., 2005; Christensen et al., 2016; Cross et al., 2006). Additionally, eye movements can reveal what is attended to during action observation (e.g., the dancer's body or face, or other aspects of the scene) and to what extent movements are anticipated or predicted, potentially reflecting embodiment or motor simulation. For example, trained dancers have been found to exhibit shorter fixations and faster saccades (rapid directed eye movements) when watching dance, and to spend less time fixating the background of dance scenes (Stevens et al., 2010). Future research on observation of dance could therefore increase understanding of the effects of dance training on action representation in PD.

5. Conclusions

A growing number of studies indicate potential benefits of dance for people living with PD across motor and non-motor domains, but further work is needed to more clearly demonstrate the range of possible outcomes and to increase understanding of the mechanisms underlying these effects.

In this article we have considered how internal action representations may contribute to the beneficial effects of dance in people with PD. Evidence from various lines of investigation indicates that (i) action observation, imitation and motor imagery can facilitate movement in people with PD; (ii) dance can enhance motor imagery and embodiment in healthy participants; and (iii) action observation and imagery may contribute to physical and emotional effects of dance. Based on this evidence, we have proposed a role for action representation mechanisms in producing positive outcomes of dance for people with PD, and indeed that these processes may be enhanced through dance, allowing individuals to apply action observation and imagery more effectively in everyday situations beyond the dance class. We have also discussed links between music, rhythm and action representation, as well as how the aesthetic and expressive aspects of dance may utilise and enhance action representations.

Future research should explore the role of action representation within dance for people with PD and investigate related outcomes such as motor imagery, social-emotional cognition and communication, for different forms of dance. The relationship between action representation, music and movement in people with PD should also be explored, as well as longer-term outcomes in terms of neural changes in sensorimotor areas associated with action representation and transfer of skills to everyday tasks.

Understanding action representation processes in dance for people with PD could indicate ways in which the benefits of dance may be further enhanced. These may include the incorporation of imagery and imitation within dance programmes, consideration of individual differences in action representation, or provision of additional imagery- and observation-based training to supplement classes or for those unable to attend.

It should be noted that, although the multidimensional nature of dance provides a rich context in which to study the effects of action representation in people with PD, action observation and motor imagery are embedded in many forms of sport, exercise, musical performance and other creative activities. While beyond the scope of the present review, the therapeutic potential of action representation within these other activities also warrants investigation.

Finally, beneficial effects of dance have also been found in other populations, such as healthy older adults and those with dementia (Kshtriya et al., 2015; McNeely et al., 2015a); research and practice in broader therapeutic applications of dance could therefore also be informed by consideration of action representation mechanisms.

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Table 1. Outcomes of dance in people with PD: Studies showing positive and null/negative effects in each domain (authors, year, dance style, study design/comparison group(s); *indicates randomised controlled trial). Further details for each study are included in the supplementary material.

Domain; outcome measure	Studies reporting positive effects	Studies reporting null/negative effects
Motor severity		
Unified Parkinson's Disease Rating Scale (UPDRS) III	Allen et al. (2017): Tango; uncontrolled Duncan & Earhart (2012)*: Tango vs. no-intervention Duncan & Earhart (2014)*: Tango vs. no-intervention Hackney & Earhart (2009a): Tango; uncontrolled Heiberger et al. (2011): Mixed; uncontrolled Marchant et al. (2010): Modern (contact improvisation); uncontrolled McKay et al. (2016): Tango; uncontrolled McKee & Hackney (2013)*: Tango vs. education McNeely et al. (2015): Tango McNeely et al. (2015): Mixed (Dance for PD) Rabinovich et al. (2017): Tango; uncontrolled Shanahan et al. (2015): Irish set; uncontrolled Volpe et al. (2013)*: Irish set vs. individual physiotherapy Westheimer et al. (2015): Mixed (Dance for PD); uncontrolled	Hackney et al. (2007a)*: Tango vs. strength/flexibility training Hackney & Earhart (2009a): Tango; uncontrolled Hackney & Earhart (2009b)*: Tango vs. no-intervention Hackney & Earhart (2009b)*: Waltz/Foxtrot vs. no-intervention Hashimoto et al. (2015): Modern vs. exercise vs. no-intervention Rawson et al. (2019): Tango vs. treadmill training vs. stretching Rios Romenets et al. (2015)*: Tango vs. self-directed exercise Shanahan et al. (2017)*: Irish set vs. no-intervention
Balance		
Berg Balance Scale	Allen et al. (2017): Tango; uncontrolled Bearss et al. (2017): Mixed (Dance for PD) Hackney et al. (2007a)*: Tango vs. strength/flexibility training Hackney & Earhart (2009b)*: Tango vs. no-intervention Hackney & Earhart (2009b)*: Waltz/Foxtrot vs. no-intervention Hackney & Earhart (2010)*: Tango partnered and unpartnered Hashimoto et al. (2015): Modern vs. exercise vs. no-intervention Marchant et al. (2010): Modern (contact improvisation); uncontrolled McKay et al. (2016): Tango; uncontrolled Volpe et al. (2013)*: Irish set vs. individual physiotherapy	De Natale et al. (2017)*: Tango vs. traditional rehabilitation Shanahan et al. (2015): Irish set; uncontrolled Westheimer et al. (2015): Mixed (Dance for PD); uncontrolled

Mini-BESTest	Duncan & Earhart (2012)*: Tango vs. no-intervention Duncan & Earhart (2014)*: Tango vs. no-intervention McNeely et al. (2015): Mixed (Dance for PD) McNeely et al. (2015): Tango Rios Romenets et al. (2015)*: Tango vs. self-directed exercise	Rawson et al. (2019): Tango vs. treadmill training vs. stretching Shanahan et al. (2017)*: Irish set vs. no-intervention
Fullerton Advanced Balance scale	Allen et al. (2017): Tango; uncontrolled Batson (2010): Modern (improvisational); uncontrolled Batson et al. (2014): Modern (improvisational); uncontrolled Houston & McGill (2013): Ballet; uncontrolled McKay et al. (2016): Tango; uncontrolled McKee & Hackney (2013)*: Tango vs. education	
Activities-Specific Balance Confidence Scale	Hackney et al. (2007b)*: Tango vs. strength/flexibility training	
Four Square Step Test	McNeely et al. (2015): Mixed (Dance for PD) McNeely et al. (2015): Tango	De Natale et al. (2017)*: Tango vs. traditional rehabilitation McKee & Hackney (2013)*: Tango vs. education
Functional Reach Test		Hackney et al. (2007b)*: Tango vs. strength/flexibility training McKay et al. (2016): Tango; uncontrolled
Single-Leg Stance Test	Hackney & Earhart (2010)*: Tango partnered and unpartnered	Hackney et al. (2007b)*: Tango vs. strength/flexibility training
Semi-Tandem Test		Heiberger et al. (2011): Mixed; uncontrolled
Standing balance		Ventura et al. (2016)*: Mixed (Dance for PD) vs. no-intervention
Functional mobility		
Timed Up and Go	Bearss et al. (2017): Mixed (Dance for PD) McNeely et al. (2015): Tango De Natale et al. (2017)*: Tango vs. traditional rehabilitation Rios Romenets et al. (2015)*: Tango vs. self-directed exercise	Allen et al. (2017): Tango; uncontrolled Batson (2010): Modern (improvisational); uncontrolled Batson et al. (2014): Modern (improvisational); uncontrolled Duncan & Earhart (2014)*: Tango vs. no-

	Volpe et al. (2013)*: Irish set vs. individual physiotherapy	intervention Hackney et al. (2007a)*: Tango vs. strength/flexibility training Hackney & Earhart (2009a): Tango; uncontrolled Hackney & Earhart (2009b)*: Tango vs. no-intervention Hackney & Earhart (2009b)*: Waltz/Foxtrot vs. no-intervention Hackney & Earhart (2010)*: Tango partnered and unpartnered Hashimoto et al. (2015): Modern vs. exercise vs. no-intervention Heiberger et al. (2011): Mixed; uncontrolled Marchant et al. (2010): Modern (contact improvisation); uncontrolled McKay et al. (2016): Tango; uncontrolled McKee & Hackney (2013)*: Tango vs. education McNeely et al. (2015): Mixed (Dance for PD) Ventura et al. (2016)*: Mixed (Dance for PD) vs. no-intervention
Timed Up and Go Dual-Task	Duncan & Earhart (2014)*: Tango vs. no-intervention Rios Romenets et al. (2015)*: Tango vs. self-directed exercise	Batson et al. (2014): Modern (improvisational); uncontrolled McKay et al. (2016): Tango; uncontrolled McKee & Hackney (2013)*: Tango vs. education
6 Minute Walk Test	Allen et al. (2017): Tango; uncontrolled Hackney & Earhart (2009b)*: Tango vs. no-intervention Hackney & Earhart (2009b)*: Waltz/Foxtrot vs. no-intervention McNeely et al. (2015): Tango McNeely et al. (2015): Mixed (Dance for PD) De Natale et al. (2017)*: Tango vs. traditional rehabilitation	Duncan & Earhart (2012)*: Tango vs. no-intervention Duncan & Earhart (2014)*: Tango vs. no-intervention Hackney & Earhart (2009a): Tango; uncontrolled Hackney & Earhart (2010)*: Tango partnered and unpartnered Marchant et al. (2010): Modern (contact improvisation); uncontrolled McKay et al. (2016): Tango; uncontrolled Rawson et al. (2019): Tango vs. treadmill training vs. stretching Shanahan et al. (2015): Irish set; uncontrolled Shanahan et al. (2017)*: Irish set vs. no-intervention
5 Times Sit-to-Stand Test	McNeely et al. (2015): Tango McNeely et al. (2015): Mixed (Dance for PD)	Marchant et al. (2010): Modern (contact improvisation); uncontrolled

Gait		
Velocity	Duncan & Earhart (2012)*: Tango vs. no-intervention Hackney & Earhart (2010)*: Tango partnered and unpartnered Ventura et al. (2016)*: Mixed (Dance for PD) vs. no-intervention Westbrook & McKibben (1989): DMT vs. exercise (cross-over)	Allen et al. (2017): Tango; uncontrolled Duncan & Earhart (2012)*: Tango vs. no-intervention Duncan & Earhart (2014)*: Tango vs. no-intervention Hackney et al. (2007b)*: Tango vs. strength/flexibility training Hackney & Earhart (2009a): Tango; uncontrolled Marchant et al. (2010): Modern (contact improvisation); uncontrolled McNeely et al. (2015): Tango McNeely et al. (2015): Mixed (Dance for PD) Rawson et al. (2019): Tango vs. treadmill training vs. stretching
Other gait characteristics (e.g., cadence, stride length)	Hackney & Earhart (2009a): Tango; uncontrolled Hackney & Earhart (2010)*: Tango partnered and unpartnered McKay et al. (2016): Tango; uncontrolled Marchant et al. (2010): Modern (contact improvisation); uncontrolled	Hackney & Earhart (2009a): Tango; uncontrolled Marchant et al. (2010): Modern (contact improvisation); uncontrolled Rawson et al. (2019): Tango vs. treadmill training vs. stretching
Dynamic Gait Index	Allen et al. (2017): Tango; uncontrolled McKay et al. (2016): Tango; uncontrolled	De Natale et al. (2017)*: Tango vs. traditional rehabilitation
Freezing of gait		
FoG-Q	Volpe et al. (2013)*: Irish set vs. individual physiotherapy	Duncan & Earhart (2012)*: Tango vs. no-intervention Duncan & Earhart (2014)*: Tango vs. no-intervention Hackney et al. (2007a)*: Tango vs. strength/flexibility training Hackney & Earhart (2009b)*: Tango vs. no-intervention Hackney & Earhart (2009b)*: Waltz/Foxtrot vs. no-intervention Marchant et al. (2010): Modern (contact improvisation); uncontrolled McKay et al. (2016): Tango; uncontrolled McKee & Hackney (2013)*: Tango vs. education

Dexterity		
9 Hole Peg Test	Duncan & Earhart (2012)*: Tango vs. no-intervention	
Activities of Daily Living		
UPDRS-II	Duncan & Earhart (2014)*: Tango vs. no-intervention	Duncan & Earhart (2012)*: Tango vs. no-intervention
Falls		
Falls Efficacy Scale	Ventura et al. (2016)*: Mixed (Dance for PD) vs. no-intervention	Hackney et al. (2007b)*: Tango vs. strength/flexibility training
Non-motor symptoms of PD		
UPDRS-I	Duncan & Earhart (2014)*: Tango vs. no-intervention	Duncan & Earhart (2012)*: Tango vs. no-intervention
Fatigue Scale	Rios Romenets et al. (2015)*: Tango vs. self-directed exercise	
Quality of life		
Parkinson's Disease Questionnaire (PDQ-39)	Hackney & Earhart (2009c)*: Tango vs. Waltz/Foxtrot vs. Tai Chi vs. no-intervention Shanahan et al. (2015): Irish set; uncontrolled	Hackney & Earhart (2009c)*: Waltz/Foxtrot vs. Tango vs. Tai Chi vs. no-intervention McKee & Hackney (2013)*: Tango vs. education McNeely et al. (2015): Tango McNeely et al. (2015): Mixed (Dance for PD) Rawson et al. (2019): Tango vs. treadmill training vs. stretching Shanahan et al. (2017)*: Irish set vs. no-intervention Ventura et al. (2016)*: Mixed (Dance for PD) vs. no-intervention Volpe et al. (2013)*: Irish set vs. individual physiotherapy Wesheimer et al. (2015): Mixed (Dance for PD); uncontrolled
Oregon Quality of Life Questionnaire	Heiberger et al. (2011): Mixed; uncontrolled Westheimer (2008): Mixed (Dance for PD)	Bearss et al. (2017): Mixed (Dance for PD); uncontrolled
EuroQol-5D		Blandy et al. (2015): Tango; uncontrolled
Short Form Health Survey SF-12		McKee & Hackney (2013)*: Tango vs. education

Activities Card Sort	Foster et al. (2013)*: Tango vs. no-intervention	
Cognition		
Montreal Cognitive Assessment (MoCA)	McKee & Hackney (2013)*: Tango vs. education Rios Romenets et al. (2015)*: Tango vs. self-directed exercise	
Test of Everyday Attention	Ventura et al. (2016)*: Mixed (Dance for PD) vs. no-intervention	
Mental Rotation	Hashimoto et al. (2015): Modern vs. no-intervention	
Trail Making Test	De Natale et al. (2017)*: Tango vs. traditional rehabilitation	
Brooks Spatial Test	McKee & Hackney (2013)*: Tango vs. education	
Digit span forward	Ventura et al. (2016)*: Mixed (Dance for PD) vs. no-intervention	
Digit span backward		Ventura et al. (2016)*: Mixed (Dance for PD) vs. no-intervention
Frontal Assessment Battery	Hashimoto et al. (2015): Modern vs. no-intervention	De Natale et al. (2017)*: Tango vs. traditional rehabilitation
Verbal fluency (category/ action)		Ventura et al. (2016)*: Mixed (Dance for PD) vs. no-intervention
Reverse Corsi Blocks		McKee & Hackney (2013)*: Tango vs. education
Stroop Task		De Natale et al. (2017)*: Tango vs. traditional rehabilitation
Mood/Affect		
Beck Depression Inventory	Blandy et al. (2015): Tango; uncontrolled	Rios Romenets et al. (2015)*: Tango vs. self-directed exercise Westbrook & McKibben (1989): DMT vs. exercise (cross-over) Westheimer et al. (2015): Mixed (Dance for PD); uncontrolled
Self-report Depression Scale	Hashimoto et al. (2015): Modern vs. exercise vs. no-intervention	
Geriatric Depression Inventory	Ventura et al. (2016)*: Mixed (Dance for PD) vs. no-intervention	

Profile of Mood States	Lewis et al. (2016): Mixed; uncontrolled	
Brunel University Mood Scale		Lewis et al. (2016): Mixed; uncontrolled
Apathy Scale	Hashimoto et al. (2015): Modern vs. exercise vs. no-intervention	Rios Romenets et al. (2015)*: Tango vs. self-directed exercise
Philadelphia Geriatric Morale Scale		Hackney et al. (2007b)*: Tango vs. strength/flexibility training

Notes: Hackney & Earhart (2010) effects apply to both partnered and unpartnered Tango groups. Hashimoto et al. (2015) both dance and exercise group improved on Frontal Assessment Battery and Mental Rotation compared with the control group.

Table S1. Sensorimotor outcomes of dance reported in people with PD

Article	Dance intervention: duration, frequency	Study design; control/ comparison group(s)[1]	References to action representation	Participants per group (n female); age; Hoehn & Yahr stage (H&Y); time since diagnosis.[2]	Outcome measures; medication status at assessment (meds)	Follow-up	Results
Allen et al. (2017)	Tango: 3 weeks, 5 x 90 minutes.	Uncontrolled N/A		6 (1f); age 64.0 years; H&Y 2-3; duration 7.0 years.	UPDRS-III; TUG; BBS; FAB; DGI; 6MWT; Gait velocity (preferred,fast).	N/A	Medium to large effect sizes for UPDRS-III, (0.55), BBS (1.17); FAB (0.83); DGI (0.87); 6MWT (0.79); small effect for TUG (0.46).
Batson (2010)	Modern (improvisational): 3 weeks, 85 minutes	Uncontrolled N/A	Motor imagery	11 (6f); age 72.7 years; H&Y 1 - 2.5; duration 1-6 years.	TUG; FAB Meds: on	N/A	Improvement on FAB (p <.01)
Batson et al. (2014)	Modern (improvisational): 7 weeks, 3 x 60 minutes. Followed by single case study - 5 consecutive days, 60 minutes.	Uncontrolled two-phase study (group/ individual case) N/A	Imaging	7 (5f); age 67 years; H&Y 2.5 (mode); duration NR.	TUG; TUG-DT; FAB Meds: NR	N/A	Group improvement on FAB (p=.02). Case study showed increased functional connectivity.
Bearss et al. (2017)	Dance for PD: 12 weeks (outcomes tested at weeks 2 and 12), 75 minutes	Uncontrolled N/A	Imagery; mirroring	9 (4f); age 67.8 years; H&Y 0.8; duration 5.6 years.	TUG; BBS Meds: NR	N/A	Improvements on BBS (p = .02) and TUG (p = .04)
Delextrat et al. (2016)	Zumba Gold: 6 weeks, 45-60 minutes (increasing with class progression)	Uncontrolled feasibility N/A		11 (6f); age 64 years; H&Y 1.5 (Mdn); duration NR.	Physical activity (triaxial accelerometers); physiological load (heart rate). Meds: on	Interview 6 months later (n = 8)	Improvement in activity levels (p=.02) between first and last session.

Article	Dance intervention: duration, frequency	Study design; control/ comparison group(s)[1]	References to action representation	Participants per group (n female); age; Hoehn & Yahr stage (H&Y); time since diagnosis.[2]	Outcome measures; medication status at assessment (meds)	Follow-up	Results
Duncan & Earhart (2012)	Tango; 12 months (outcomes tested at 3, 6 and 12 months), 2 x 60 minutes	RCT Control: no intervention		Dance: 26 (11f); age 69.3 years; H&Y 2.6; duration 5.8 years. Control: 26 (11f); age 69 years; H&Y 2.5; duration 7 years.	MDS-UPDRS III and II; Mini-BESTest; gait velocity (forward-comfortable, forward-fast, dual-task, backward); 6MWT; FOGQ; nine-hole peg test. Meds: off	N/A	Dance group improved vs. control group on UPDRS-III and Mini-BESTest (p<.001) by 3 months, forward-comfortable (p = .04) and dual-task (p = .02) gait velocity and nine-hole peg test (p = .01) by 6 months. Controls deteriorated on FOGQ and 6MWT by 12 months while dance group showed no change.
Duncan & Earhart (2014)	Tango: 2 years, 2 x 60 minutes	Pilot RCT Control: no intervention.		Dance: 5 (1f); age 69.6 years; H&Y 2 - 3; duration 6.6 years. Control: 5 (1f); age 66 years; H&Y 2- 2.5; duration 11 years.	MDS-UPDRS III and II; Mini-BESTest; gait velocity (forward and backward); TUG; TUG-DT; 6MWT; FOGQ. Meds: off	N/A	Dance group improved vs. control group on UPDRS-III (p<.001) Mini-BESTest (p<.001) at 12 and 24 months, and UPDRS-II (p =.05) at 24 months. Across the duration of the study dance group improved on TUG-DT but controls worsened (p<.05); dance group showed no change on 6MWT while controls worsened on (p=.01).
Hackney et al. (2007a)	Tango: 13 weeks (10 weeks of classes), 2 x 60 minutes	RCT Exercise: structured strength/ flexibility training	Imagery	Dance: 9 (3f); age 72.6 years; H&Y 2.3; duration 6.2 years. Exercise: 10 (4f); age 69.6 years; 2.2; duration 3.3 years.	UPDRS-III; BBS; TUG; FOGQ. Meds: on	N/A	Both groups improved on UPDRS-III (p<.001). Dance group improved on BBS (p = .01).

Article	Dance intervention: duration, frequency	Study design; control/ comparison group(s)[1]	References to action representation	Participants per group (n female); age; Hoehn & Yahr stage (H&Y); time since diagnosis.[2]	Outcome measures; medication status at assessment (meds)	Follow-up	Results
Hackney et al. (2007b)	Tango: 13 weeks (10 weeks of classes), 2 x 60 minutes	RCT Exercise: structured strength/ flexibility training		Dance: 9 (NR). Exercise: 10 (NR). Matched numbers of healthy controls in each group; all aged 55+ years. Disease stage and duration NR.	ABC Scale; Modified Falls Efficacy Scale; Functional Reach Test; One Leg Stance Test; gait velocity (motion capture). Meds: NR	N/A	PD Tango group improved vs. PD exercise group on ABC scale. Healthy controls showed the reverse pattern.
Hackney & Earhart (2009a)	Tango; 2 weeks, 5 x 90 minutes	Uncontrolled N/A		12 (4f); age 67.2 years; H&Y 2.4 (Mdn); duration 9.1 years.	UPDRS-III; BBS; TUG; 6MWT; gait analysis (preferred; forward and backward) using instrumented walkway. Meds: on	N/A	Improvements on UPDRS-III (p=.03), BBS (p=.02), percent stance time during forward walking (p=.02).
Hackney & Earhart (2009b)	Tango, Waltz/ Foxtrot: 13 weeks (10 weeks of classes), 2 x 60 minutes	RCT Control: no intervention.		Tango: 14 (3f); age 68.2 years; H&Y 2.1; duration 6.9 years. Waltz/Foxtrot: 17 (6f); age 66.8 years; H&Y 2.0; duration 9.2 years. Control: 17 (5f); age 66.5 years; H&Y 2.2; duration 5.9 years.	UPDRS-III; BBS; TUG; 6MWT; FOGQ. Meds: on	N/A	Both dance groups improved on BBS (Waltz/Foxtrot p <.001; Tango p = .001) and 6MWT (both p<.001). Control group worsened on UPDRS-III (p = .002).

Article	Dance intervention: duration, frequency	Study design; control/ comparison group(s)[1]	References to action representation	Participants per group (n female); age; Hoehn & Yahr stage (H&Y); time since diagnosis.[2]	Outcome measures; medication status at assessment (meds)	Follow-up	Results
Hackney & Earhart (2010)	Partnered Tango, Unpartnered Tango: 10 weeks, 2 x 60 minutes	RCT N/A		Partnered: 19 (6f); age 69.6 years; H&Y 2.5 (Mdn); duration 9.5 years. Non-partnered: 20 (5f); age 69.6 years; H&Y 2 (Mdn); duration 7.9 years.	BBS; tandem stance; single-leg stance; TUG; 6MWT; gait analysis (preferred, fast) using GAITrite walkway. Meds: on	4 weeks	Both groups improved on BBS, preferred and fast walking velocity and cadence, fast swing percent and double support percent, single-leg and tandem stance time. All except single-leg stance time maintained at one-month follow-up.
Hashimoto et al. (2015)	Modern dance: 12 weeks, 60 minutes.	Quasi-RCT Exercise: physical therapy and PD-specific exercises. Control: no intervention.	Visualisation	Dance: 15 (12f); age 67.9 years; H&Y 2.7; duration 6.3 years. Exercise: 17 (15f); age 62.7 years; H&Y 2.7; duration 7.8 years. Control: 14 (7f); age 69.7 years; H&Y 3.0; duration 6.9 years.	UPDRS-III; TUG; TUG step count; BBS. Meds: on	N/A	All groups improved on TUG time (dance $p = .006$; exercise $p = .04$; control $p = .03$). Dance and exercise groups improved on TUG step count (dance $p < .01$; exercise $p = .01$). Dance group improved on BBS ($p = .001$).
Heiberger et al. (2011)	Mixed style: 8 months, 75 minutes. (outcomes tested pre/post a single class in ongoing participants.	Uncontrolled N/A	Motor imagery	11 (6f); age 71.3 years; H&Y 3.3; duration NR.	UPDRS-III; TUG; Semi-tandem test. Meds: off	N/A	Improvement in UPDRS-III ($p = .001$).
Houston & McGill (2013)	Adapted ballet: 16 weeks (12 weeks of classes), 90 minutes.	Uncontrolled/ mixed-methods N/A	Imagery (kinaesthetic, visual and musical)	Participants completing quantitative assessments: 6 (3f); age 70.0 years; H&Y 1-4 (estimated); duration NR.	FAB; plumb-line assessment; qualitative analysis of movement from video recordings. Meds: on	N/A	Improvement on FAB ($p = .01$). Qualitative improvements in movement noted from video analysis.

Article	Dance intervention: duration, frequency	Study design; control/ comparison group(s)[1]	References to action representation	Participants per group (n female); age; Hoehn & Yahr stage (H&Y); time since diagnosis.[2]	Outcome measures; medication status at assessment (meds)	Follow-up	Results
Marchant et al. (2010)	Modern (contact improvisation): 2 weeks, 5 x 90 minutes.	Uncontrolled pilot study N/A		11 (7f); age 71.2 years; H&Y 2.4; duration 9.0 years.	UPDRS-III; BBS; TUG; 6MWT; 5 times sit-to-stand test; gait analysis (preferred-forward; fast-forward; preferred-backward) using GAITRite walkway; FOGQ. Meds: on	N/A	Improvements on UPDRS-III, BBS, percentage of cycle in stance and swing during forward preferred speed gait (all $p \leq .02$).
McKay et al. (2016)	Tango: 3 weeks, 5 x 90 minutes.	Uncontrolled N/A		22 (15f); age 65.4 years; H&Y 2 - 3; duration 3 - 14 years.	UPDRS-III; BBS; TUG; TUG-DT; ABC; FOGQ; dyskinesia rating; DGI; FAB; 6MWT; two-footed jump test; functional reach; gait speed (preferred, fast) using a stopwatch. Subset (n = 9) assessed for perturbation response pre/post intervention. Meds: on	One month	Improvements on BBS, ($p< 0.01$), FAB ($p< 0.001$), and DGI ($p = 0.01$); maintained at one-month follow-up. CoM displacement during forward perturbation reduced at post-test ($p = .03$). Preferred ($p <.01$) and fast ($p = .03$) cadence and UPDRS-III ($p<0.01$) improved from pre-test to follow-up. Reductions in forward CoM displacement correlated with increased scores on BBS ($p=0.04$) and DGI ($p=0.03$).
McKee & Hackney (2013)	Tango: 12 weeks (10 weeks of classes), 90 minutes.	RCT Educational seminars: lectures, discussion and structured group learning activities.		Dance: 24 (12f); age 68.4 years; H&Y 2.3 (Mdn); duration 7.0 years. Education: 9 (1f); age 74.4 years; H&Y 2.0 (Mdn); duration 7.2 years.	UPDRS-III; FAB; TUG; TUG-DT (cognitive and manual tasks); 4SST; FOGQ. Meds: on	10-12 weeks	Both groups improved on 4SST ($p = .03$). Dance group improved on UPDRS-III ($p = .02$), FAB ($p = .004$), which were maintained at 10-12 week follow-up. Education group worsened on UPDRS-III ($p=.04$).

Article	Dance intervention: duration, frequency	Study design; control/ comparison group(s)[1]	References to action representation	Participants per group (n female); age; Hoehn & Yahr stage (H&Y); time since diagnosis.[2]	Outcome measures; medication status at assessment (meds)	Follow-up	Results
McNeely et al. (2015)	Dance for PD, Tango: 12 weeks, 2 x 60 minutes.	Between-groups	Dance for PD: imagery; mirroring	Dance for PD: 8 (4f); age 68.3 years; H&Y 2.3; duration 10.1 years. Tango: 8 (4f); age 67.7 years; H&Y 2.1; duration 5.4 years.	UPDRS-III; Mini-BESTest; 6MWT; 5 times sit-to-stand; 4SST; gait analysis (comfortable-forward; fast-forward; backward; cognitive dual-task) using GAITRite walkway. Meds: off	N/A	Both groups improved on UPDRS-III (p=.001), Mini-BESTest (p=.04), 5 times sit-to-stand (p=.004), 4SST (P=.003), 6MWT (p=.03). Tango group showed greater improvement in UPDRS-III (interaction p=.01); TUG time improved in Tango group but worsened in Dance for PD group (interaction, p=.04).
De Natale et al. (2017)	Tango: 10 weeks, 2 x 60 minutes.	RCT Traditional rehabilitation: static and dynamic balance exercises, gait and coordination training		Dance: 9 (2f); age 66.0 years; H&Y 2.5; duration 6.0 years. Traditional rehabilitation: 7 (3f); age 70.0 years; H&Y 2.6; duration 6.33 years.	BBS; TUG; 6MWT; DGI; 4SST. Meds: on	8 weeks	Dance group improved on 6MWT (p=.003), TUG (p=.007); greater improvement in TUG in dance vs. traditional rehabilitation group (interaction, p = .009). Improvements maintained at 8 week follow-up.
Rabinovich et al. (2017)	Tango: 2 weeks, 5 x 90 minutes.	Uncontrolled N/A		8 (NR); age NR; H&Y 1-2; duration NR.	MDS-UPDRS-III. Meds: NR	N/A	Improvement in MDS-UPDRS-III (p<.05).

Article	Dance intervention: duration, frequency	Study design; control/ comparison group(s)[1]	References to action representation	Participants per group (n female); age; Hoehn & Yahr stage (H&Y); time since diagnosis.[2]	Outcome measures; medication status at assessment (meds)	Follow-up	Results
Rawson et al. (2019)	Tango: 12 weeks, 60 minutes.	Prospective controlled trial Treadmill training Stretching		Tango: 39 (14f), age 66.7 years; H&Y 1-4; duration 6.1 years. Treadmill: 31 (14f), age 68.5 years; H&Y 1-4; duration 5.6 years. Stretching: 26 (12f), age 66.2 years; H&Y 2-4; duration 4.4 years.	MDS-UPDRS-III; Mini-BESTest; 6MWT; gait velocity and stride length forwards and backwards. Meds: off	12 weeks	Dance group showed a trend* for improvement on 6MWT from baseline to post-test (p <.026) but declined from post-test to follow-up (p <.01). Treadmill group showed improved forward and backward gait velocity (p <.001) at post-test and follow-up. Stretching group improved on backward velocity (p < .01) and UPDRS-III (p <.001) from baseline to post-test. *Significance level adjusted for multiple comparisons.
Rios Romenets et al. (2015)	Tango: 12 weeks, 2 x 60 minutes.	Pilot RCT Exercise: self-directed daily home practice of exercises provided in pamphlet		Dance: 18 (6f); age 63.2 years; H&Y 1.7; duration 5.5 years. Exercise: 15 (8f); age 64.3 years; H&Y 2.0; duration 7.7 years.	MDS-UPDRS-III; Mini-BESTest; TUG; TUG-DT; walk with pivot turns. Meds: on	N/A	Dance group improved vs. control group on Mini-BESTest (p=.03), TUG time (p=.04), TUG-DT (p=.01), and walking with pivot turns (trend; p=.07).
Shanahan et al. (2015)	Irish set dance: 8 weeks, 90 minutes plus home practice 2 x 20 minutes.	Uncontrolled feasibility	Mental rehearsal	9 (2f); 66.7 age years; H&Y 1.5 (Mdn); duration 7.3 years.	UPDRS-III; BBS; 6MWT Meds: on	N/A	Trend towards improvement on UPDRS-III (p = .05).
Shanahan et al. (2017)	Irish set dance: 10 weeks, 90 minutes plus home practice 3 x 20 minutes.	Pilot RCT Control: no intervention	Mental rehearsal	Dance: 20 (7f); age 69.0 years (Mdn); H&Y 1.25(Mdn); duration 5.5 years. Control: 21 (8f); age 69.0 years (Mdn); H&Y 2.0 (Mdn); duration 6.0 years.	UPDRS-III; Mini-BESTest; 6MWT Meds: on	N/A	No significant changes in either group.

Article	Dance intervention: duration, frequency	Study design; control/ comparison group(s)[1]	References to action representation	Participants per group (n female); age; Hoehn & Yahr stage (H&Y); time since diagnosis.[2]	Outcome measures; medication status at assessment (meds)	Follow-up	Results
Ventura et al. (2016)	Dance for PD: 4.5 months, 75 minutes.	RCT Control: no intervention.	Mirroring	Dance: 8 (8f); age 71.8 years; H&Y 1.7; duration 6.1 years. Control: 7 (5f); age 70.4 years; H&Y 1.6; duration 4.3 years.	TUG; Standing Balance Test; Falls Efficacy Scale-International; gait speed (preferred). Meds: on	N/A	Dance group showed large within-group effect sizes (≥0.8) for gait speed and Falls Efficacy. Control group showed large positive effect size for balance and large negative effect size for gait speed. Large between-group effect sizes showed greater improvements for dance in gait speed and falls efficacy.
Volpe et al. (2013)	Irish set dance: 6 months, 90 minutes.	RCT Exercise: individual physiotherapy - strength, mobility, balance and postural control.		Dance: 12 (5f); age 61.6 years; H&Y 2.2; duration 9.0 years. Exercise: 12 (6f); age 65.0 years; H&Y 2.2; duration 8.9 years.	UPDRS-III; TUG; BBS; FOG-Q. Meds: NR	N/A	Both groups improved on UPDRS-III and TUG ($p<.001$), with interactions showing greater improvements in dance group (UPDRS-III, $p = .02$; TUG $p=.007$). Dance group also improved on FOG-Q ($p<.001$; interaction $p = .001$) and BBS (trend, $p=.05$).
Westbrook & McKibben (1989)	Dance/movement therapy: 6 weeks, 60 minutes.	Cross-over Exercise: half of participants completed 6 weeks of dance intervention first; half completed 6 weeks of exercise first.		37 (n per group NR); H&Y 2-3; duration NR. Dance-first:14% female; age 72.6 years. Exercise-first: 60% female; age 69.9 years.	Gait speed (fast). Meds: NR	N/A	Both groups improved on gait speed with dance vs. exercise ($p<.05$).
Westheimer et al. (2015)	Dance for PD: 8 weeks, 2 x 75 minutes.	Uncontrolled/ mixed-methods N/A	Imagery, mirroring	12 (6f); age 66.2 years; H&Y 2.33; duration NR.	Hoehn & Yahr stage; UPDRS-III; BBS. Meds: on	N/A	Improvement on UPDRS-III ($p=.04$).

[1]Duration and frequency of alternative interventions matching dance group unless specified; [2]means or ranges reported unless specified.

NR = not reported. RCT = randomized controlled trial.

Test abbreviations: 4SST = four-square step test; 6MWT = six-minute walking test; ABC = Activities-Specific Balance Confidence scale; BBS = Berg Balance Scale; FAB = Fullerton Advanced Balance scale; FOGQ = Freezing of Gait Questionnaire; Mini-BESTest = Mini Balance Evaluation Systems Test; TUG = timed up and go; TUG-DT = timed up and go with dual task (cognitive unless stated); UPDRS = Unified Parkinson's Disease Rating Scale.

Table S2. Non-motor outcomes of dance reported in people with PD

Article	Dance intervention: duration, frequency	Study design; control/ comparison group(s).[1]	References to action representation	Participants per group (n female); age; Hoehn & Yahr stage (H&Y); time since diagnosis.[2]	Outcome measures; medication status at assessment (meds)	Follow-up	Results
Bearss et al. (2017)	Dance for PD: 12 weeks (outcomes tested at weeks 2 and 12), 75 minutes	Uncontrolled N/A	Imagery; mirroring	9 (4f); age 67.8 years; H&Y 0.8; duration 5.6 years.	Oregon Health and Sciences University Quality of Life Scale; well-being questionnaire administered following classes. Meds: NR	N/A	No overall change on QoL scale but ratings on two individual questions relating to relationships and learning improved.
Blandy et al. (2015)	Tango: 4 weeks, 60 minutes	Uncontrolled feasibility N/A	N/A	6 (3f); age 64 years; H&Y 2.0; duration 8.6 years.	BDI; Euroqol-5D Meds: on	N/A	Improvement on BDI scores.
Duncan & Earhart (2012)	Tango; 12 months (outcomes tested at 3, 6 and 12 months), 2 x 60 minutes	RCT Control: no intervention		Dance: 26 (11f); age 69.3 years; H&Y 2.6; duration 5.8 years. Control: 26 (11f); age 69 years; H&Y 2.5; duration 7 years.	MDS-UPDRS I Meds: off	N/A	No change in either group.
Duncan & Earhart (2014)	Tango: 2 years, 2 x 60 minutes	RCT Control: no intervention.		Dance: 5 (1f); age 69.6 years; H&Y 2 - 3; duration 6.6 years. Control: 5 (1f); age 66 years; H&Y 2- 2.5; duration 11 years.	MDS-UPDRS-I Meds: off	N/A	Dance group improved on UPDRS-I vs. control group at 12 and 24 months (interaction, p = .02).

Article	Dance intervention: duration, frequency	Study design; control/ comparison group(s).[1]	References to action representation	Participants per group (n female); age; Hoehn & Yahr stage (H&Y); time since diagnosis.[2]	Outcome measures; medication status at assessment (meds)	Follow-up	Results
Foster et al. (2013)	Tango: 1 year, 2 x 60 minutes	RCT Control: no intervention.		Dance: 26 (11f); age 69.3 years; H&Y 2-3; duration 5.8 years. Control: 26 (11f); age 69 years; H&Y 2 - 4; duration 7 years.	Activity Card Sort Meds: Off	N/A	Dance group showed increased current participation at 3, 6 and 12 months ($p < .008$); also increases in retention of previous activities and acquisition of new activities. Control group showed no increase in participation.
Hackney et al. (2007b)	Tango: 13 weeks (10 weeks of classes), 2 x 60 minutes	RCT Exercise: structured traditional strength/ flexibility training.	Imagery	Dance: 9 (NR). Control: 10 (NR). Matched numbers of healthy controls in each group; all 55+ years. Disease stage and duration NR.	17-item Philadelphia Geriatric Center Morale Scale Meds: NR	N/A	No change in either group.
Hackney & Earhart (2009c)	Tango, Waltz/Foxtrot: 13 weeks (10 weeks of classes), 2 x 60 minutes	RCT Tai Chi. Control: no intervention.		Tango: 14 (3f); age 68.2 years; H&Y 2.1; duration 6.9 years. Waltz/Foxtrot: 17 (6f); age 66.8 years; H&Y 2.0; duration 9.2 years. Control: 17 (5f); age 66.5 years; H&Y 2.2; duration 5.9 years. Tai Chi: 13 (2f); age 64.9 years; H&Y 2.0; duration 8.7 years.	PDQ-39 Meds: on	N/A	Tango group improved on PDQ-39 domains of Mobility ($p = 0.03$), Social Support ($p = 0.05$) and PDQ-39 Summary Index ($p < 0.01$). No changes in Waltz/Foxtrot, Tai Chi or control group.

Article	Dance intervention: duration, frequency	Study design; control/ comparison group(s).[1]	References to action representation	Participants per group (n female); age; Hoehn & Yahr stage (H&Y); time since diagnosis.[2]	Outcome measures; medication status at assessment (meds)	Follow-up	Results
Hashimoto et al. (2015)	Modern dance: 12 weeks, 60 minutes.	Quasi-RCT Exercise: physical therapy and PD-specific exercises. Control: no intervention.	Visualisation	Dance: 15 (12f); age 67.9 years; H&Y 2.7; duration 6.3 years. Exercise: 17 (15f); age 62.7 years; H&Y 2.7; duration 7.8 years. Control group: 14 (7f); age 69.7 years; H&Y 3.0; duration 6.9 years.	Frontal Assessment Battery at bedside; Mental Rotation Task; SDS; AS. Meds: on	N/A	Dance and Exercise groups improved on Frontal Assessment Battery (dance p = .001; exercise p=.01) and Mental Rotation Task (dance p<.001; exercise p=.002). Dance group also improved on AS (p<.001) and SDS (p=.006).
Heiberger et al. (2011)	Mixed style: 8 months, 75 minutes (outcomes tested only after 8 months of participation).	Uncontrolled N/A	Motor imagery	11 (6f); age 71.3 years; H&Y 3.3; duration NR.	Modified Oregon Health and Sciences University Quality of Life Scale; well-being questionnaire Meds: off	N/A	Self-reported improvements in mood, mobility and quality of life.
Lewis et al. (2016)	Mixed styles changing every two weeks: 12 weeks (10 weeks of classes), 50 minutes	Uncontrolled N/A		18 (NR); age 65.9 years; H&Y 1- 3; duration NR. Also 10 healthy controls; age 64.5 years.	Long- and short-cycle mood assessment: Profile of Mood States before and after 12 weeks; Brunel University Mood Scale before and after 9th class. Meds: on	N/A	Long-cycle: PD and control participants showed improvement in overall mood and decreased anger. Short-cycle: no effects found.

Article	Dance intervention: duration, frequency	Study design; control/ comparison group(s).[1]	References to action representation	Participants per group (n female); age; Hoehn & Yahr stage (H&Y); time since diagnosis.[2]	Outcome measures; medication status at assessment (meds)	Follow-up	Results
McKee & Hackney (2013)	Tango: 12 weeks (10 weeks of classes), 90 minutes	RCT Educational seminars: lectures, discussion and structured group learning activities.		Dance: 24 (12f); age 68.4 years; H&Y 2.3 (Mdn); duration 7.0 years. Education: 9 (1f); age 74.4 years; H&Y 2.0 (Mdn); duration 7.2 years.	PDQ-39; MoCA; Reverse Corsi Blocks; Brooks Spatial Task; Short Form health survey-12 (SF-12). Meds: on	10-12 weeks	Both groups improved on MoCA (p =.01). Dance group also improved on Brooks Spatial Task (interaction p = .02), which was maintained at follow-up.
McNeely et al. (2015)	Dance for PD, Tango: 12 weeks, 2 x 60 minutes	Between-groups	Imagery; mirroring	Dance for PD: 8 (4f); age 68.3 years; H&Y 2.3; duration 10.1 years. Tango: 8 (4f); age 67.7 years; H&Y 2.1; duration 5.4 years.	PDQ-39 Meds: off	N/A	No change in either group.
De Natale et al. (2017)	Tango: 10 weeks, 2 x 60 minutes	RCT Traditional rehabilitation: static and dynamic balance exercises, gait and coordination training		Dance: 9 (2f); age 66.0 years; H&Y 2.5; duration 6.0 years. Traditional rehabilitation: 7 (3f); age 70.0 years; H&Y 2.6; duration 6.33 years.	Frontal Assessment Battery, TMT A and B; Stroop Test. Meds: on	8 weeks	Interactions showed greater improvements for dance vs. rehabilitation on TMT-B (p=.04). Dance group also improved on TMT-A (p=.01). Effects maintained at 8 week follow-up.

Article	Dance intervention: duration, frequency	Study design; control/ comparison group(s).[1]	References to action representation	Participants per group (n female); age; Hoehn & Yahr stage (H&Y); time since diagnosis.[2]	Outcome measures; medication status at assessment (meds)	Follow-up	Results
Rawson et al. (2019)	Tango: 12 weeks, 60 minutes.	Prospective controlled trial Treadmill training Stretching		Tango: 39 (14f), age 66.7 years; H&Y 1-4; duration 6.1 years. Treadmill: 31 (14f), age 68.5 years; H&Y 1-4; duration 5.6 years. Stretching: 26 (12f), age 66.2 years; H&Y 2-4; duration 4.4 years.	PDQ-39 Meds: off	12 weeks	Only stretching group improved from post-test to follow-up (p <.001).
Rios Romenets et al. (2015)	Tango: 12 weeks, 2 x 60 minutes	Pilot RCT Exercise: self-directed daily home practice of exercises provided in pamphlet		Dance: 18 (6f); age 63.2 years; H&Y 1.7; duration 5.5 years. Control: 15 (8f); age 64.3 years; H&Y 2.0; duration 7.7 years.	MoCA; BDI, AS, Krupp Fatigue Severity Scale. Meds: on	N/A	Trends for improvement on MoCA (p = .08) and Fatigue Severity Scale (p = .06).
Shanahan et al. (2015)	Irish set dance: 8 weeks, 90 minutes plus home practice 2 x 20 minutes.	Uncontrolled feasibility	Mental rehearsal	9 (2f); 66.7 age years; H&Y 1.5 (Mdn); duration 7.3 years.	PDQ-39 Meds: on		Significant improvement on PDQ-39 (p = .01).
Shanahan et al. (2017)	Irish set dance: 10 weeks, 90 minutes plus home practice 3 x 20 minutes.	Pilot RCT Control: no intervention	Mental rehearsal	Dance: 20 (7f); age 69.0 years (Mdn); H&Y 1.25(Mdn); duration 5.5 years. Control: 21 (8f); age 69.0 years (Mdn); H&Y 2.0 (Mdn); duration 6.0 years.	PDQ-39 Meds: on		No significant changes in either group.

Article	Dance intervention: duration, frequency	Study design; control/ comparison group(s).[1]	References to action representation	Participants per group (n female); age; Hoehn & Yahr stage (H&Y); time since diagnosis.[2]	Outcome measures; medication status at assessment (meds)	Follow-up	Results
Ventura et al. (2016)	Dance for PD: 4.5 months, 75 minutes	RCT Control: no intervention.	Mirroring	Dance: 8 (8f); age 71.8 years; H&Y 1.7; duration 6.1 years. Control: 7 (5f); age 70.4 years; H&Y 1.6; duration 4.3 years.	TEA visual elevator test; action fluency; category fluency; digit span forward and backward; GDS; PDQ-39. Meds: on	N/A	Dance group: large within-group effect sizes (≥ 0.8) for TEA, digit span forward and GDS; large effect size in favour of dance group for TEA.
Volpe et al. (2013)	Irish set dance: 6 months, 90 minutes.	RCT Exercise: individual physiotherapy sessions - strength, mobility, balance and postural control.		Dance: 12 (5f); age 61.6 years; H&Y 2.2; duration 9.0 years. Exercise: 12 (6f); age 65.0 years; H&Y 2.2; duration 8.9 years.	PDQ-39 Meds: NR	N/A	No change in either group.
Westbrook & McKibben (1989)	Dance/ movement therapy: 6 weeks, 60 minutes.	Cross-over Exercise: 50% participants completed dance intervention first; 50% completed exercise first.		37 (n per group NR); H&Y 2 - 3; duration NR. Dance-first group 14% female; age 72.6 years. Exercise-first group 60% female; age 69.9 years.	BDI Meds: NR	N/A	No change in either group.

Article	Dance intervention: duration, frequency	Study design; control/ comparison group(s).[1]	References to action representation	Participants per group (n female); age; Hoehn & Yahr stage (H&Y); time since diagnosis.[2]	Outcome measures; medication status at assessment (meds)	Follow-up	Results
Westheimer et al. (2008)	Dance for PD: ongoing classes, 75 minutes. Assessment conducted after classes running for 17 months.	Uncontrolled N/A	Imagery; mirroring	15 (8f) respondents from ongoing class; age 50-87 years; H&Y 1-4; duration 1-10 years.	Modified Oregon Health and Sciences University Quality of Life Scale; qualitative investigation via questions emailed to 5 participants. Meds: on	N/A	Self-reported improvements in quality of life including physical health, socialisation, creative expression, and mobility.
Westheimer et al. (2015)	Dance for PD: 8 weeks, 2 x 75 minutes.	Uncontrolled/ mixed-methods N/A	Imagery; imitation	12 (6f); age 66.2 years; H&Y 2.33; duration NR.	PDQ-39 Summary Index; BDI. Meds: on	N/A	

[1]Duration and frequency of alternative interventions matching dance group unless specified; [2]means or ranges reported unless specified.

NR = not reported. RCT = randomized controlled trial.

Test abbreviations: AS = Apathy Scale; BDI = Beck Depression Inventory; GDI = Geriatric Depression Inventory; MocA = Montreal Cognitive Assessment; PDQ-39 = Parkinson's Disease Questionnaire; SDS = Self-report Depression Scale; TEA = Test of Everyday Attention; *TMT = Trail Making Test; UPDRS = Unified Parkinson's Disease Rating Scale.*