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Dance for neuroplasticity: A descriptive systematic review

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ABSTRACT

We conducted a systematic review of randomized clinical trials to investigate whether dance practice promotes neuroplasticity. We also determined how dancing is able to alter (1) brain volumes and structures (2) brain function, (3) psychomotor adjustment and (4) levels of neurotrophic factors. This systematic review formulated a research question based on PICO, according to the guidelines for systematic reviews and meta-analyzes (PRISMA), “What is the influence of dance practice on neuroplasticity in already mature brains?” We screened 1071 studies and from these eight studies were included in the review. Of the selected studies, all demonstrated positive structural and/or functional changes. Structural changes included increased hippocampal volume, gray matter volume in the left precentral and parahippocampal gyrus, and white matter integrity. Functional changes included alterations in cognitive function such as significant improvement in memory, attention, body balance, psychosocial parameters and altered peripheral neurotrophic factor. Based on the evidence, dance practice integrates brain areas to improve neuroplasticity.

Plain language summary

Studies show that dance provides a unique model for investigating how the brain integrates movement and sound, as well as how motor experience develops when associated with artistic creativity, performance and dexterity. This review looked at studies published up to July 2018 in order to investigate dance for neuroplasticity. Eight studies were used in our review: they showed that dancing can strengthen the connectivity between both cerebral hemispheres, because the complex movements in dancing recruit different motor, somatosensory and cognitive brain areas. Dance practice may be effective at improving several aspects of neuroplasticity. However, it remains to be determined whether these benefits are applicable in neurological conditions. Thus, even though dance interventions saw better outcomes in terms of psychosocial, posture and balance parameters when compared with conventional exercise programs, further studies should be conducted to obtain information about whether dance induces a more noticeable impact on cognitive functions than other exercise interventions.

1. Introduction

Dancing is one of the most primitive forms of human communication and expression. It is one of the more synchronized activities that the body can perform. Dancing involves perceiving and performing rhythm: when someone hears music, its compass is marked with fingers, hands, feet, body or internally. This inherent condition for unconscious synchronization is the essence of dance, through the confluence of movements, rhythms and emotional and gestural representations (Brown et al., 2006; Karpati et al., 2015).

Dance and music have probably evolved as ways of generating rhythm, but dance goes far beyond that: it has the ability to convey ideas, and from the beginning of humanity to present day it has been used as a form of language. Dance therefore enables interpersonal coordination in space-time, which is almost non-existent in other social contexts. There are studies that show that dance provides a unique model for investigating how the brain integrates movement and sound, as well as how motor experience develops when associated with artistic creativity, performance and dexterity. Dance offers a unique window into studying neuroplasticity and the interaction between brain and behavior (Brown et al., 2006; Calvo-Merino et al., 2006; Cruz-Garza et al., 2014; Jola et al., 2013; Karpati et al., 2015).

Our knowledge of neuroplasticity suggests that neural networks show adaptation to environmental and intrinsic change. Studies investigating neuroplastic changes associated with learning and performing motor tasks have shown that carrying out such tasks results in increased neural activation in several specific regions of brain. In

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addition, studies comparing specialists and non-specialists in particular activities suggest that specialists employ less neuronal activation than non-specialists when performing a familiar motor task, probably because it becomes easier to perform (Bar and DeSouza, 2016; Christov-Moore et al., 2017; Gallese and Sinigaglia, 2011).

Dance offers an opportunity to investigate neuronal plasticity and its interaction with behavior. Many studies have investigated behavioral correlates of dance, but little is known about how brain circuits are processed during artistic practice (Bar and DeSouza, 2016; Karpati et al., 2016). Dance observation studies elucidate that practicing it over the long-term positively affects brain activity in observation and simulation networks, substantially modifying white and gray matter in various brain regions (Karpati et al., 2015, 2017, Olshansky et al., 2015; Ono et al., 2014; Tipper et al., 2015).

Dance integrates several brain functions such as those connected with kinesthesia (perception of one's own body movement), musicality (interpretation of sound) and emotion (the extent to which music and movement are expressed). The way in which dancing affects the brain is fascinating, although there are still many questions that remain unanswered. To this end, the present review aims to identify how dance promotes neuroplasticity, and seeks to describe how dance practice can alter (1) brain volumes and structures (2) brain function, (3) psychomotor adjustment and (4) levels of neurotrophic factors.

2. Methods

2.1. Registration

The review protocol was registered with the International Prospective Register of Systematic Reviews (PROSPERO) on 21 June 2018 (CRD42018098870).

2.2. Design

This narrative descriptive systematic review formulated its research question based on PICO: P – population, patient or problem, I – intervention, C – comparative interventions, O – outcomes. This strategy enables the search for information to be carried out in a replicable way. In this study, the intervention question was elaborated, namely how a certain practice influences human neuroplasticity in certain circumstances. Using the criteria, the following question was formulated: “What is the influence of dance practice on neuroplasticity in already mature brains?”, i.e. P - adults; I - dance practice, C - dance, physical exercise, sports or other activities and O - neuroplasticity induction.

Many different kinds of literature on the subject were examined: printed and/or electronic journal manuscripts. We included randomized clinical trial (RCT) studies that observed the maturation and activation of the central nervous system through dance. Studies on humans of all ages and both genders were included. Also dance interventions and research comparing dancing with other interventions, e.g. physical exercise and sports.

2.3. Search strategy

This review was performed according to the guidelines for systematic reviews and meta-analyzes (PRISMA) and followed the recommendations of the international guideline PRESS - Peer Review of Electronic Search Strategies - 2015 (Shamseer et al., 2015). Electronic searches were carried out to identify the largest number of articles on dance, brain and neuroplasticity up to July 2018. Specific search strategies were developed for each database (Tables 1–3).

2.3.1. MEDLINE

Largest component of PubMed, the biomedical citation database and abstracts of the United States National Library of Medicine (NLM). It is searchable on the web, by PubMed, at no cost. MEDLINE covers over 5400 journals published in the United States and in more than 80 other countries from the 1940s to the present. It includes records of indexed articles, information about publishers of journals with terms from MeSH (Medical Subject Heading). MeSH is a controlled vocabulary, i.e. a list of subjects used by the National Library of Medicine for indexing articles on the MEDLINE database.

2.3.2. Scopus

A multidisciplinary database maintained by Elsevier Editors and available for access to indexed peer-reviewed academic titles, open access titles, conference proceedings, trade publications, book series, content web pages (meeting in Scirus) and office patents. It has functionalities to support results analysis (bibliometrics) such as identification of authors and affiliations, analysis of citations, analysis of publications and h-index. It covers Biological Sciences, Health Sciences, Physical Sciences and Social Sciences. Period of access from 1823 to the present.

2.3.3. Web of science (WOS)

A multidisciplinary database maintained by Clarivate Analytics and available for access to the indexes of approximately 12,000 journals and the collection of the Science Citation Index Expanded (SCI-EXPANDED) - with availability of access from 1945 to the present; Social Sciences Citation Index (SSCI) - with availability of access from 1956 to the present; Arts & Humanities Citation Index (A&HCI) - with availability of access from 1975 to the present; Conference Proceedings Citation Index - Science (CPCI-S) - with availability of access from 1991 to the present and Conference Proceedings Citation Index - Social Science & Humanities (CPCI-SSH) - with availability of access from 1991 to the present and Conference Proceedings Citation Index - Social Science & Humanities (CPCI-SSH) - with availability of access from 1991 to the present.

The search results from all the databases were inserted in the reference manager EndNote Web that manages duplicates of the searched documents. First, the titles and summaries of the documents identified for possible inclusion were analyzed. Then, the complete documents were read and the ones that met the inclusion criteria were included.

A form was created specifically for this study to collect relevant information from each study including: a) author, b) year of publication, c) study design, d) objectives, e) participants, f) intervention, g) measurements, h) outcome.

2.4. Quality, risk of bias

The Standard Quality Assessment criteria (Kmet checklist) were applied to assess the methodological quality of each selected study. Scale and trend risk were reported, relative to the level of quality. The 14-item Kmet checklist contains a three-point, ordinal scale (0 = no, 1 = partial, 2 = yes), giving a systematic and quantifiable means for assessing the quality of studies of a variety of research designs. Checklist items assess the sampling strategy (including sample size calculations and collection), participant characteristics, description and justification of analytic methods, results, controls for confounding variables, and whether conclusions reflect reported results. A convention was used for the classification of methodological quality: a score of > 80% was considered strong quality, a score of 70–79%, good quality, 50–69%, fair quality and < 50% was considered poor methodological quality (Kmet et al., 2004).

All abstracts were reviewed by one researcher for inclusion, and a second researcher reviewed a randomly selected 100% of the abstracts to ensure accuracy in study selection for the review. Data were synthesized and summarized into different categories: study design, participant characteristics, inclusion criteria, intervention components and outcomes. The same researchers also rated the extracted data regarding methodological quality of all included studies using the Kmet checklist. Inter-rater reliability between the two independent researchers was

Table 1
Electronic search strategy in MEDLINE database.

Strategy	Search details
#1	Topic: ("dancing"[MeSH Terms] OR "dancing"[All Fields] OR "dance"[All Fields]) AND ("brain"[MeSH Terms] OR "brain"[All Fields]) ("dancing"[MeSH Terms] OR "dancing"[All Fields] OR "dance"[All Fields]) AND ("neuronal plasticity"[MeSH Terms] OR ("neuronal"[All Fields] AND "plasticity"[All Fields]) OR "neuronal plasticity"[All Fields] OR "neuroplasticity"[All Fields])
#2	Topic: bibliometr*
#3	Topic: danc*

Filters applied to the search strategy: peer-reviewed and academic journals. Selected period until July 2018.

established for both the abstract selection and Kmet ratings of each included study.

The risk of bias was reduced in the extraction of data and the rating of study quality for this review; none of the researchers have any affiliations with any of the authors of the included studies. Data were synthesized and summarized into different categories: study design, participant characteristics, inclusion criteria, intervention procedures, assessments and outcomes, and methodological quality.

3. Results

The electronic search identified 1071 references in the databases. Two reviewers rated the abstracts for inclusion. The first author assessed all 1071 eligible abstracts against the inclusion criteria, with a randomly selected 100% of the studies assessed by a second rater for inter-rater reliability. The agreement between raters measured by Weighted Kappa was 0.80 (95% CI). After assessing the abstracts against the inclusion criteria, 102 of the 1071 studies were selected, excluding 441 that clearly did not address dance and neuroplasticity or were repeated in different databases and 528 that did not report the selected words for this systematic review. Full text records were assessed to further determine whether studies met the inclusion criteria in this review. Of these 102 studies, 13 were review studies, two were animal models, 14 did not investigate dance intervention, 20 did not present neuroplasticity outcomes, 40 were cross-sectional studies and five were case reports. The remaining eight articles were included in this review. Synthesis of identification, screening, eligibility and the references of included studies are shown in Fig. 1.

Data points were collected and synthesized as follows: studies for promoting neuroplasticity by dance practice (Table 4), intervention components and outcomes (Table 5). Tables 4 and 5 include a detailed description of the included studies.

The eight studies that met the eligibility criteria included 889 participants (562 women, 299 men) aged between 18 and 94 years of age. Of these eight studies, one study investigated dance in mild cognitive impairment and schizophrenia, and the others studied dance in healthy seniors. See details in Table 4.

Dance's influence on the brain was assessed using several conditions. All of them used scales to quantify mental condition, such as Mini-Mental State Examination (MMSE). Six studies measured brain activity by Magnetic Resonance Imaging (MRI), two by Diffusion Tensor Imaging (DTI). Cognitive function was measured by Virginia Cognitive Aging Project (VCAP), nonmemory domain (Trail Making Tests A and B) scores, Everyday Competence Questionnaire (ECQ), Non-verbal concentration test (AKT), Frankfurt Attention Inventory (FAIR), Repeatable Battery of Neuropsychological Status (RBANS), Raven Standard Progressive Matrices (RSPM), Reaction Time Analysis (RA). Brain-derived neurotrophic factor (BDNF) plasma levels measured neurotrophic mechanisms. Sensory Organization Test and Stabilometry assessed postural control. See details in Table 4.

Table 3
Electronic search strategy in Web of Science (WOS) database.

Strategy	Search details
#1	Topic: ("dance" OR "dancing" OR "brain" OR "neuroplasticity")
#2	Tópico: bibliometr*
#3	Tópico: danc*

Index = SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, stipulated period until July 2018.

Pre- and post-treatment were reported in all studies. Follow-up data were presented in Müller et al. (2017) (but time frames were not ranged), with time frames ranging from six to 18 months post cessation of the intervention. Burzynska et al. (2017) reported on results collected from the same sample following the same course of intervention as Ehlers et al. (2017) but the studies reported results from different brain regions that are activated by dance. Burzynska et al. (2017); Ehlers et al. (2017); Baniqued et al. (2018), and Rehfeld et al. (2017/2018) also reported results from the intervention study of similar groups. The treatment outcome(s) for each study is presented in Table 5.

All studies were Randomized Clinical Trials (RCT). The studies by Baniqued et al. (2018) and Burzynska et al. (2017) investigated social dance; Doi et al. (2017) studied ballroom dance, including salsa, rumba, waltz, cha-cha, blues, jitterbug, and tango; Ehlers et al. (2017) looked at dance intervention focused on aerobic and cognitive training; Kattenstroth et al. (2013) studied a special dance program developed for elderly people called Agilando™; Müller et al. (2017) studied a dance program focused on learning new movement sequences in every class. These comprised five different genres, of which the authors reported four: line dance, jazz dance, rock 'n' roll and square dance. Finally, Rehfeld et al. (2017/2018) investigated dance classes involving new choreographic sequences. Control interventions varied, including health education, playing instruments, walking, aerobic exercises and sports (see details in Table 6).

The standard quality assessment checklist was used to evaluate methodological quality of the selected primary research. Sample strategy, characteristics of participants, sample size calculations and

Table 2
Electronic search strategy in SCOPUS database.

Strategy	Search details
#1	TITLE-ABS Key Topic: ("dancing"[MeSH Terms] OR "dancing"[All Fields] OR "dance"[All Fields]) AND ("brain"[MeSH Terms] OR "brain"[All Fields]) ("dancing"[MeSH Terms] OR "dancing"[All Fields] OR "dance"[All Fields]) AND ("neuronal plasticity"[MeSH Terms] OR ("neuronal"[All Fields] AND "plasticity"[All Fields]) OR "neuronal plasticity"[All Fields] OR "neuroplasticity"[All Fields])
#2	TITLE-ABS Key bibliometr*
#3	TITLE-ABS Key danc*

Years of publication until July 2018.

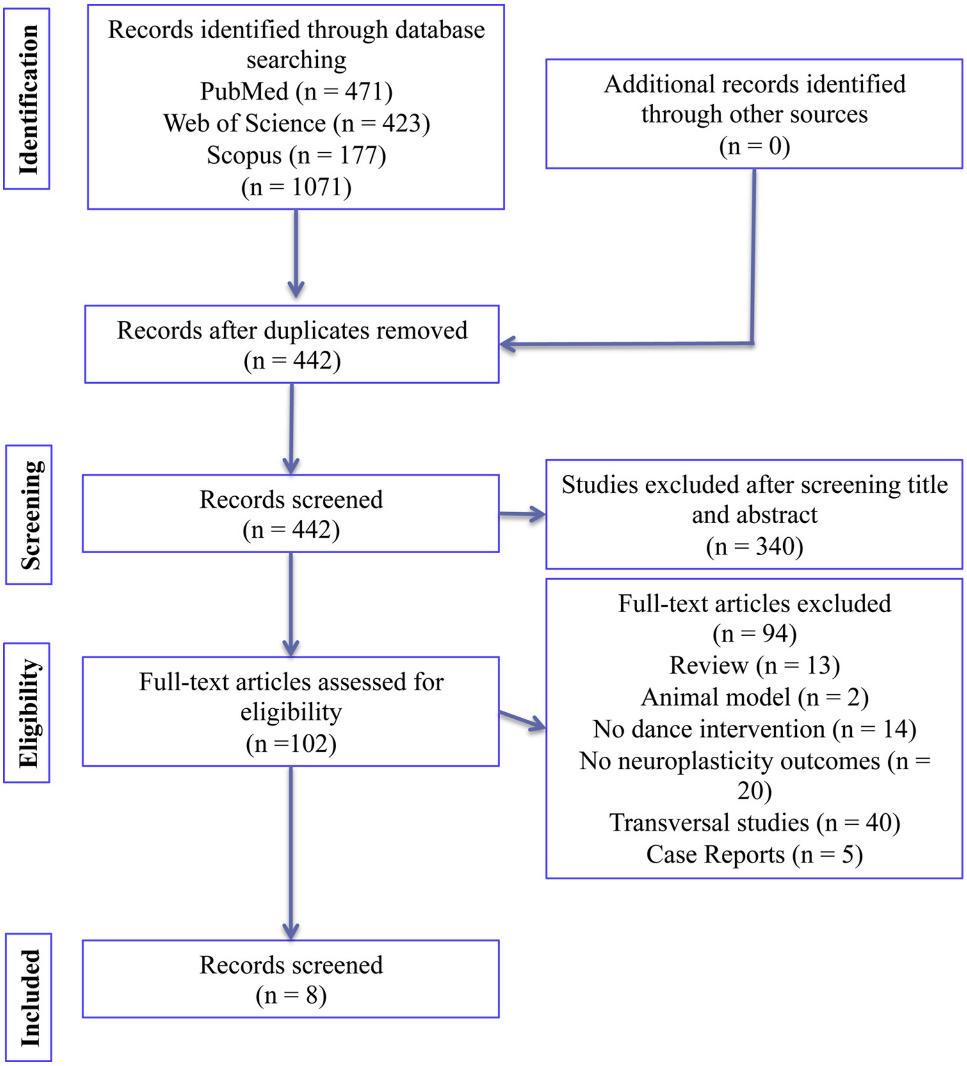


Fig. 1. A flow diagram of the systematic review literature search.

Table 4
Summary of participants and assessments.

1 st Author (year)	Country	Participants						Assessment
		N	Groups	Descriptions	Male	Female	Age	
Baniqued et al. (2018)	USA	128	Treatment: 32 Controls: 96	Healthy Seniors	9 32	23 64	60 to 80	MMSE, MRI, VCAP, CRF
Burzynska et al. (2017)	USA	174	Treatment: 49 Controls: 125	Healthy Seniors	12 42	37 83	60 to 79	MRI, DTI, VCAP, CRF
Doi et al. (2017)	Japan	201	Treatment: 67 Controls: 134	Mild Cognitive Impairment	33 66	34 68	76	MMSE and nonmemory domain (Trail Making Tests A and B) scores.
Ehlers et al. (2017)	USA	247	Treatment: 69 Controls: 178	Healthy Seniors	78	179	65.39 ± 4.56	MRI T1
Kattenstroth et al. (2013)	Germany	35	Treatment: 25 Controls: 10	Healthy Seniors	11 3	17 7	60 to 94	ECQ, AKT, FAIR, RBANS, RSPM, RA, Stabilometry, Spiroergometry
Müller et al. (2017)	Germany	26	Treatment: 14 Controls: 12	Healthy Seniors	7 7	7 5	63 to 80	MRI, BDNF
Rehfeld et al. (2017)	Germany	26	Treatment: 14 Controls: 12	Healthy Seniors	7 7	7 5	68.67 ± 2.57	Sensory organization test and MRI
Rehfeld et al. (2018)	Germany	52	Treatment: 26 Controls: 26	Healthy Seniors	13 13	13 13	63 to 80	MRI, BDNF, Cognitive and Physical tests

MRI: Magnetic Resonance Imaging, fMRI: Functional Magnetic Resonance Imaging, VCAP: Virginia Cognitive Aging Project, CRF: Cardiorespiratory Fitness Test, DTI: Diffusion Tensor Imaging, MMSE: Mini-Mental State Examination, ECQ: Everyday Competence Questionnaire, AKT: Non-verbal concentration test, FAIR: Frankfurt Attention Inventory, RBANS: Repeatable Battery of Neuropsychological Status, RSPM: Raven Standard Progressive Matrices, RA: Reaction Time Analysis, BDNF: Brain-derived Neurotrophic Factor, EEG: Electroencephalography.

Table 5
Summary of study design, procedures and outcomes.

1 st Author (year)	Sudy Design	Comparison condition	Period and Frequency	Time points measured	Outcome
Baniqued et al. (2018)	RCT	SSS, Walk, Walk Plus	3/week, 60 min, 6 months	Baseline, 6 months	Dance group findings showed the smallest effects between groups.
Burzynska et al. (2017)	RCT	Walk, Walk Plus, Active Control	3/week, 60 min, 6 months	Baseline, 6 months	Over 6 months FA in fornix declined in most groups. Dance intervention increased fractional anisotropy in the fornix.
Doi et al. (2017)	RCT	Playing musical instruments, Health education	60 minutes weekly for 40 weeks	Baseline and after 40 weeks	Although no intervention has promoted significant changes in attention and executive functions, memory function and general cognitive status have improved mainly in the dance group.
Ehlers et al. (2017)	RCT	SSS, Walk, Walk Plus	3/week, 60 min, 6 months	Baseline, 6 months	Amigdala and pre-frontal cortex are associated in processing emotional and social experiences. Interventions focusing social support environment may explain stress reduction.
Kattenstroth et al. (2013)	RCT	no dance intervention	1/week, 24 weeks	Baseline, 6 months	Dance practice influences not only on dance-related parameters (posture and balance), but it interferes on cognitive and sensory functions.
Müller et al. (2017)	RCT	Sport	18 months	Baseline, 6 months, 18 months	Dancing can induce neuroplastic processes, since it requires multisensory activation, besides the orientation and coordination of the whole body in space.
Rehfeld et al. (2017)	RCT	Fitness	2/week, 90 min, 6 months; 90 min weekly for 12 months	Baseline, 6 months, 12 months	Both dance and fitness training can induce hippocampal plasticity in the elderly, but only dance training improved balance capabilities.
Rehfeld et al. (2018)	RCT	Sport	2/week, 90 min, 6 months	Baseline, 6 months	Dance program induced brain volumes and BDNF plasma levels increase.

RCT: Randomized Clinical Trial, SSS: Stretching, Strengthening and Stability, Walk Plus: walk with daily supplement formula, PVA: Physical, Visual and Auditory experience, VA: Visual and Auditory experience, A: Auditory experience only, UNT: no experience/trained, PE: primitive experience.

Table 6
Methodological quality of the studies.

Study	Intervention	Control	Randomisation	Blinding
Baniqued et al. (2018)	Social Dance was reported but not described	SSS, Walk, Walk Plus	Randomisation of participants to groups was reported but procedure not described	Blinding of participants and executors not reported
Burzynska et al. (2017)	Social Dance in a socially engaging environment	Walk, Walk Plus, Active Control	Randomization was stratified by gender and age. A computer data management system and baseline adaptive randomization scheme	Blinding of participants and executors not reported
Doi et al. (2017)	Ballroom dance, including salsa, rumba, waltz, cha-cha, blues, jitterbug, and tango	(1) Playing percussion instruments, such as the conga. (2) Health Education regarding the aging process, falls, healthy diet, oral care, and frailty.	A computerized randomization scheme at a 1:1:1 ratio by a blinded researcher	Professional instructors taught/supervised sessions/classes for each intervention
Ehlers et al. (2017)	Dance intervention focused in aerobic and cognitive training condition	Walk and Walk Plus represented aerobic training only, and SSS served as the active, non-aerobic control condition	Randomization of participants was stratified using a computer data management system and baseline-adaptive randomization scheme	Blinding of participants and executors not reported
Kattenstroth et al. (2013)	A special dance program developed for elderly people called Agilando™	no intervention	Randomisation of participants to groups was reported but procedure not described	Blinding of participants and executors not reported
Müller et al. (2017)	Dance program focused in learn new movement sequences every class. It comprised five different genres, but authors reported four: line dance, jazz dance, rock 'n' roll and square dance	a conventional strength-endurance training program with mainly repetitive exercises and low demands in terms of whole-body coordination and memory	Randomisation of participants was stratified using the website www.randomisation.com	Professional instructors taught/supervised sessions/classes for each intervention
Rehfeld et al. (2017)	Dance classes involved new choreographic sequences. Training intervention focused on elementary longitudinal turns, head-spins, shifts of center of gravity (COG), single-leg stances, skips and hops, different steps, and additional arm patterns enforced imbalance	Sport program included endurance training, strength-endurance training, and flexibility training (stretching and mobility)	Randomisation of participants to groups was reported but procedure not described	Blinding of participants and executors not reported
Rehfeld et al. (2018)	Dance program was focused on continuous learning of new choreographies, and coordinative demands, time pressure and complexity were increased during protocol application.	Sport program was composed by a repetitive program divided in three units: endurance training, strength-endurance training, and flexibility training.	A pseudo-randomization was reported but not described	Blinding of participants and executors not reported

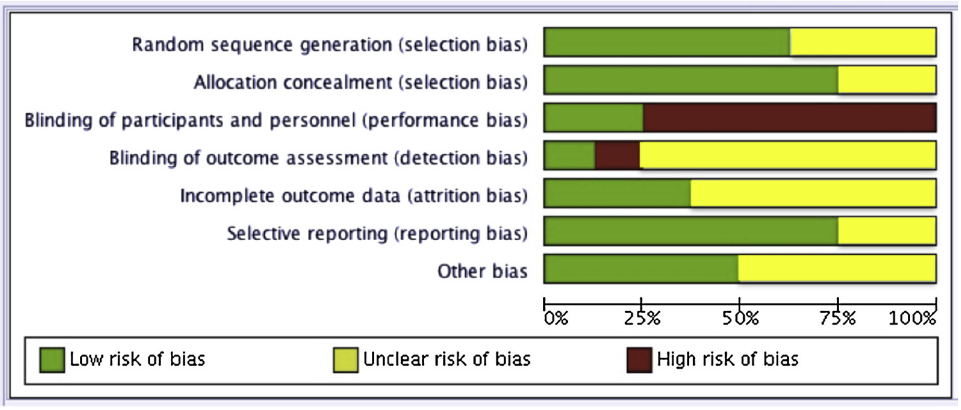
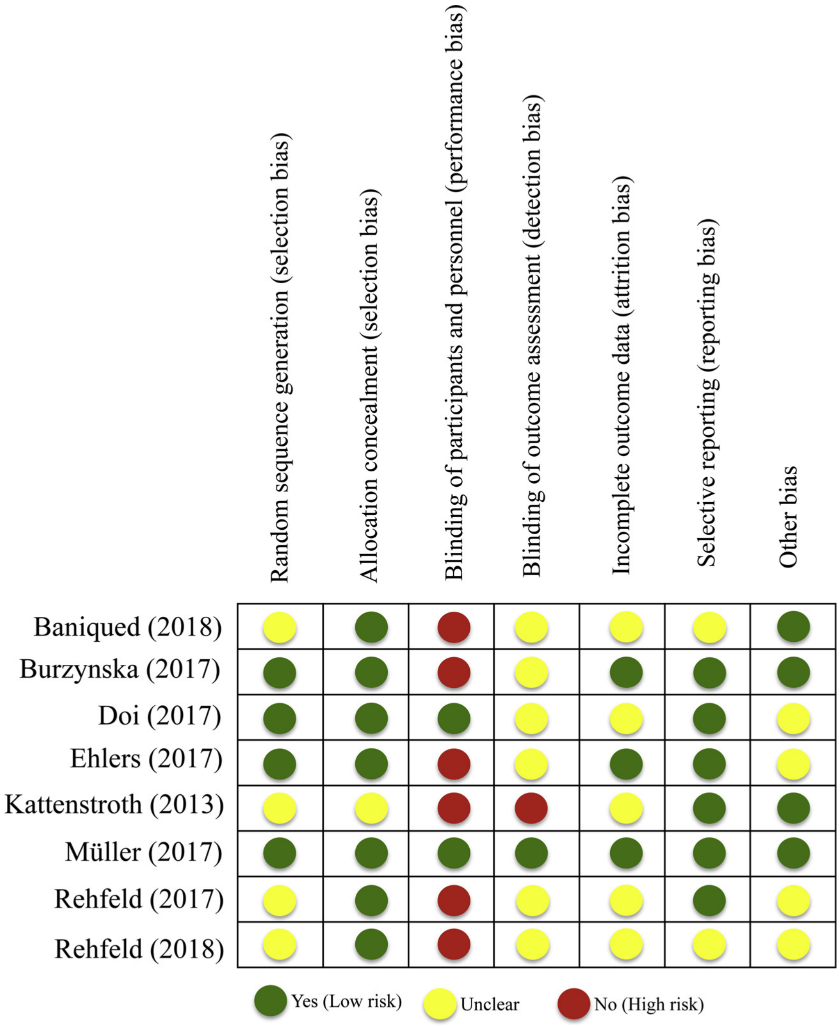


Fig. 2. Authors' judgements about each risk of bias item presented as percentages across all included studies.

collection, description and justification of analytic methods, findings, controls for confounding variables and conclusions according to results reported are assessed using the Kmet checklist. The Müller et al. (2017) study was considered to be of strong quality (> 80%), the studies by Burzynska et al. (2017); Doi et al. (2017); Ehlers et al. (2017); Kattenstroth et al. (2013), and Rehfeld et al. (2017/2018) were considered to be good quality (from 70 to 79%), and the study by Baniqued et al. (2018) of fair methodological quality (68%) according to the Kmet Checklist (Fig. 2).

Fig. 3 shows the quality assessment of all included studies. The risk of bias tool covers six domains of bias (selection, performance, detection, attrition, reporting, and other bias) based on seven principles for assessing risk of bias: (1) do not use quality scales (quality scales and their resulting scores are not an appropriate way to appraise clinical trials because associations of different scales with intervention effect estimates are inconsistent and unpredictable); (2) focus on internal validity (applicability depends on the purpose for which the study is to be used and is less relevant without internal validity, according to



	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding of participants and personnel (performance bias)	Blinding of outcome assessment (detection bias)	Incomplete outcome data (attrition bias)	Selective reporting (reporting bias)	Other bias
Baniqued (2018)	🟡	🟢	🔴	🟡	🟡	🟡	🟢
Burzynska (2017)	🟢	🟢	🔴	🟡	🟢	🟢	🟢
Doi (2017)	🟢	🟢	🟢	🟡	🟡	🟢	🟡
Ehlers (2017)	🟢	🟢	🔴	🟡	🟢	🟢	🟡
Kattenstroth (2013)	🟡	🟡	🔴	🔴	🟡	🟢	🟢
Müller (2017)	🟢	🟢	🟢	🟢	🟢	🟢	🟢
Rehfeld (2017)	🟡	🟢	🔴	🟡	🟡	🟢	🟡
Rehfeld (2018)	🟡	🟢	🔴	🟡	🟡	🟡	🟡

🟢 Yes (Low risk) 🟡 Unclear 🔴 No (High risk)

Fig. 3. Quality assessment of all selected studies.

precise narrow confidence intervals); (3) assess the risk of bias in trial results (not the quality of reporting or methodological problems that are not directly related to the risk of bias, for example, blinding in some cases will not necessarily influence the quality of the study); (4) the basis for assessments of risk of bias require judgment (it should be made explicit, including the judgment itself); (5) choose domains to be assessed based on a combination of theoretical and empirical considerations (empirical studies are associated with bias, such as blinding, dealing with incomplete outcome data, and study design); (6) focus on risk of bias in the data as represented in the review rather than as originally reported (inappropriate participant exclusion); and (7) report outcome specific evaluations of risk of bias (some aspects of trial conduct, such as recurrence or morbimortality) (Kmet et al., 2004).

4. Discussion

4.1. Summary of main results

The results of this systematic review of eight studies indicate that dance practice can induce expressive brain plasticity. Of the selected studies, all demonstrated positive structural and/or functional changes. Structural changes included increased hippocampal volume (Rehfeld et al., 2017), gray matter volume in the left precentral (Rehfeld et al., 2018; Müller et al., 2017) and parahippocampal gyrus (Müller et al., 2017), and white matter integrity (Burzynska et al., 2017; Rehfeld et al., 2018). Functional changes included alterations in cognitive function such as significant improvement in memory (Kattenstroth et al., 2013; Doi et al., 2017; Müller et al., 2017; Rehfeld et al., 2018), attention (Müller et al., 2017; Kattenstroth et al., 2013; Rehfeld et al., 2018), as well as balance (Rehfeld et al., 2017; Kattenstroth et al., 2013), psychosocial parameters (Ehlers et al., 2017) and altered peripheral neurotrophic factor (Müller et al., 2017; Rehfeld et al., 2018).

4.2. Quality of evidence

4.2.1. Impact of dance on brain structure

Although there are several studies which demonstrate the effects of dance on brain plasticity, only a limited number report the influence of dance practice on brain structure. Thus, findings showing the influence of dance practice on brain morphology have caused some discussion in the literature. In our selected studies, interesting and promising outcomes were found. In the study by Rehfeld et al. (2017), both dancing and traditional health fitness over 18 months produced an increase in left hippocampal volume (CA1, CA2 subfields and subiculum). However, only the dance group showed further increases in the left dentate gyrus and right subiculum. It seems that dance exerts an additional positive influence to produce such changes. Sensory stimulus has a strong impact on brain plasticity, mainly in the hippocampus. Animal research has demonstrated that the combination of physical exercise with sensory enrichment can result in the production of more new neurons in the dentate gyrus (Kempermann et al., 1997; Van Praag et al., 2005). The authors suggest that these additional alterations in hippocampal volume might be attributable to different stimuli found in dance practice such as cognitive and sensorimotor tasks (Rehfeld et al., 2017). A previous study by the same group observed an enhancement in gray matter volume in the left precentral gyrus of seniors after six months of a dance program and an increase in the right parahippocampal gyrus after 18 months of dance intervention (Müller et al., 2017). Interestingly, a more recent investigation by the same research group found significantly greater volumes in addition to the above-cited areas, such as in the cingulate cortex, the left supplementary motor area, the left medial frontal gyrus, the left insula, the left superior temporal gyrus and the left postcentral gyrus (Rehfeld et al., 2018). Although the training intervention for both dancers and sport groups seems to be similar across the three studies, different sample size and methods of quantitative analysis may have contributed to variances in the outcomes.

Structural changes are not limited to gray matter but can also be identified in white matter. In recent years, an increasing number of investigations have reported that experience or cardiorespiratory fitness affects white matter integrity (Scholz et al., 2009; Voss et al., 2013; Pettersson et al., 2017), which is associated with learning and cognitive level. However, only two selected studies analyzed white matter changes specifically in relation to dance. For instance, the elegant work conducted by Burzynska et al. (2017) examined white matter integrity in 174 healthy older subjects submitted to four lifestyle interventions (Dance, Walking, Walking + Nutrition, and Control) over a period of six months. Of the 21 brain regions analyzed, only the fornix showed significant time x group interaction in white matter integrity. Interestingly, this integrity declined over six months in all groups and increased in all but the dance group, where it actually increased.

Although the fornix is involved in the encoding, consolidation, and recall of declarative and episodic memory, the authors suggest that its association with processing speed found in their study may also be related to its function in other cognitive domains. In the second study (Rehfeld et al., 2018), a six-month dance program increased the volume of white matter in frontal and parietal areas. In this investigation, a remarkable increase in the corpus callosum was noted in dancers compared with the sport group. The dance practice in this study consisted of learning several choreographic sequences, while the sport intervention was composed of endurance, strength-endurance and flexibility training. The corpus callosum is responsible in particular for nearly all communication between the two cerebral hemispheres. According to the authors' interpretation, dancing is able to strengthen the connectivity between both cerebral hemispheres; the complex movements of dancing employ different motor, somatosensory and cognitive brain areas.

4.2.2. Impact of dance on brain function

Although the influence of dance practice on brain function is not well understood, some recent investigations on this subject have reported interesting findings. Dance can be a way of getting involved in a physical activity or as a form of pleasurable exercise. Indeed, current literature has strongly supported the influence of the environment and/or physical exercise on functional brain plasticity (Sale et al., 2014; Erickson et al., 2011).

Meta-analyses have reported beneficial effects of exercise on cognition, mainly in older adults including improvements in attention, processing speed, executive function, and memory (Smith et al., 2010; Colcombe and Kramer, 2003). Recent studies have reported that dance can impact on functional brain plasticity (Kattenstroth et al., 2013; Doi et al., 2017; Müller et al., 2017; Rehfeld et al., 2017, 2018). Cognition is often associated with several characteristics of dance such as sensorimotor stimulation and balance performance.

Studies attempting to explore the association between dance and cognitive functioning have presented promising, but mixed results. For instance, among the eight studies identified in our systematic review, five performed memory tests, but four studies resulted in significant improvements (Kattenstroth et al., 2013; Doi et al., 2017; Müller et al., 2017; Rehfeld et al., 2018). In these studies, recruited participants were healthy and elderly and in one study they were elderly with mild cognitive impairment (Doi et al., 2017).

A six-month dance program induced a substantial improvement in working memory compared with control subjects (Kattenstroth et al., 2013), in spatial memory compared with conventional fitness training (Rehfeld et al., 2018) or in verbal memory after an 18-month dance program (Müller et al., 2017). Better memory function (story memory) was also observed in older adults with mild cognitive impairment after a 40-week dance program (Doi et al., 2017). Conversely, in another investigation, executive function was improved after the fitness training program but not after the dance intervention (Baniqued et al., 2018). Low intensity and diversity of dance sessions were possible reasons for poor substantial findings.

With regard to attention, three studies from this review using different tests of attention found positive outcomes after a six-month dance intervention (Kattenstroth et al., 2013; Müller et al., 2017; Rehfeld et al., 2018). These findings support previous evidence about the favorable effects of physical exercise on cognition (Bamidis et al., 2014).

The contribution of the visual, somatosensory, and vestibular systems to the maintenance of posture and balance are important factors for dance motor behavior. Studies have demonstrated the benefits of dance for balance and posture (Crotts et al., 1996; Sofianidis et al., 2009). In our systematic review, only two investigations examined balance parameters. Balance performance improved after a six-month dance program but not in the control group in one study (Kattenstroth et al., 2013). In another investigation, the effect on balance after an 18-month dance intervention was superior to the traditional health fitness program. While the dance group presented improvements in the three sensory systems (somatosensory, visual and vestibular systems), the sports group showed better performance in the somatosensory and vestibular systems (Rehfeld et al., 2017).

The importance of reducing social isolation and loneliness to bring back or improve well-being and quality of life in old age is well-recognized. Moreover, there is increasing evidence of an association between psychosocial behavior with cognitive functioning in old age (Wilson and Bennett, 2017) and increased physical activity and reduced social isolation (Robins et al., 2018). Ehlers et al. (2017) was the only study in our review to examine an association between dance intervention and psychosocial parameters. Perceived loneliness decreased after six months not only in the dance group but for all exercise interventions used in their study. Although the impact of exercise on psychosocial variables is well established, the positive influence of exercise on psychological outcomes may also be related to social interaction during the physical exercise program (McHugh and Lawlor, 2012). Consequently, the social component of dance might be contributing to this effect.

Neurotrophic factors have been thought to play an important role in the positive effects of physical exercise on brain health, exerting several functions on neuroplasticity. Among the neurotrophic factors, BDNF (brain derived neurotrophic factor) is extensively expressed in the brain, affecting a number of essential functions in the central nervous system, such as cell proliferation, growth, differentiation and survival, protection against neuronal death in the hippocampus (Binder and Scharfman, 2004; Almeida et al., 2005), and cognitive function (Vaynman et al., 2004; Goldberg et al., 2008). Previous reviews on this topic have mostly concluded that exercise increases peripheral BDNF concentrations in humans (Knaepen et al., 2010; Coelho et al., 2013).

Two studies in our systematic review showed similar results to previous reports which examined long-term physical exercise on blood BDNF. Assessment of BDNF levels carried out in healthy, elderly volunteers submitted to a dance or sport intervention showed a significant increase in BDNF levels after six months in the dance group, while no change was noted in the group submitted to conventional training (Müller et al., 2017). Interestingly, no significant change was noted in cardiovascular fitness between the groups. A factor that may have been implicated in these results is the intensity of repetitive exercise compared with the constant learning of new choreographies during the dance intervention. Increased peripheral BDNF levels are dependent on exercise type and intensity (Ferris et al., 2007) (see also reviews by Knaepen et al., 2010 and Coelho et al., 2013). Similar results were observed in the subsequent study from the same group (Rehfeld et al., 2018).

5. Authors' conclusion

5.1. Implications for practice

A number of studies have focused on physical exercise programs in order to improve neuroplasticity. Dance is a non-pharmacological and inexpensive intervention, which can be carried out easily and efficaciously. This review provides evidence that dance programs can induce expressive brain plasticity, at both structural and functional levels. As suggested by previous studies (Kattenstroth et al., 2013; Müller et al., 2017), the combination of physical exercise and sensory enrichment during dance, such as the integration of sensory information and motor control, may be an advantage over a standard fitness program. In this way, dance practice may be effective at improving several aspects of neuroplasticity. Although some studies have investigated dance intervention on neurological conditions, such as cerebral palsy (Teixeira-Machado et al., 2017; López-Ortiz et al., 2018), stroke (Demers and McKinley, 2015) and Parkinson disease (Earhart, 2009; Michels et al., 2018), there is no current evidence of the impact of dance on structural changes in the brain. Thus, future studies should determine whether these morphological alterations are also applicable in neurological disorders.

5.2. Implications for research

To strengthen the positive impact of dance on brain plasticity, future investigations should improve their reporting of a number of aspects. While this review indicated that dancing may be a promising intervention to induce positive neuroplasticity in the elderly, investigations in the younger population would ensure that these effects are not only related to older individuals. Even though better outcomes in psychosocial, posture and balance parameters were identified in a dance intervention when compared with conventional exercise programs, further studies are needed to obtain information about whether dance induces a more pronounced impact on cognitive functions than other exercise interventions. Accordingly, in the selected studies, several outcomes are limited from the same research groups. Investigations into subjects with distinctive socioeconomic characteristics may provide information that can affect the outcomes.

In general, the scientific literature has suggested a positive link between participation in intellectual, social and physical sport/activities and better performance in several cognitive tasks (van Boxtel et al., 1996; Wikee and Martella, 2018). In this respect, the concept of cognitive reserve has been attributed as a key factor for the prevention of neurological diseases and cognitive decline. A previous investigation reported that higher levels of musical training might be associated with increased cognitive reserve (Gooding et al., 2014). It is likely that factors that affect cognitive reserve, such as dance practice, may even inhibit or retard the development of the neurological disorder *per se*.

A meta-analysis was not suitable here due to the variations in the studies selected such as the baseline characteristics of the participants and differences between study designs, clinical, methodological and statistical heterogeneity, intervention on different subpopulations, the contexts of or variations in the dance intervention, which could be misleading and invalidate any conclusions. Therefore, further robust large-scale RCT interventions are needed to confirm the impact of dance on neuroplasticity at different ages as well as in different neurological conditions, with the aim of providing a better understanding of the influence of dance on the brain.

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