# The value of Tai Chi to enhance physical and psychosocial health for people with multiple sclerosis

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**About the structure of this manuscript:**

1. This cumulative dissertation is based on three publications. A theoretical framework to these articles is outlined in the first three chapters of this document.

2. The chapters include the following information: Chapter 1 provides an overview on the theoretical background. Chapter 2 delineates scientific interest and formulates core research questions. Chapter 3 provides a brief summary of the main findings within a concluding discussion and points out perspectives for future research. Chapter 4 consists of the articles' published versions and an overview on each author's contribution. The articles were reprinted with the journals' permission.

3. The Appendix includes all supplementary materials that were published online when the articles were released. The format of these documents was slightly adapted to improve readability within this document.

4. The References Section exclusively contains all sources mentioned in Chapters 1 to 3. You will find the sources of each publication within its original references section (Chapter 4). Citation is based on the APA guidelines (6th edition). For quotations and paraphrases the corresponding page numbers are included. Sources cited without a page number refer to the whole article.

5. This manuscript was designed for online publication. Links are displayed in colour. To facilitate navigation, a link to the table of contents (toc) is included at the bottom of each page (except for the first page of each chapter).

# Abstract

**Background**
The contribution of exercise to physical and psychosocial health is beyond dispute. Especially individuals with chronic diseases, such as multiple sclerosis (MS), have much to gain from being physically active. MS predominantly occurs during young adulthood. Dependent on disease activity, it leads to a gradual decline of mobility, social participation, and quality of life. A long-term perspective is essential for effective MS management.

**Research interest**
Pharmacological treatment primarily relies on early intervention to counter disease activity. To detect functional impairment as early as possible, the development of assessment tools is necessary. Further strategies to impede or even restore functional damage are scarce. Only recently, exercise has been recognised as an essential part of MS management. Despite substantial evidence in support of physical activity, specific recommendations on choice and dose of available exercise programs are lacking. There are strong arguments in favour of Tai Chi, a Chinese martial art, to meet the specific needs of this target population. Particularly the principle of mindfulness, which is entangled with the concept of Tai Chi, could be a valuable asset in coping with MS.

**Strategies**
*We evaluated dynamic characteristics of walking behaviour,* comparing 37 persons with MS to 25 healthy controls. To describe the change of speed in walking behaviour, we analysed its approximation to three different velocity profiles in two time-framed walking tests. In sum, the observed differences varied depending on test duration (6 versus 12 minutes), disease severity (mild versus moderate disability level) and observed parameter (mean walking speed versus temporal change of walking speed). Our findings indicate an early influence of MS on walking behaviour. We present the linear decline of walking speed as a new, clinically relevant feature of walking ability in persons with MS. The decline in walking speed is particularly suitable to assess walking behaviour with regard to fatigue, because it better reflects the individual's subjective constraints than the commonly assessed parameter mean walking speed.

*We analysed both the concept of Tai Chi and research on Tai Chi with special regard to methodology*. The concept of Tai Chi is highly pluralistic. Scientific research on Tai Chi is just as manifold. Such divergent investigation makes it difficult to collect convergent evidence. The complexity within this field should receive more attention. Tai Chi is a complex intervention that requires an elaborate and well-designed scientific approach. A first step into this direction is to improve the quality of reporting and standardisation. In addition, the inclusion of high quality qualitative research should be pushed forward.

*We devised a standardised Tai Chi program and analysed its therapeutic value for persons with MS.* We evaluated the program within a 6-month intervention, comparing a Tai Chi group (n = 15) to a group that received treatment as usual (n = 17). We found a consistent pattern of beneficial effects on the following parameters: balance, coordination, fatigue, depression, and life satisfaction.

**Conclusion**
Dynamic characteristics of walking behaviour could support improved monitoring of mobility in MS. Tai Chi is a promising opportunity for persons with MS to engage in long-term physical activity and foster both physical and psychosocial resources.

**Keywords:** multiple sclerosis, physical activity, exercise, mobility, walking test, complex intervention, research methodology, Tai Chi, mindfulness

# Zusammenfassung


**Hintergrund**
Die Bedeutung körperlicher Aktivität für die physische und psychosoziale Gesundheit steht außer Frage. Insbesondere die Betroffenen chronischer Erkrankungen wie Multipler Sklerose (MS) können von körperlicher Aktivität profitieren. MS tritt vor allem im jungen Erwachsenenalter auf und führt – abhängig von der Kranheitsaktivität – zu einer allmählich fortscheitenden Einschränkung von Mobilität, sozialer Teilhabe und Lebensqualität. Eine langfristig vorausschauende Perspektive ist unerlässlich, um eine effektive Behandlung zu gewährleisten.

**Forschungsinteresse**
Der Erfolg einer medikamentösen Behandlung hängt vor allem davon ab, wie schnell auf einen Krankheitsschub reagiert werden kann. Um funktionelle Beeinträchtigungen frühzeitig zu erfassen, ist es notwendig, geeignete Messverfahren zu entwickeln. Neben einer medikamentösen Therapie gibt es aktuell keine wirksamen Strategien, um das Fortscheiten der Erkrankung aufzuhalten oder sogar rückgängig zu machen. Erst vor kurzer Zeit wurde körperliche Aktivität als ein essentielles Element in der Behandlung von MS erkannt. Während die aktuelle Studienlage den Wert körperlicher Aktivität für MS Betroffene eindeutig hervorhebt, fehlt es an genauen Empfehlungen zur Auswahl und Anwendung verfügbarer Bewegungsprogramme und Sportarten. Es gibt klare Argumente dafür, dass Tai Chi, eine chinesische Kampfkunst, sich sehr gut für die speziellen Bedürfnisse dieser Zielgruppe eignet. Vor allem das Prinzip der Achtsamkeit, das mit Tai Chi untrennbar verbunden ist, könnte für die Therapie von MS bedeutsam sein und sich als besonders hilfreich erweisen.

**Strategien**
*Wir untersuchten dynamische Kenngrößen im Gehverhalten 37 MS Betroffenener* und 25 gesunder Kontrollpersonen. Um die Geschwindigkeitsveränderung im Gehverhalten zu beschreiben, untersuchten wir deren Annäherung an drei verschiedene Geschwindigkeitsprofile während zweier Gehtests mit Zeitlimitierung. Die Ausprägung der Gruppenunterschiede variierte in Abhängigkeit der Testdauer (6 Minuten gegenüber 12 Minuten), des Behinderungsgrades (geringfügig gegenüber moderat) und der beobachteten Kenngrößen (mittlere Gehgeschwindigkeit gegenüber Verlangsamung der Gehgeschwindigkeit). An unseren Ergebnissen lässt sich ablesen, dass sich MS frühzeitig auf die Gehfähigkeit der Betroffenen auswirkt. Wir schlagen den linearen Abfall der Gehgeschwindigkeit als einen neuen, klinisch relevanten Parameter vor, um die Gehfähigkeit MS Betroffener zu erfassen. Der lineare Trend eignet sich insbesondere, um das Gehverhalten im Hinblick auf Fatigue zu untersuchen, da dieser Parameter das subjektive Empfinden MS Betroffener besser widerspiegelt als die üblicherweise gemessene mittlere Gehgeschwindigkeit.

*Wir analysierten das Konzept, das sich hinter dem Namen Tai Chi verbirgt, sowie die Art und Weise, wie Tai Chi bisher wissenschaftlich untersucht wurde.* Dabei fand die Forschungsmethodik eine besondere Berücksichtigung. Das Konzept Tai Chi ist überaus vielfältig. Analog dazu hat sich die Forschung über Tai Chi in viele verschiedene Richtungen verzweigt. Eine solch divergente Herangehensweise erschwert die Zusammenführung und Interpretation der gewonnenen Ergebnisse. Es ist notwendig, der Komplexität in diesem Gebiet mehr Aufmerksamkeit zu schenken. Tai Chi als Intervention ist sehr komplex. Dies erfordert eine ausgeklügelte und durchdachte wissenschaftliche Strategie. Der erste Schritt in diese Richtung ist eine bessere Berichterstattung und Standardisierung. Zusätzlich sollten gezielt qualitative Forschungsmethoden stärker mit einbezogen werden.

*Wir entwickelten ein standardisiertes Tai Chi Programm und untersuchten dessen therapeutischen Wert für MS Betroffene.* Dazu evaluierten wir das Programm im Rahmen einer 6-monatigen Intervention und verglichen die Tai Chi Gruppe (n = 15) mit einer Kontrollgruppe (n = 17), die ihre übliche Behandlung beibehielt. Unsere Analyse ergab ein einheitliches Muster positiver Effekte in den folgenen Variablen: Gleichgewicht, Koordination, Fatigue, Depression und Lebenszufriedenheit.

**Schlussfolgerung**

Die Untersuchung der Gehfähigkeit von MS Betroffenen sollte dynamische Kenngrößen des Gehverhaltens berücksichtigen. Tai Chi ist eine vielversprechende Möglichkeit für MS Betroffene, sich langfristig körperlich zu betätigen und ihre physischen und psychosozialen Ressourcen zu stärken.

**Schlüsselwörter:** Multiple Sklerose, körperliche Aktivität, Bewegung, Sport, Gehtest, Gehfähigkeit, komplexe Intervention, Tai Chi, Achtsamkeit

# Table of Contents

# 1 Background

In the first section of this chapter (1.1), we introduce MS as a disease with many faces but without cure. While the knowledge on pathological mechanisms and treatment strategies has been growing, there is still a need for innovative strategies to complement MS therapy. We provide an overview on the state of the art research, focusing on the importance of physical activity for persons with MS in the second section (1.2). While the effects of physical activity tend to be beneficial, there is a lack of specific recommendations for available exercise programs. On this basis, we highlight the martial art Tai Chi as a particularly suitable type of exercise for people with MS in the third section (1.3).

## 1.1 What is multiple sclerosis?

Multiple sclerosis is an autoimmune disease of the central nervous system (CNS). Its main feature are chronic inflammatory processes within the brain and spinal cord. Depending on the severity and dissemination of affected areas, a variety of different symptoms can occur. These processes lead to a gradual decrease in multiple functional areas. Disease onset predominantly occurs during early adulthood, causing considerable impact on both, affected individuals and society. Despite extensive research efforts and remarkable advances in treatment possibilities, the cause of MS remains a mystery, its course unpredictable and a cure has yet to be discovered. This uncertainty puts to the test the coping skills of affected individuals and their families. Additionally, the multi-dimensional and intangible phenotype of MS challenges scientists and healthcare providers.

### 1.1.1 Prevalence and socio-economic scope

About 2.1 million people are affected by MS worldwide (DeLuca & Nocentini, 2011, p. 197). It is important to note that the estimated incidence rates differ between countries relative to the rigour and quality of disease investigation. Medical progress (such as magnetic resonance imaging (MRI) techniques) and an increased life expectancy partially contribute to a longitudinal rise observed in MS incidence and prevalence rates.

In Europe, more than 500.000 people are estimated to live with MS (Flachenecker et al., 2014, p. 1). With the intention of enabling systematic acquisition and analysis of data on MS in Europe, the European Register for Multiple Sclerosis (EUReMS) project was set up in 2010 (Flachenecker et al., 2014). The incidence of MS is highest during early adulthood, between the ages of 20 and 40 (Kamm, Uitdehaag & Polman, 2014, p. 132). The lifetime risk of developing MS is 2.5% in women and 1.4% in men (Kamm et al., 2014, p. 133).

The progressive accumulation of disability along the disease course contributes to a rising economic burden. Even within the first 5-10 years after diagnosis, the unemployment rate of people with MS is 70-80%, (DeLuca & Nocentini, 2011, p. 203). The main reasons for unemployment are fatigue and cognitive impairment. While about 40% of unemployed persons with MS would like to go back to work, this is extremely difficult to accomplish without giving up obtained disability benefits (DeLuca & Nocentini, 2011, p. 203). In 2006, the annual health care costs per patient were estimated to range from €18.000 in mild disability, to €62.000 in severe disability (Kobelt, Berg, Lindgren, Fredrikson & Jönsson, 2006, p. 918).

### 1.1.2 Aetiology, pathogenesis and pathophysiology

The aetiology of MS is unknown. Its onset seems to depend on a combination of genetic susceptibility and environmental factors (Kamm et al., 2014, p. 133 - 134). Triggered by a viral infection or infectious agent, the immune response initiates a chronic inflammation of the central nervous system (Kamm et al., 2014, p. 133; Compston & Coles, 2008).

**Inflammation and neurodegeneration**

Briefly summarized, these inflammatory processes lead to tissue damage and neurodegeneration. Prior to the time of MRI techniques, the evaluation of neural tissue damage occurred predominantly *post mortem* – on the basis of visible lesions of sclerotic tissue, disseminated across the CNS (Murray, 2009, p. 4). These "plaques" constitute the core of MS pathology (DeLuca & Nocentini, 2011, p. 199). On MR images, they appear as white spots. Upon closer inspection, three different stages of plaque development can be differentiated: demyelination, axonal loss and sclerosis.

It is not clear to what extent the inflammatory and neurodegenerative processes interact with one another. Further, it is unknown whether one precedes the other (Compston & Coles, 2008, p. 1509; Kamm et al., 2014, p. 134). These two possibilities are referred to as outside-in model (neuronal damage is caused by an auto-immune reaction) and inside-out model (neuronal injury causes an auto-immune reaction) (Kamm et al., 2014, p. 132 - 134).

In sum, MS pathology involves the following processes: acute and/or chronic inflammation, demyelination, lack of myelin producing cells (oligodendrocytes), excess of sclerotic tissue (astrocytes) as well as degeneration of axons and neurons (Frohman, Racke & Raine, 2006).

The severity and interplay of these processes significantly influences the balance between functional impairment and functional recovery.

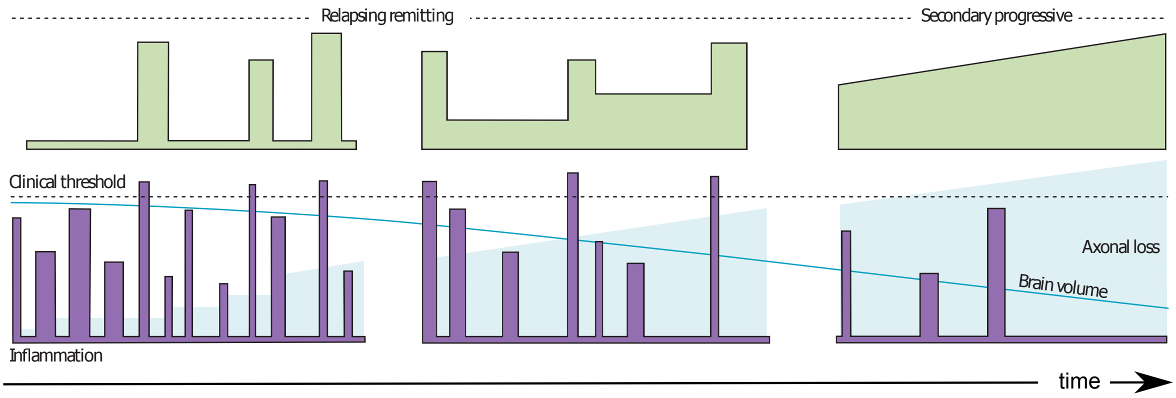


**Figure 1: Clinical course of multiple sclerosis**. The figure shows the connection and interplay between the processes involved in MS pathology: inflammation, symptom presentation and neurodegeneration. If disease activity does not exceed a certain degree (clinical threshold), damage can remain undetected by the individual. However, as soon as the capacity of the CNS to compensate for damage reaches its limit, functional disturbances in various domains occur. Along its course, MS can lead to an increasing loss of axons, a decreasing brain volume and a progressive accumulation of disability. (This figure was reprinted from The Lancet, Compston, A. & Coles, A. (2008). Multiple sclerosis. 372(9648), p.1508 with permission from Elsevier.)

### Functional impairment and functional recovery

On the one hand, the pathological processes cause tissue damage and functional impairment that is disseminated across the CNS. In sum, the excitation, conduction, and synaptic transmission of signals become increasingly attenuated (Compston & Coles, 2008). Demyelination impedes saltatory conduction across affected axons. Additionally, it enables non-synaptic transmissions of electrical impulses (ephaptic transmission) and spontaneous depolarisation (Compston & Coles, 2008, p. 1509). Apart from this, the damage to the axons themselves leads to a gradual disconnection and demise of the neural network.
On the other hand, there are two adaptive mechanisms working towards functional recovery. Firstly, myelin producing cells counteract the pathological processes by repairing the axons' myelin sheath (remyelination) (Luessi, Kuhlmann & Zipp, 2014). Secondly, neuroplasticity enables adaptive remapping of cortical representations (functional reorganization) (Tomassini et al., 2012, p. 3). In this case, additional cortical regions that are not typically involved in a task are activated to compensate the neuronal damage (Döring, Pfueller, Paul & Dörr, 2012, p. 8; Tomassini et al., 2012).

### Defining the course of MS

In summary, the symptomatic phenomena of MS depend on localization and severity of the involved pathological processes (see Figure 1). In large part, early stages of MS are determined by the waxing and waning of acute inflammation and plaque activity. Later stages of the disease are characterized by a slight but continuously expanding inflammation around former plaques and diffuse neurodegenerative processes (Kamm et al., 2014, p. 134). This differentiation between the sudden appearance/exacerbation of symptoms and their steady worsening, defines the course of MS. In addition to this, the presence of acute relapses and the extent of their remission are key criteria. A relapse is defined as an acute progression of the disease. In this context, it is important to differentiate between real relapses and pseudo relapses (for additional information see Frohman et al., 2013): A *relapse* in MS "is a reflection of a sub-acute to acute focal inflammatory event in the CNS that has damaged myelinated axons or neurons, which has lead to failure of neurological signalling." (Vollmer, 2007, p. 9)

> A *pseudo relapse* reflects "a change in neurological function in patients with MS due to physiological processes other than a new inflammatory process in the CNS (e.g., fever) that lead to increased conduction delay and block in previously damaged white matter and that is reversible when the physiologic stress is removed." (Vollmer, 2007, p. 6)

The disease course is variable and usually categorized according to a definition formulated by Lublin and Reingold in 1996. The definition includes four main types that differ in frequency of occurrence (DeLuca & Nocentini, 2011, p. 199; Lublin & Reingold, 1996). Approximately 85% of new diagnoses are relapsing-remitting MS (see Figure 2). About 80% of these patients transition into secondary-progressive MS at individual time points (see Figure 4). Primary-progressive MS is less frequent (10%) (see Figure 3). Relapsing-progressive courses are rare (5%) (see Figure 5). In 2013, this scheme of categorization was revised, for example to include information about the current state of disease activity (Lublin et al., 2014).

### 1.1.3 Symptoms and clinical presentation

The manifestation of symptoms in MS depends on the balance between functional impairment (severity of inflammation and extent of neuronal damage) and functional recovery (degree of remyelination and success of cortical reorganization) (Tomassini et al., 2012). Theoretically, a multitude of symptoms can appear depending on the localization of damage within the CNS (Compston & Coles, 2008, p. 1503). Yet, there are MS specific patterns regarding predominantly affected areas (DeLuca & Nocentini, 2011, p. 198).
Prevalent symptoms comprise impaired *motion control* (such as disturbed coordination and balance, spasticity, paresis, ataxia, impaired ability to speak or swallow), *visual impairment, sensory dysfunction* (such as pain and paraesthesia) and *autonomic dysfunction* (such as bladder, bowel and sexual dysfunction) (Döring et al., 2012, p. 1). About 60 - 80% of MS patients reported that a rise in body temperature leads to a temporary worsening of their symptoms (*Uhthoff's Phenomenon*) (Döring et al., 2012, p. 6; Frohman et al., 2013). According to Frohman & colleagues (2013), this phenomenon "can be triggered by factors including the perimenstrual period, exercise, infection, fever, exposure to high ambient temperatures, and psychological stress" (p. 535). In large part, the symptoms of MS manifest in the following multi-dimensional constructs: fatigue, mobility impairment, cognitive impairment, and depression.

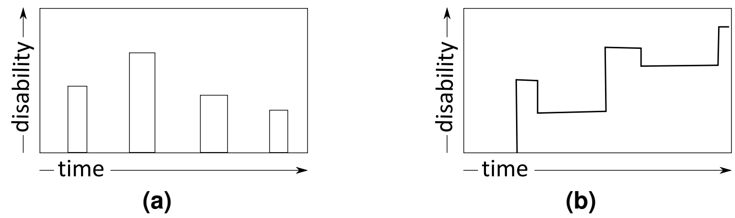


**Figure 2:** "**Relapsing-remitting (RR) MS** is characterized by clearly defined acute attacks with full recovery (a) or with sequelae and residual deficit upon recovery (b). Periods between disease relapses are characterized by lack of disease progression." (Lublin & Reingold, 1996, p. 908)

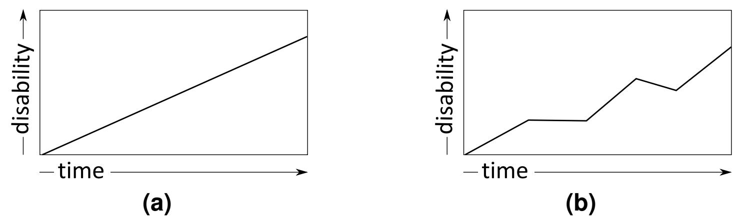


**Figure 3:** "**Primary progressive (PP) MS** is characterized by disease showing progression of disability from onset, without plateaus or remissions (a) or with occasional plateaus and temporary minor improvements (b)." (Lublin & Reingold, 1996, p. 909)

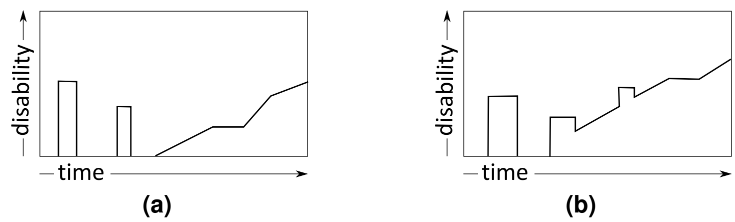


**Figure 4:** "**Secondary progressive (SP) MS** begins with an initial RR course, followed by progression of variable rate (a) that may also include occasional relapses and minor remissions (b)." (Lublin & Reingold, 1996, p. 909)

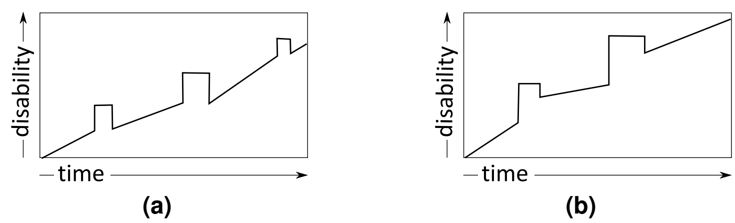


**Figure 5:** "**Progressive-relapsing (PR) MS** shows progression from onset but with clear acute relapses with (a) or without (b) full recovery." (Lublin & Reingold, 1996, p. 910)

#### Fatigue

Fatigue is one of the most common symptoms of MS. While the overall prevalence rate of fatigue is almost 80%, 55% of the patients report fatigue to be one of the worst symptoms they experience (Khan, Amatya & Galea, 2014, p. 1). For further information see Asano & Finlayson (2014) and Kos, Kerckhofs, Nagels, D'hooghe & Ilsbroukx (2008). The feeling of fatigue is highly subjective and difficult to define or measure (Dobkin, 2008). The lack of a homogeneous terminology regarding name, causes and dimensions of fatigue challenges comprehensibility and comparability of scientific studies (Asano & Finlayson, 2014, p. 1,6; Burschka, 2010, p. 23 - 40; Kos et al., 2008, p. 97). In 1998, Fatigue was defined as "a subjective lack of physical and/or mental energy that is perceived by the individual or caregiver to interfere with usual and desired activities" (Multiple Sclerosis Council for Clinical Practice Guidelines, 1998, p. 2). In 2007, the following definition was developed and evaluated on the basis of four additional definition attempts:

> "Fatigue is defined as reversible, motor and cognitive impairment with reduced motivation and desire to rest, either appearing spontaneously or brought on by mental or physical activity, humidity, acute infection and food ingestion. It is relieved by daytime sleep or rest without sleep. It can occur at any time but is usually worse in the afternoon. In MS, fatigue can be daily, has usually been present for years and has greater severity than any pre-morbid fatigue." (Mills & Young, 2008, p. 57)

Despite the development of several theories, the origin of fatigue in MS remains unknown. Primary and secondary contributing factors to fatigue are discussed (Khan et al., 2014, p. 2; Kos et al., 2008): Primary factors result directly from disease activity. They could originate locally due to demyelination and neurodegeneration or be systemic due to the immune response. Moreover, the mechanisms to compensate for neuronal damage (such as cortical reorganization and increased central motor drive) could lead to an elevated energy expenditure (Burschka, 2010, p. 26; Kos et al., 2008, p. 91).

In contrast to this, secondary fatigue could result from MS-related complications, musculosceletal problems, concomitant diseases, pharmacological treatment, sleep quality and personal factors (such as nutrition and physical activity). In addition to the multitude of possible causes, fatigue manifests in different dimensions, for example with regard to time (acute or chronic onset) and functional impairment (motion or cognition) (Khan et al., 2014, p. 1). The multi-dimensionality of fatigue makes it very difficult to pinpoint specific causes at the individual level. Moreover, it is difficult to distinguish fatigue from other MS symptoms, such as cognitive impairment and depression. For an exemplary overview on fatigue in MS, see Figure 6.

#### Mobility impairment

Mobility impairment is both a prominent symptom even early in the disease and a long-term consequence of MS (Motl, 2013, p. 326). The estimated prevalence ranges from 41% to 75% (Motl, 2013, p. 326). It is important to note that impaired mobility can result in a substantial decrease in quality of life (Motl, 2013, p. 333). Disease progression affects two viable

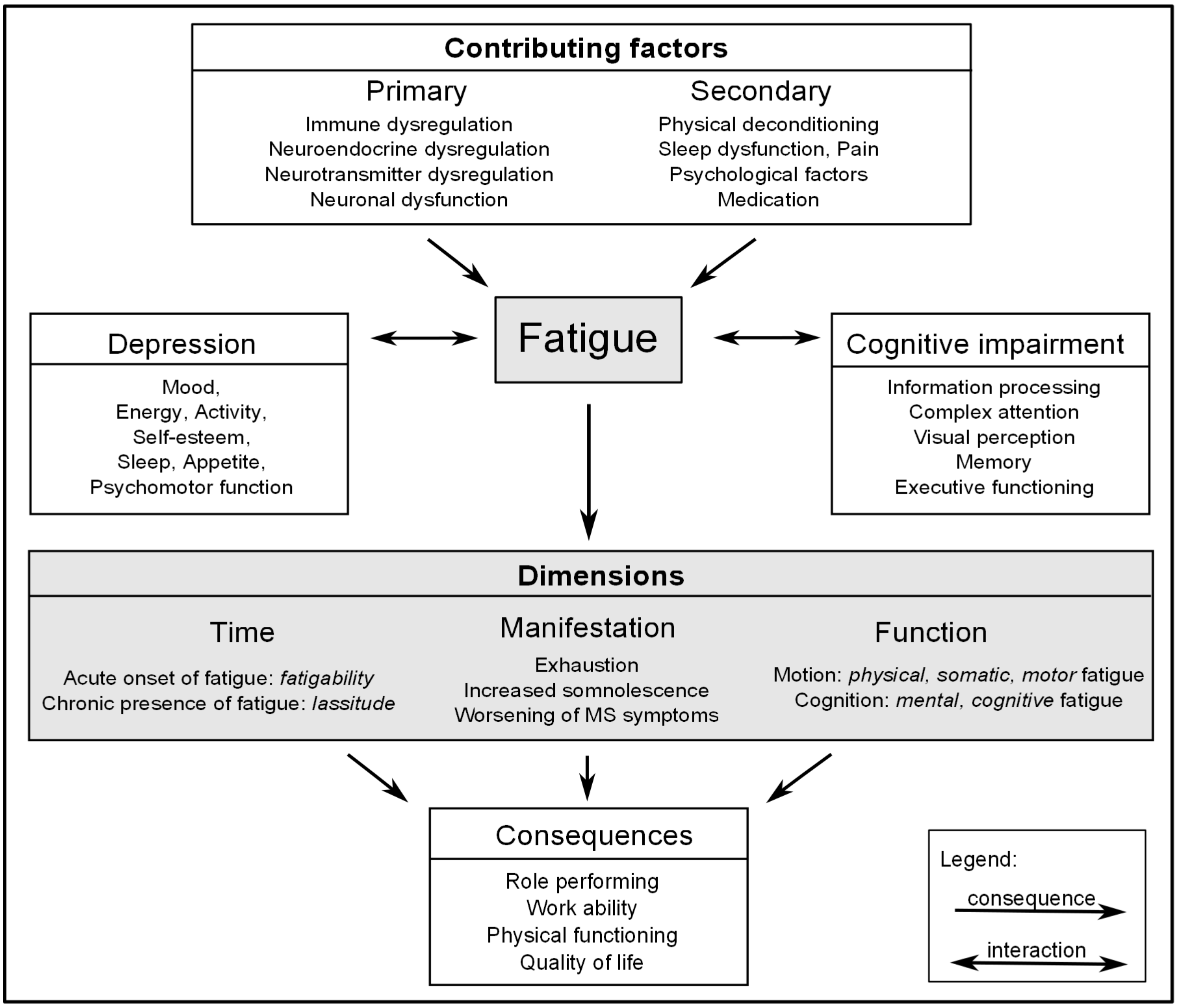


**Figure 6: Overview on the different dimensions of fatigue in MS** (Khan et al., 2014; Krupp, Serafin & Christodoulou, 2010; MacAllister & Krupp, 2005). Depending on the perspective, a multitude of different parameters involved in the occurrence and consequences of fatigue in MS can be differentiated. First, primary and secondary causes of fatigue can be distinguished. Second, fatigue can be entangled with other symptoms of MS, such as depression and cognitive impairment. Third, fatigue can manifest in different dimensions, for example regarding time and affected function. This multi-dimensionality of fatigue makes it very difficult to pinpoint specific causes at the individual level and to provide appropriate therapy.

components of ambulatory ability: motion control and sensory function (Motl, 2013, p. 326). Sensory dysfunction such as visual impairment and paraesthesia (for example numbness, pain, pins and needles) reduce the quality of sensory feedback. This challenges orientation, balance and the ability to adapt movement to changes in the environment. Motoric dysfunction such as inappropriate muscle innervation (for example spasticity, weakness, ataxia) additionally challenges coordination. While in healthy people the ability to walk relies on automatic and unconscious mechanisms, MS patients have to resort to a higher level of conscious motion control (Motl, 2013, p. 327). This could require a decrease in walking speed in order to process relevant information in time. In sum, the elevated level of required resources could lead to earlier energy depletion and occurrence of fatigue (Motl, 2013, p. 328 - 329).

**Cognitive impairment**

Cognitive impairment is a frequent symptom of MS. The prevalence ranges from 43% to 70% (Chiaravalloti & DeLuca, 2008, p. 1139). However, the neuropsychological presentation of cognitive impairment differs among MS patients and may be influenced by a wide range of factors (Motl, Sandroff & Benedict, 2011, p. 1035). Predominantly affected cognitive domains include information processing, memory, complex attention, executive functioning, and visual perceptual skills (Chiaravalloti & DeLuca, 2008; DeLuca & Nocentini, 2011, p. 201 - 202). In addition to this, cognitive impairment can significantly impact quality of life, activities of daily living and the ability to work (Motl et al., 2011, p. 1035; Siegert & Abernethy, 2005, p. 469).

**Depression**

Depression rates are high among MS patients, suggesting a lifetime-risk of 25 to 50%, which is 2 to 5 times higher than observed in the general population (Feinstein, Magalhaes, Richard, Audet & Moore, 2014, p. 508). However, such estimates should be treated with caution. First, symptoms of depression may overlap with other symptoms of MS, including fatigue, pain, anxiety, and cognitive impairment (Feinstein et al., 2014, p. 509). Second, there is little consensus among researchers about standard assessments to diagnose depression (Siegert & Abernethy, 2005, p. 470). Third, reports on estimated depression rates were based on different populations (Siegert et al., 2005, p. 470). According to the ICD-10 (World Health Organization, 2015), a depressive episode (F.32) is characterized by the following criteria: lowering of mood, reduction of energy, decrease in activity, reduced self-esteem, sleep and appetite disturbances, and psychomotor retardation. In addition to this, depression is closely related to abnormal cognitive mechanisms, such as rumination (World Health Organization, 2015, F42.0).

The symptoms delineated above can significantly impact the affected individuals' quality of life. They appear as complex constructs that are highly individual and tend to comprise multiple interacting components. Especially the attempt to clearly differentiate between fatigue, cognitive impairment, and depression is a vexed issue with regard to both, identifying possible causes and providing well-directed treatment. This multi-dimensionality particularly challenges the development, evaluation and adequate prescription of effective interventions.

### 1.1.4 Diagnosis, diagnostics and treatment

The intangible and complex phenotype of MS poses great challenges to diagnosis and treatment. Presently, there is no test available to definitely diagnose MS (Milo & Miller, 2014, p. 518; National Clinical Guideline Centre, 2014, p. 48). The diagnosis is made with the help of specific criteria that keep being adapted according to the advancing knowledge and possibilities (Milo & Miller, 2014, p. 518). The core of MS diagnosis consists of examining the dissemination of inflammatory processes in space and time by MR imaging of the CNS (DeLuca & Nocentini, 2011, p. 201). In fact, MRI machines have contributed substantially to reducing the time between disease onset and diagnosis (Haghikia & Gold, 2013, p. 358).

#### Clinical assessment

The assessment of disease-related parameters primarily relies on MRI, clinical evaluation, functional tests and measures of self-report. *MR imaging* plays a key role in monitoring the disease course, treatment efficiency and side effects (Haghikia & Gold, 2013, p. 376 - 377). The most widely used tool to assess neurological function in MS is the *Expanded Disability Status Scale (EDSS)* (Kurtzke, 1983). In the EDSS the overall state of disease progression is quantified by the assessment of eight functional systems (pyramidal, cerebellar, brain stem, sensory, bowel and bladder, visual, mental, other) on a six point rating scale, in addition to mobility and activities of daily living. The EDSS score ranges from zero (no dysfunction) to ten (death as a consequence of MS). The main focus of the EDSS includes motor function and ambulatory ability.

#### Assessments of global functioning and self-report measures

Further assessments of global functioning in MS include the *Barthel Index (BI)* and the *Multiple Sclerosis Functional Composite (MSFC)*. The BI evaluates a person's ability to carry out basic activities of daily living. The MSFC evaluates cognition, fine motor skills and ambulation[1] (DeLuca & Nocentini, 2011, p. 204). It is important to note, that the assessment of ambulatory ability is an integral part of monitoring disease progression and treatment success (Motl, 2013, p. 327). The most commonly used tests to assess walking performance are the *Timed 25-Foot Walk (T25-FW)* and the *6-minute walk (6-MW)* (Motl, 2013, p. 327 - 328). Both assessments rely on result-oriented parameters of walking behavior, such as the time needed to cover a predefined distance (T25-FW) or the total distance walked during a

[1] The MSFC includes the following tests: 9-Hole Peg Test, Paced Audio Serial Addition Test (PASAT), Timed 25-Foot Walk (T25-FW).

given amount of time (6-MW). Apart from clinical evaluation, many assessments resort to patient self-report measures, for example on fatigue, depression and quality of life.
In summary, clinical assessments are needed to differentiate between normal functioning and pathological impairment, with regard to the severity and duration of a specific symptom, its impact on everyday activities and psychological strain. Moreover, subjective as well as objective assessments are essential in determining whether specific treatment is necessary and whether it is successful. In general, treatment options are divided into pharmacological treatment and non-pharmacological treatment.

**Pharmacological treatment**

Pharmacological treatment of MS can be divided into: treatment of relapses, immunomodulatory therapy (basic therapy, escalating therapy) and symptomatic therapy (Kamm et al., 2014). Many MS patients also turn to alternative treatment options, such as complementary and alternative medicine (DeLuca & Nocentini, 2011, p. 209).
To date, there are eight approved pharmacological agents in the domain of immunomodulatory therapy (Kamm et al., 2014, p. 137). All of these drugs primarily aim to decrease the number and severity of relapses by early anti-inflammatory intervention. Thus, an early diagnosis plays a crucial role in the possibilities of treating MS. The interventional approach is chosen with regard to individual symptom presentation, disease course and prognosis. However, despite the growing body of knowledge on factors influencing disease progression, their prognostic value at the individual level remains poor (DeLuca & Nocentini, 2011, p. 199). Moreover, the rising number of treatment options contributes to the complexity of MS management, especially with regard to an individualized therapy (Kamm et al., 2014, p. 139).
Apart from decreasing the rate and severity of relapses via early immunomodulatory treatment, the possibilities to save neural tissue are scarce (Haghikia & Gold, 2013, p. 377). In particular, there is a lack of tools available to counter and reverse neurodegeneration, especially in progressive courses of the disease. Current investigative efforts regarding neuroprotection include experiments with regeneration of axonal injury and stem cell administration (Haghikia & Gold, 2013).

**Non-pharmacological treatment**

Non-pharmacological treatment is an important complement to pharmacological treatment. In some cases, it might be superior to drug-based treatment, for example in the management of fatigue (Asano & Finlayson, 2014, p. 4; Khan et al., 2014, p. 14). Non-pharmacological treatment consists of physical therapy (physiotherapy, ergotherapy, logopedics and rehabilitation) as well as psychological therapy and social therapy (Döring et al., 2012, p. 2). Basically, this approach to deal with arising symptoms primarily focuses on rehabilitation. However, a prevention-oriented approach could further increase the chances of successfully dealing with MS. For example, it was suggested to include behavioural interventions

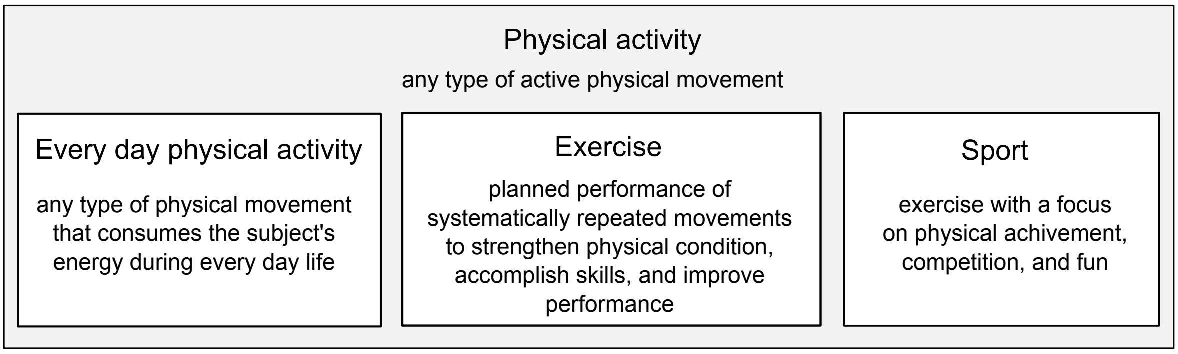


**Figure 7: Terminology to distinguish different domains of physical activity** in this manuscript. This scheme was built according to the definitions provided by the WHO (2014) and Döring et al., (2012, p. 3).

into standard MS management (Döring et al., 2012; Ellis & Motl, 2013). This request is in line with the recent interest in the impact of exercise on disease progression and life quality. Exercise can contribute essentially to MS management (Dalgas & Stenager, 2012; DeLuca & Nocentini, 2011; Döring et al., 2012; Motl & Pilutti, 2012; National Clinical Guideline Centre, 2014). Despite this recognition as a valuable tool to increase function and quality of life in MS patients, exercise is not commonly offered or prescribed as an integral part of MS therapy (Döring et al., 2012).

## 1.2 Why is physical activity important for MS management?

The World Health Organization (WHO) defined *physical activity* as "any bodily movement produced by skeletal muscles that requires energy expenditure" (WHO, 2014, What is physical activity?, para. 1). It is important to distinguish between the terms *physical activity* and *exercise*. *Exercise* is "a subcategory of physical activity that is planned, structured, repetitive, and purposeful in the sense that the improvement or maintenance of one or more components of physical fitness is the objective" (WHO, 2014, What is physical activity?, para. 2). The term *sport* is used in current literature on the same track as the term exercise. It was suggested to define sport as "exercise with a focus on physical achievement, competition and fun" (Döring et al., 2012, p. 3). The main difference between the terms *physical activity* and *exercise/sport* lies in the degree of deliberate planning involved. Despite these clear definitions, it remains difficult to unambiguously denote whether the term *physical activity* points to physical activity in *everyday life* (excluding exercise/sport) or to physical activity *in genera*l (including exercise/sport). The terminology used in this manuscript was chosen according to the categorization in Figure 7.

Since the 1990s scientific interest in the effects of physical activity on MS has been rising tremendously (Tallner, Mäurer & Pfeifer, 2013, p. 1239). However, due to the delayed recognition of its therapeutic potential, the evidence on specific effects of physical activity on disease progression is still limited. In traditional MS management, bed rest was medically prescribed and patients were advised against physical activity (Tallner et al., 2013). Two main reasons for these recommendations were the observation of symptom aggravation along with a rise in body temperature and the intent of conserving energy to minimize fatigue. Even though first calls towards the inclusion of physical therapy into MS management came up in the 1960s, the potential of regular physical activity only started to gain attention during the 1980s (Tallner et al., 2013, p. 1241). By comparison, physical activity in the field of heart disease had already been established via outpatient exercise groups and a specific education for exercise instructors (Tallner et al., 2013, p. 1243).

### 1.2.1 The chances of physical activity

Compared to healthy controls, people with MS show a reduced level of physical functioning, including cardiorespiratory capacity, muscle strength and balance (Döring et al., 2012, p. 8). It is important to note that such symptoms can aggravate due to physical inactivity (Döring et al., 2012, p. 3). Additionally, physical inactivity comprises the risk of secondary morbidities to MS, such as obesity, diabetes, osteoporosis, cardiovascular damage and additional complications (Döring et al., 2012; National Clinical Guideline Centre, 2014; Tallner & Pfeifer, 2008).

Yet, many persons with MS take on a physically inactive lifestyle and miss out on the therapeutic potential of physical activity (Dalgas & Stenager, 2012; DeLuca & Nocentini, 2011; Döring et al., 2012; Motl & Pilutti, 2012; National Clinical Guideline Centre, 2014). The prevalence of physical inactivity in the MS population (reaching up to 78%) seems not only higher than in the general population but even higher compared to people with other chronic diseases (Latimer-Cheung et al., 2013b, p. 1801). To promote a shift towards the engagement of people with MS in physical activity, exercise has explicitly been recommended in current clinical guidelines: "Encourage people with MS to exercise. Advise them that regular exercise may have beneficial effects on their MS and does not have any harmful effects on their MS" (National Clinical Guideline Centre, 2014, p. 119).

### 1.2.2 Mechanisms of exercise induced benefits

While the therapeutic value of exercise was recognized, the mechanisms of exercise induced benefits on the course of MS are just starting to be explored. Current research is mainly focusing on the fields of immune-modulation, neuroprotection and neuroplasticity. The effects of exercise on the immune system of athletes are known to depend on training intensity. While vigorous exercise increases the risk and frequency of infectious disease, moderate exercise intensity contributes to their prevention (Döring et al., 2012, p. 7). In multiple sclerosis, exercise is reported to exert further adaptive immune-modulating effects (Döring et al., 2012, p. 7).

The most promising mechanisms are the effects of exercise on cytokines and neurotrophic factors. The effect of exercise on cytokines could beneficially shift the imbalance between pro-inflammatory and anti-inflammatory processes in people with MS (Dalgas & Stenager, 2012, p. 91). In this way, exercise could support the effect of drug-based immune modulating therapy. Due to the short-term nature of these effects, frequent and regular training intervals are advocated (Döring et al., 2012, p. 7). Moreover, exercise seems to counter the neurodegenerative effects of MS pathology by fostering the release of nerve growth factors (Dalgas & Stenager, 2012, p. 92 - 93). These neuroactive proteins support cell proliferation, synaptic plasticity, neuroprotection and neurogenesis. In addition, neuroprotective mechanisms may also be fostered by exercise induced activation of antioxidant enzymes (Döring et al., 2012, p. 7).

Furthermore, exercise could exert beneficial effects on such mechanisms that compensate damage in the CNS, for example neuroplasticity and cortical reorganization (Döring et al., 2012, p. 8; Tomassini et al., 2012, p. 4). Impaired motion control seems to be compensated by the recruitment of additional cortical regions that are not typically involved in motor planning and execution (Döring et al., 2012, p. 8). "Repetitive activation of the motor programs strengthens the cortical engrams and causes neuroplastic and adaptive processes like improved motor unit activation and synchronization of firing rates. In contrast periods of inactivity are associated with opposite effects" (Döring et al., 2012, p. 7). In summary, exercise seems to exert disease modifying effects, but the evidence base is very limited (Dalgas & Stenager, 2012; Motl & Pilutti, 2012). Current data is also not sufficient to draw definite causal conclusions on exercise induced alterations in brain morphology (Döring et al., 2012, p. 8).

### 1.2.3 Evidence for exercise-induced effects

The evidence base of exercise induced effects in persons with MS was summarized in a well-structured review (Motl & Pilutti, 2012): they reported that extensive and consistent supportive evidence suggests beneficial effects on aerobic capacity, muscular strength, and ambulatory performance of persons with MS; limited but supportive evidence existed for fatigue, gait, balance and quality of life; no consistent evidence existed on the effects of exercise on MS pathogenesis (inflammation, neurodegeneration, axonal and neuronal loss) and on participation-related variables (activities of daily living, recreation, leisure and work); evidence on the effects of exercise on depression and cognition was also inconsistent (Motl & Pilutti, 2012).

In a more recent review, it was suggested that the effect of exercise on depression tends to be beneficial, but that current evidence does not allow for solid causal conclusions (Dalgas, Stenager & Sloth, 2014). However, in patients with depression, exercise was shown to exert moderate to large effects (Josefsson, Lindwall, & Archer, 2014). While there is limited research available on exercise and cognition in MS, promising effects were found in gerontology (Motl et al., 2011, p. 1035). In fact, firm evidence exists on exercise induced preservation of brain structure in older people, indicating beneficial effects on cognitive function (Motl & Pilutti, 2012, p. 489). Motl & colleagues (2011) explicitly encouraged the systematic examination of exercise training and cognition in MS by adopting knowledge and experience from gerontology research.

In conclusion, research on the therapeutic potential of exercise for MS management is still in its infancy with much left to do. In particular, there is a lack of solid information on choice, dose, and advantages of specific exercise programs for people with MS (Latimer-Cheung et al., 2013b).

### 1.2.4 Recommendations on physical activity in MS

Only recently, the first steps were taken towards the development of evidence-informed physical activity guidelines. This section provides four examples, involving different parties within the field. First, the National Clinical Guideline Centre issued the following recommendations on exercise in MS to initiate their promotion by healthcare professionals. In summary, these guidelines include goal-setting, physical functions (aerobic capacity, strength, balance), compliance, support and choice:

> "Ensure people with MS and mobility problems have access to an assessment to establish individual goals and discuss ways in which to achieve them. This would usually involve rehabilitation specialists and physiotherapists with expertise in MS. Consider supervised exercise programmes involving moderate progressive resistance training and aerobic exercise to treat people with MS who have mobility problems and/or fatigue. Consider vestibular rehabilitation for people with MS who have fatigue or mobility problems associated with limited standing balance. Encourage people with MS to keep exercising after treatment programmes end for longer term benefits (...). Help the person with MS continue to exercise, for example by referring them to exercise referral schemes. If more than one of the interventions recommended for mobility or fatigue are suitable, offer treatment based on which the person prefers and whether they can continue the activity when the treatment programme ends." (National Clinical Guideline Centre, 2014, p. 460)

Second, Latimer-Cheung & colleagues (2013a, p. 1834) developed evidence-based recommendations for the minimum level of exercise required to enhance physical fitness, mobility, and health related quality of life, while decreasing fatigue. The guidelines advocate a combination of moderate aerobic activity (2 times per week for 30 minutes) and strength training (2 times per week, 2x15 repetitions finished barely but safely for each exercise). Suggested aerobic activities comprise arm cycling, leg cycling or walking and elliptical trainer. Strength training exercises comprise weight machines, free weights, and cable pulleys. Further exercises advocated are elastic resistance bands, aquatic exercise, and callisthenics.

Third, the MS Society of Canada started an exemplary and pragmatic approach to facilitate physical activity for people with MS in the society. The initiative "MS Active NOW, Activating Your Life" targets persons with MS, fitness professionals, and health professionals. It aims to provide all three stakeholders with information material on MS and exercise, including opportunities, challenges and means to overcome barriers (Carlyle, Johnston, Rattray & Wheeler, 2009; Johnston, Carlyle & Rattray, 2007, 2008; Johnston, Wheeler & Rattray, 2009a, 2009b). The initiative encourages the inclusion of persons with MS into local facilities (e.g. fitness centres), promoting social interaction and support for persons with MS.

Fourth, Tallner & Pfeifer (2008, p. 5–6) pointed out the following considerations regarding the suitability of exercise programs for persons with MS. Due to considerable individual variation in the course of symptoms in MS, exercise programs should allow for tailoring to the specific abilities and needs of the participant. In particular, common symptoms such as fatigue, balance problems, and cognitive decline should be taken into account. Moreover, such programs should allow for exercise intensity changes according to the participant's perceived level of exertion. In fact, the conscious control and self-reliant adjustments should be a specific aim of the program. Additionally, the setting should be chosen with regard to temperature and the possibility of taking individual breaks (to adjust exercise intensity or to deal with incontinence). Exercise programs should specifically aim to facilitate long-term adherence and to endorse the establishment of exercise and everyday physical activity as an integral part of MS management. Thus, exercise programs for people with MS should also account for traditional exercise and group-based activity programs, which are broadly available to the community. These offers should be perceived as pleasant, accessible and accomplishable.

It has to be noted that all of the recommendations above were based on studies with several limitations, including design, sample selection, intervention protocol, endpoints, outcome measures, and reporting of information. There is a need for well-conducted studies to provide a solid basis for detailed and systematic recommendations on choice, dose, and benefits of suitable exercise programs for people with MS (Döring et al., 2012).

## 1.3 Why could Tai Chi be particularly suitable?

People with MS are a very heterogeneous target group, requiring specific attention in the conceptualization, conduction, and implementation of exercise programs. The Chinese martial art Tai Chi could be a particularly suitable and cost-effective type of exercise because it allows individual support and tailoring to specific needs, even within group-based settings.

### 1.3.1 Tai Chi is gentle and accessible

Tai Chi is a living tradition with a long history. Especially Yang's Style Tai Chi practice consists of flowing and dance-like chains of motion, which are performed in a slow and gentle manner. Such choreography is called a *form*. Originally designed as a secret martial art in ancient China, Tai Chi gained a good reputation as a favourable sport in healthcare. The question *What is Tai Chi?* is further discussed in section 4.2 (page 42). In fact, Tai Chi has been gaining increasing attention in both, Eastern and Western healthcare research. There is growing evidence in favour of Tai Chi to induce health benefits in various neurological groups, including Parkinson's disease, Fibromyalgia, chronic stroke, peripheral neuropathy and MS (Au-Yeung, Hui-Chan & Tang, 2009; Li et al., 2012; Li & Manor, 2010; Mills, Allen & Carey-Morgan, 2000; Wang et al., 2010). Since the early twentieth century, the dissemination of Tai Chi via group lessons grew along with the number of Tai Chi instructors and schools. To increase suitability for mainstream, the original forms were shortened and simplified. Today, Tai Chi classes for all age groups are broadly available to the public.

### 1.3.2 Tai Chi can be adapted to specific needs

The Tai Chi forms available vary depending on traditional lineage and personal experience of their practitioners. The variability could be a hint that the core of Tai Chi is not the form itself but the principles carried within the form. This is why Tai Chi could be particularly interesting for people with motoric deficits, as it allows tailoring of the movements according to individual abilities. To some degree, necessary adjustments in conscious control of motion can be guided by experienced Tai Chi instructors. There is a wide range of possibilities allowing to adjust the elements of Tai Chi practice to the participants' needs (for example via individual breaks, variation in speed, range of motion, stance width, number and characteristics of the figures within a form). In the end, subtle adjustments are primarily up to the awareness and creativity of the practitioners themselves.

Mindful awareness is an important component of Tai Chi practice (Nedeljkovic, Wirtz & Ausfeld-Hafter, 2012; Wayne & Kaptchuk, 2008, p. 96 - 97). In fact, the concept of mindfulness is compatible with the concept of Tai Chi, which is described in Section 4.3 (page 58). Briefly summarized, the concept of mindfulness involves regulation of attention and focusing on the here and now. The development of an observant, accepting and non-elaborative perspective is assumed to increase access to information on current experience, fostering self-awareness and the ability of self-regulation (Bishop et al., 2004). The development and consolidation of this ability is essential in patient-oriented rehabilitation programs. It is particularly important for persons with MS, who need to rediscover their body and its abilities over and over. Further, convergent evidence suggests a positive association between mindfulness and psychological health (Keng, Smoski & Robins, 2011, p. 17). Few interventions incorporate both physical and mindfulness exercises. A recent review reported a successful combination of tailored exercise programs and mindfulness-based interventions in MS (Simpson et al., 2014).

### 1.3.3 Tai Chi could help to overcome barriers to exercise participation

In addition to this, the adaptability and gentle way of Tai Chi practice could help people with MS to overcome barriers to exercise participation. Possible factors contributing to a hesitant perspective on physical activity comprise traditional thinking, lack of confidence, fatigue, and motivational issues as well as acute worsening of symptoms during of following physical exertion.

First, the traditional perspective on exercise could still be present in peoples' mind (Tallner et al., 2013, p. 1238). In a survey on health enhancement (n = 2200 persons with MS), 19% of the sample attributed beneficial effects to endurance training. Contrarily, 17% of the same sample reported that endurance training increased their disease severity (Simmons, Ponsonby, van der Mei, & Sheridan, 2004, p. 206). We suggest that people with MS might be more confident to try a rather gentle and recreational activity, such as Tai Chi, over engaging in other types of exercise.

Second, the waxing and waning of debilitating symptoms and the unpredictability of the MS course could promote a lack of confidence in one's own capabilities (Döring et al., 2012, p. 1). Moreover, perceived inability resulting from impaired motion control could contribute to a hesitant perspective on physical activity, especially with regard to safety issues. Compared to the general population, the risk of falling is two or three times increased in persons with MS (Tallner & Pfeifer, 2008, p. 1). At this point it is important to note, that scientific research on Tai Chi as a sport in healthcare mainly focused on the improvement of balance in the elderly (Burschka, Kuhn, Menge & Oschmann, 2013). Moreover, it was reported that the effects of Tai Chi on fall prevention seem to primarily depend on an increase in general self-efficacy rather than improved balance, gait or fear of falling (Tousignant et al., 2012). Self-efficacy in turn seems to be related to health promoting behaviour like engagement in exercise (Stroud, Minahan & Sabapathy, 2009, p. 2216; Tallner & Pfeifer, 2008, p. 2).

Third, fatigue and motivational issues could be a barrier to exercise engagement. With the intent to manage fatigue and conserve energy, people with MS might refrain from physical activity (Tallner et al., 2013, p. 1238). In fact, physical exertion was designated as the greatest barrier to exercise – irrespective of the current level of physical activity (Stroud et al., 2009, p. 2221). However, refraining from exercise comprises the risk of general de-conditioning and symptom exacerbation (see Section 1.1.3, page 4). Thus, it is crucial for people with MS to find a balance between exercise engagement and fatigue (Kayes et al., 2011, p. 1050). In line with this suggestion, self-management approaches have been reported to be highly effective in fatigue management (Asano & Finlayson, 2014, p. 6, 9). Mindful Tai Chi practice could be particularly suitable to increase body awareness and emotional awareness in persons with MS. Moreover, Tai Chi practice could provide a safe and convenient setting to practice self-management strategies.

Fourth, acute worsening of MS symptoms relative to a rise in body temperature may also play an important role in physical activity behaviour. This barrier could be related to all of the barriers above, as delineated subsequently. Despite the sharp turn from advising bed rest to encouraging physical activity, the experience or fear of symptom exacerbation could still be a strong argument against physical activity from the individual's point of view. Moreover, a lack of confidence could diminish the motivation to explore personal boundaries with regard to physical ability and fatigue. As delineated earlier, Tai Chi can easily be adapted to the current perception of exertion. The repetitive character of Tai Chi practice and its mindfulness-component could be particularly valuable in (re-) gaining the ability of estimating, meeting and expanding personal boundaries and resilience, both physical and non-physical.

# 2 Research interest

There is a promising evidence base in favour of various therapeutic benefits, of both *physical activity* in MS management and *Tai Chi* in various neurological patient groups. However, there is still a lack of conclusive data regarding a targeted practical implementation. The multi-dimensionality and variability in this field pose particular challenges to scientific analysis, generalizability and reproducibility of results. In current literature, this problem is addressed by the term *complexity*. The key feature of complexity is the involvement of multiple interacting components. The main challenge of complex phenomena lies in their inherent difficulty to be described, analysed, understood, and predicted. To enable scientific discussion on complex phenomena, a common ground in research terminology is needed. This is particularly important when analysing multi-dimensional constructs, such as fatigue, physical ability, and physical activity in people with MS. In addition, it is necessary to be aware that the use of a common terminology does not necessarily imply common ground in the researched phenomenon.

Together with a uniform understanding of the terminology, common ground in research methodology needs to be established. This includes adequate test inventory. The assessment of prevalent MS symptoms, such as impaired walking ability (see Section 1.1.3, page 6), is important to monitor disease activity and success of treatment strategies. However, ambulation is a multi-dimensional construct influenced by sensory, motor, and cognitive parameters. Thus, impaired walking ability is difficult to define and to measure. As described in Section 1.1.4 (page 9), common assessments of walking ability in MS primarily rely on result-oriented parameters, such as the total distance walked during a specific time frame. However, healthy individuals were observed to show a stereotypical U-shaped velocity profile during timed walking. This profile was characterized by a high starting speed, subsequent slowing and acceleration towards the end of the test. Hence, the assessment of dynamic walking features in people with MS warrants further investigation. Such information could contribute to an early detection of changes in walking performance, which is a key to disease management and the evaluation of therapeutic interventions.

Apart from the test inventory, the quality of research methodology relies on choice, description, and standardization of the intervention under investigation. As pointed out in Section 1.2 (page 11), physical activity could essentially contribute to MS management. However, there is a lack of knowledge about types, working mechanisms, dose, and effects of exercise programs for people with MS. As outlined in Section 1.3 (page 15), Tai Chi could be particularly worth investigating. Its gentle, mindful way coupled with its adaptability seems especially suited to meet the specific needs of persons with MS and to overcome barriers to exercise participation. It is important to note that this adaptability makes a Tai Chi interven-

tion difficult to describe and standardize. Moreover, the concept of Tai Chi itself is manifold. While scientific interest in the effects of Tai Chi has been rising tremendously, little attention was directed at how Tai Chi has scientifically been studied. Such research could guide the development of theories on working mechanisms and clear recommendations about which way of practising Tai Chi is likely to induce most beneficial effects.
In summary, there is a need for increased awareness about the complexity inherent in the research fields of MS and Tai Chi. We need common ground in research terminology and methodology to take on the challenge. Theories on underlying mechanisms could both support this goal and gain from it.

We chose to further investigate this field of interest by pursuing the following questions:

**First**

We examined 37 persons with MS and 25 healthy controls within two timed walking tests (6-minute walk, 12-minute walk). Prior to the assessment, the MS group was divided into two subgroups according to the subjects' disability levels (mild MS group and moderate MS group). In addition to mean walking speed, we observed dynamic features of walking behaviour, namely deceleration and the degree to which velocity profiles approximated a U-shape. Additionally, we applied a self-report assessment to quantify subjective fatigue. The publication is named: An exploration of impaired walking dynamics and fatigue in multiple sclerosis.

- Do the 6-minute walk and the 12-minute walk reveal temporal dynamic features of walking in MS?
- Do these features differ between people with MS and healthy controls?
  If yes, do these differences depend on disability level and test duration?
- Are abnormal walking dynamics related to the individuals' subjective constraints?

**Second**

We explored the martial art Tai Chi with regard to its tradition, scientific evaluation and its challenges to research methodology. The publication is named: Research on Tai Chi as a sport in health care: The challenge of complex interventions.

- What is Tai Chi?
- To which areas has Tai Chi been directed at?
  Which way of practising Tai Chi was assumed to hold therapeutic potential?
- What makes a complex intervention complex?
  What problems evolve from this complexity?
  How can we deal with these problems?

- What makes Tai Chi a complex intervention?
  How could a Tai Chi intervention be described?
  How could a Tai Chi intervention be analysed scientifically?

**Third**

We devised a standard Tai Chi program for persons with MS. Subsequently, we analysed its effects on physical and psychosocial parameters within a 6-month intervention, comparing a Tai Chi group (n = 15) to a group that received treatment as usual (n = 17). The publication is named: Mindfulness-based interventions in multiple sclerosis: beneficial effects of Tai Chi on balance, coordination, fatigue and depression

- Is our newly devised, standardized Tai Chi program safe and feasible for people with MS?
- Does it induce beneficial effects on prevalent MS symptoms (impaired balance and coordination, fatigue, depression) and life satisfaction?

# 3 Discussion and perspectives

Our primary aim was to promote research on physical activity for persons with multiple sclerosis (MS), specifically considering physical and psychosocial health. MS is an autoimmune disease, which is characterized by chronic inflammation, neurodegeneration, and gradual functional decrease in multiple areas. Prevalent symptoms include reduced walking ability, fatigue, cognitive impairment and depression. These symptoms tend to be multi-causal and variable. Although a cure for MS remains to be found, significant progress was achieved regarding the knowledge of pathology and treatment options.

## 3.1 What did we ask?

The continuous assessment of disease related parameters plays a crucial role throughout MS management, especially for the goal of achieving a targeted and individualized therapy. First, it aims to differentiate between normal functioning and the severity of pathological impairment. Second, it helps to clarify the necessity, choice, and success of available treatment approaches. Assessment relies on both self-report and performance-based measures, because it is important to account for both patient burden and actual impairment of function. Walking ability is commonly assessed by means of result-oriented walking tests. Recent interest in the connection between walking performance and fatigue raised the question about how dynamic features of walking ability could also be respected. This approach seemed particularly interesting because persons with MS have been reported to display abnormal temporal walking dynamics compared to healthy controls. Such improvement of the test inventory may help in responding to disease exacerbation as early as possible.
Pharmacological treatment primarily relies on early intervention to counter inflammation and alleviate arising symptoms. Further strategies to save or even restore neural tissue and impaired functions are lacking. Only recently, the therapeutic value of physical activity has been acknowledged to contribute fundamentally to MS management. However, there is a need for clear recommendations on choice and dose of exercise for persons with MS. In addition, scientific interest in the therapeutic benefits of mindfulness-based interventions has grown. The Chinese martial art Tai Chi incorporates both physical and mindfulness components. Due to its adaptability and gentle way it is predisposed for heterogeneous target groups. It could be particularly suitable to enhance physical activity in persons with MS. The therapeutic potential of Tai Chi has recently been analysed in various neurological groups and effects tend to be beneficial. However, due to the heterogeneity of the studies available, repetition and generalization of the observed effects is difficult. A key to approaching

this problem may be to raise awareness about the inherent variability of the concept that is simply referred to as *Tai Chi*.
In sum, we aimed at improving the assessment of physical function (walking ability) and at developing exercise programs (Tai Chi) for persons with MS. We delineated our research questions in the previous chapter.

## 3.2 What did we do?

*We explored dynamic characteristics of walking behaviour in MS patients.* Walking tests are commonly used to assess physical function in MS. The tests primarily rely on result oriented parameters, such as the total distance walked during a time frame. However, dynamic walking characteristics (such as deceleration or acceleration of walking speed during the test) may also be relevant for an adequate assessment of walking ability. Investigating velocity profiles seemed particularly warranted because healthy individuals were reported to display a stereotypical U-shaped pattern during timed walking (high starting speed, subsequent slowing and final acceleration). In addition, velocity profiles had been observed to differ between persons with MS and healthy controls.
In sum, we analysed three different velocity profiles in two walking tests, comparing 37 MS patients to 25 healthy, age-matched controls. The group of MS patients was further divided into subgroups according to their disability level. Disability was analysed with the Expanded Disability Status Scale (EDSS, see Section 1.1.4, page 9); Mild MS Group, n = 20, EDSS 0 – 3.5; Moderate MS Group, n = 17, EDSS 4 – 5). The walking tests included the 6-minute walk and the 12-minute walk. In these tests, subjects walked as fast as possible, back and forth a distance of 20 meters, for 6 minutes and 12 minutes respectively. The distance covered per minute was recorded. On the basis of this time series, we calculated three different velocity profiles by applying appropriate data-analytical procedures (polynomial trend analysis). In particular, we analysed the mean walking speed, the linear decline in walking speed (linear trend) and the degree to which the velocity profiles approximated a U-shape (quadratic trend). Finally, we explored the association between these performance-based measures and subjective fatigue.

*We analysed research on Tai Chi with special regard to methodology* in a problem-centred article. To our knowledge, this is the first attempt to shed light on the question of how Tai Chi has been studied scientifically. In a first step, we investigated the concept behind the rather simple name *Tai Chi*, concluding that this concept is manifold and barely tangible. In a second step, we asked, how researchers dealt with the multi-dimensionality inherent in Tai Chi. However, this multi-dimensionality was not taken into consideration. Our analysis revealed that research on Tai Chi was just as heterogeneous as the concept Tai Chi itself. Such divergent research attempts make it difficult to collect convergent evidence on the effects of Tai Chi. In a third step, we explored the ongoing discussion about complexity within healthcare interventions, including possible strategies to deal with this challenge. In a fourth step, we transferred our findings to Tai Chi research, suggesting first steps towards systematic description and implementation of Tai Chi interventions.

*We devised a Tai Chi program dedicated to persons with MS and took a thorough look on its therapeutic value.* Only recently, physical activity was recognised to fundamentally contribute to MS management and recommendations on choice and dose of exercise programs are still lacking. Tai Chi could suit the specific needs of persons with MS. Further, mindful awareness, a component of Tai Chi, could be particularly valuable for this target group.
To the best of our knowledge, the concept of mindfulness has not been considered within Tai Chi interventions. However, mindfulness is essential in Tai Chi practice. Based on this finding, we described the concept of mindfulness and explicitly highlighted the connection to the concept of Tai Chi. Briefly summarised, there are two essential components to mindfulness: first, purposeful direction and regulation of attention; second, orientation to experience. Correspondingly, learning a Tai Chi form requires constant switching of attention between exteroception (observing both the instructor and the own body) and interoception (bodily sensation involving proprioception, balance and breathing). In addition, Tai Chi principles (see Appendix on page 93) are included in the attentional focus. This requires a high amount of resources and receptivity to interoceptive information. The second component of mindfulness, namely maintaining a curious attitude, is also addressed in Tai Chi. Tai Chi practice includes the exploration of personal boundaries (limits of stability, flexibility, endurance) and encountering personal habits to cope with discovered limitations. Simultaneously, non-elaborative awareness is necessary to stay on track while playing the form. For further details, see Section 4.3 on page 59.
Our previous research indicated, that the development of a structured Tai Chi program was required to enable repeatability of interventions and to improve comparability across studies. We chose to develop our Tai Chi program on the basis of Yang's style Tai Chi, because this style features slow and gentle movements. Within this style, we chose the 10-form, which is standardized and accessible. The 10-form consists of 10 Tai Chi movements, including two single-leg stances. The movements are carried out symmetrically into two opposite directions (left and right) in an alternating way. This symmetry is space-saving and facilitates Tai Chi practice in small spaces, for example at home. The clearly arranged organisation of movements appears particularly suitable for beginners and people with motor, sensory or cognitive deficits. In our curriculum, we advocated practising the 10-form as a whole from begin on. In each session the same core elements were to be included. This allowed participants who missed a class to resume training without difficulties. A description of the program, including a video-link to the 10-form, is available in the Appendix (page 93).
In our study on the effects of this Tai Chi program, we examined a group of 32 persons with MS (EDSS < 5). The Tai Chi group (n = 15, female sex = 10) participated in a 6-month intervention, practising twice a week for 90 minutes, while the comparison group (n = 17, female sex = 12) received treatment as usual (TAU). In particular, we evaluated changes in the following domains: balance, coordination, fatigue, depression, and life satisfaction. Both

groups were assessed prior to the intervention and after the 6-month interval. To assess balance and coordination, we used an established balance and coordination test. However, this test had not previously been applied in this target group (MS). The test included a number of tasks (14 for balance and 10 for coordination) which were evaluated on a two point scale (passed or failed). The sum-score (number of tasks passed) was used for further analysis. In addition, we included self-report questionnaires to assess fatigue, depression and life satisfaction.

## 3.3 What did we learn?

We found a consistent pattern of beneficial effects of Tai Chi on the examined outcome parameters, including balance, coordination, fatigue, depression, and life-satisfaction. Our findings extend current literature on beneficial effects of mindfulness-based physical activity in persons with MS, and particularly support the suitability of Tai Chi for this target population. Further details on our findings are delineated subsequently.

*We found that even mildly disabled MS patients display abnormal walking behaviour.* In line with the available literature, our findings confirmed that MS patients walk slower than healthy controls. The fact that even mildly disabled MS patients walked significantly slower than controls hints at an early influence of MS on walking ability.

In addition to this, differences between MS patients and controls also manifested in altered temporal walking dynamics, such as continuous deceleration of walking speed during the test. Moderately disabled persons with MS displayed a stronger decrease in their walking speed than controls in both tests. Mildly disabled persons with MS also slowed down more rapidly than controls, yet this difference was only revealed by the longer test (12-minute walk). We concluded that the linear decline in walking speed may represent an additional, clinically relevant feature of impaired ambulation in persons with MS. It is important to note that different test durations are necessary to detect this feature. While for persons with moderate disability, the 6-minute walk suffices, the longer version (12-minute walk) is necessary for persons with mild disability.

We also identified a high correlation between the linear decline of walking speed and subjective fatigue. Thus, the linear decline in walking speed adequately reflects the patients' subjective constraints. Further, the linear decline in walking speed showed a more robust association to subjective somatic fatigue over mean walking speed. Hence, deceleration appears to be a more suitable parameter to assess somatic fatigue in place of mean walking speed. This finding particularly supports previous suggestions to interpret the decline in walking speed as an indicator of fatigue in MS patients.

Recently, the abbreviation of walking tests for economic reasons was advocated. Our findings hint that such an approach results in the loss of potentially relevant information on dynamic walking characteristics. We strongly recommend to choose walking tests and derived parameters with care and with respect to a specific diagnostic goal or research question.

We need a pragmatic balance between economic implementation of walking tests and early detection of impaired walking ability in persons with MS.

*We identified multi-dimensionality as a main problem within Tai Chi research.* In our analysis of both the martial art Tai Chi and scientific research on Tai Chi, we identified two aspects that are highly variable: first, the concept of Tai Chi itself; second, the multiple directions Tai Chi research branched out into – including a variety of different target groups, study designs, and outcome domains.

Tai Chi has a deep philosophical background and originated as a martial art in ancient China. Literally, "Tai Chi" means "the supreme ultimate." In Daoism, a chinese philosophy, the term Tai Chi embraces the concept of yin and yang, which is seen as the highest principle of order within the cosmos. The interplay of yin and yang is depicted in the Tai Chi symbol (☯). The martial art Tai Chi resembles this philosophic principle in its fighting technique: Encountered force (yang) is not countered with higher force (yang), but with drawback (yin) – and the simultaneous aim of unbalancing the offender. Basically, Tai Chi practice aims at performing predefined movements with respect to specific principles. Such choreography is called a *form*. In sum, the respected principles combine four basic concepts: the dynamic interplay of yin and yang, directing energy (qi), developing jin force, and motion. A wide range of Tai Chi forms can be differentiated by the number of figures included (for example 10-form, 24-form, 108-form), by traditional lineage (the main traditional styles are: Chen, Yang, Wu, Wu, and Sun), and by further criteria. For detailed information on *Tai Chi*, see section 4.2 (page 43). From its origin as a secret martial art, Tai Chi evolved to a highly pluralistic and accessible type of exercise. In addition, Tai Chi is practised with a variety of different motives, such as martial art, self-defence, meditation, aesthetics, socializing and health.

Our exemplary analysis of seven original research articles revealed a very heterogeneous implementation of Tai Chi within scientific interventions. This multi-dimensionality poses distinct challenges to the interpretation, comparison, and reproduction of obtained data. Moreover, poor reporting of the interventions' curriculum increases the risk of bias. To deal with the variability, it might be necessary to adopt a broader perspective and adjust the scientific approach. Helpful in this undertaking could be the lessons learned from complexity science. In summary, complex problems are difficult to describe, analyse, understand and predict. The key feature of a complex intervention is the entanglement of multiple interacting elements, which applies to Tai Chi practice.

To gain solid information on the therapeutic value of Tai Chi, we need a more systematic approach. A first step to this direction is awareness of the problem and an effort to gain common ground in terminology and methodology. A second step is enhancing the quality and completeness of reporting. For alignment, the description of Tai Chi interventions should use our proposed framework as orientation (Section 4.2, page 49). It guides a thorough description with respect to the following domains: motive within Tai Chi practice, estimating the dose of Tai Chi training, outlining the curriculum and introducing instructors. Further, in-depth information should reflect the characteristics of complex systems as outlined in Section 4.2 (page 51). Briefly summarized, these characteristics include differentiation between constant and variable components, interaction between components, and a component's place in a causal chain. For example, *constant components* could be defined by the curriculum: setting, choice of Tai Chi form, choice of instructor, choice of training time and intervals, and number of participants. *Variable components* could include social interactions and the differentiation between effective practice time and mere physical presence. The latter differentiation is likely to be linked to the presence of mindfulness within Tai Chi practice. A third step is the adjustment of our research methodology by including qualitative research along with quantitative research in an exploratory way. It is necessary to develop theories on underlying mechanisms and cause-effect relationships prior to extensive quantitative evaluation. Together, these steps could provide information about which Tai Chi components essentially contribute to the effectiveness and efficacy of Tai Chi for healthcare intervention.

*We devised a new, standard Tai Chi curriculum* to support a systematic course of action in researching the therapeutic value of Tai Chi for persons with MS. Based on our evaluation, we concluded that the devised Tai Chi course is safe and feasible for a 6-month intervention program in MS. We identified beneficial effects in both objective and subjective measures. During the Tai Chi intervention, the following parameters improved: coordination, balance, depression and life satisfaction. In contrast, these variables were not altered in the comparison group. Moreover, we found a maintenance effect on fatigue. While fatigue remained stable in the Tai Chi group, it deteriorated in the comparison group. Our findings clearly support improved performance levels in balance and coordination following Tai Chi practice. In addition, Tai Chi seems to positively influence mood and fatigue. Apart from this, test-retest reliability of all applied measures was sufficient. This finding indicates a systematic change within the rank ordering of the subjects' scores on the assessment tools. Thus, the employed measures provided reliable information although they are not widely used in MS literature. In sum, our findings support the utility of a structured Tai Chi training in the context of MS management. We recommended using the concept in future studies.

Collectively these findings offer a glimpse to the significant gains of a more complex perspective within current research approaches. Research on multi-dimensional constructs requires a multidisciplinary approach. We started to draw connections between different, yet highly topical research fields. Future research should further elaborate on these connections and continue our search for valuable interventions to enhance life quality for persons with MS. To enable a systematic approach to our research interest, it is crucial to find a common perspective, to find a common language and to keep returning to the research question asked.

## 3.4 Which questions remain?

Aiming to further elucidate the possibilities of MS management, the investigation of the following domains is desirable.

*The test inventory to assess and monitor functional impairment in MS should be enhanced.* Our exploration of walking dynamics appears worth continuing with regard to different disability levels and test durations. Further research should work towards the acquisition of normative data on new, clinically relevant features of walking ability.

*The therapeutic potential of Tai Chi for persons with MS should be investigated.* Different MS subgroups and comparison groups should be considered. Additionally evaluating the effects of Tai Chi should reflect different outcome domains. However, to increase comparability across studies, agreement on a common catalogue of assessment details would be helpful. The effect of Tai Chi on neural plasticity with regard to motor, sensory, and cognitive ability seems particularly interesting. Additionally, the effect of Tai Chi on autonomic regulatory processes seems worth investigating. We suggest that such research should particularly look into the contribution of mindfulness and breathing, because they both are an integral part of Tai Chi practice and have been shown to affect autonomic regulation. Apart from this, non-specific effects such as self-compassion, self-efficacy, and social support should be taken into consideration.

*A theoretical framework on the underlying mechanisms of Tai Chi needs to be established.* Thorough reporting of the conducted research is essential to reach this goal. The identification of key components that determine the intervention's success could help to define specific recommendations and strengthen beneficial effects. Future research should specifically investigate the contribution of mindfulness to the effects of Tai Chi interventions, for example with regard to body awareness, emotional awareness and rumination. Moreover, exploring the contribution of the Tai Chi instructor to the intervention's success seems particularly interesting. Such research could be achieved by a systematic implementation of different interventions (both Tai Chi and other) by the same instructor. In addition a single intervention could be explored with regard to different instructors. Simultaneously, different approaches of teaching Tai Chi could be explored. For example, practising a whole form from begin on could help participants to witness personal progress and to experience self-efficacy. In contrast, practising single movements in detail could foster a different application of Tai Chi principles and strengthen different resources.

To enable repeatability of Tai Chi interventions, future research should be based on simple Tai Chi curricula that can be described and standardised. Simple curricula could further increase comparability between studies and help estimate the dose of Tai Chi training. It is important to note, that such simplification should not impede the adaptability of the intervention to the needs of the patients. It should rather serve as a means of orientation to improve operationalizability of the research. Standardised Tai Chi interventions could also contribute to a more systematic approach of analysing distinct components of Tai Chi practice.

Moreover, the inclusion of a qualitative study arm could shed light on the participants' perspective. It could support data interpretation and help to form theories, for example, revealing factors that influence long-term adherence to Tai Chi practice. For example, the philosophical background of Tai Chi could attribute meaning to Tai Chi training and foster personal commitment to regular practice. Personal meaning within Tai Chi practice could further evolve from the transfer of Tai Chi principles to daily life. Apart from this, group dynamics seem to play an important role. The participants of our Tai Chi study initiated the establishment of two Tai Chi groups in order to continue their joint practice. Even now – two years after the intervention – both groups are still meeting on a regular basis. We expect that the interviews that we conducted with the participants will reveal further information. These interviews are yet to be evaluated, however promising preliminary findings are available (Burschka, Hofstadt-van Oy & Kuhn, 2012; Gerlach & Kuhn, 2011; Hawelka & Kuhn, 2012).

*Finally, scientists should keep in mind the following question:* How could our research beneficially shift the balance from functional impairment to functional recovery in persons with multiple sclerosis? A high priority is the enhancement of life quality and long-term adherence to physical activity. With regard to the complexity and multi-dimensionality in this research field, it is important to continue exploring the mechanisms of exercise induced effects, to take on the challenges of research methodology, and to work towards the establishment of exercise as an integral part of MS management.

# 4 Publications

## Author's contributions

Burschka, J. M., Keune, P. M., Menge, U., Hofstadt-van Oy, U., Oschmann, P. & Hoos, O. (2012). **An exploration of impaired walking dynamics and fatigue in Multiple Sclerosis.** BMC Neurology, 12(161), 1–8. doi:10.1186/1471-2377-12-161

| Participated in | Author initials, responsibility decreasing from left to right | | | |
|---|---|---|---|---|
| Study conception and design | JB | PO | OH | UM |
| Acquisition of data | JB | UH | | |
| Analysis and interpretation of data | PKe | JB | UM | OH |
| Drafting of manuscript | JB | PKe | | |
| Critical revision | OH | UM | | |
| Reviewers | Goldman, M. & Motl, R. | | | |

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http://www.biomedcentral.com/1471-2377/12/161/prepub

Burschka, J., Kuhn, P., Menge, U. & Oschmann, P. (2013). **Research on Tai Chi as a sport in health care: the challenge of complex interventions.** Sportwissenschaft, 43(3), 181–196. doi:10.1007/s12662-013-0300-1

| Participated in | Author initials, responsibility decreasing from left to right | | | |
|---|---|---|---|---|
| Study conception and design | JB | PKu | UM | PO |
| Acquisition of data | JB | | | |
| Analysis and interpretation of data | JB | PKu | | |
| Drafting of manuscript | JB | | | |
| Critical revision | PKu | | | |
| Reviewers | three anonymous reviewers | | | |

Burschka, J. M., Keune, P. M., Hofstadt-van Oy, U., Oschmann, P. & Kuhn, P. (2014). **Mindfulness-based interventions in multiple sclerosis: beneficial effects of Tai Chi on balance, coordination, fatigue and depression.** BMC Neurology, 14, 1–9. doi:10.1186/s12883-014-0165-4

| Participated in | Author initials, responsibility decreasing from left to right | | | |
|---|---|---|---|---|
| Study conception and design | JB | PO | PKu | UM |
| Acquisition of data | JB | UH | | |
| Analysis and interpretation of data | PKe | JB | UM | |
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RESEARCH ARTICLE Open Access

# An exploration of impaired walking dynamics and fatigue in Multiple Sclerosis

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## Abstract

**Background:** Physical disability in multiple sclerosis (MS) is frequently characterized by impaired ambulation. Although walking tests have been successfully employed to assess walking ability in MS patients, data analytic procedures have predominantly relied on result-oriented parameters (e.g. total distance covered during a given amount of time), whereas process-oriented, dynamic walking patterns have mostly been ignored. This is striking, since healthy individuals have been observed to display a stereotypical U-shaped pattern of walking speed during timed walking, characterized by relatively high speed during the initial phase, subsequent slowing and final acceleration. Objective of the current study was to test the utility of the 6 min Walk (6MW) and the 12 min Walk (12MW) for revealing putatively abnormal temporal dynamic features of walking in MS.

**Methods:** A group of 37 MS patients was divided into subgroups with regard to their level of disability analyzed with the Expanded Disability Status Scale (EDSS; Mild MS Group, n = 20, EDSS 0 – 3.5; Moderate MS Group, n = 17, EDSS 4 – 5). Subsequently, both groups were compared to age-matched healthy controls (n = 25) on both tests with regard to result-oriented characteristics (mean walking speed), as well as dynamic features (mean decline in walking speed, degree of observed U-shape).

**Results:** Both MS groups showed a significantly lower mean walking speed than healthy controls, independent of test duration. Compared to controls, the Moderate MS Group also slowed down more rapidly throughout both tests. The same pronounced decline in walking speed was observed for the Mild MS Group in case of the 12MW. Additionally, for both MS groups an attenuated U-shaped velocity pattern was observed relative to controls in the 6MW. Patients' subjective fatigue scores were more strongly correlated with the decline in walking speed than with the common parameter of mean walking speed in the 6MW.

**Conclusions:** MS patients display abnormal dynamics in their walking patterns. A pronounced linear decline in walking speed can be identified with the 12MW even in MS patients with seemingly mild disability. Similarly, the 6MW can be used to assess an abnormal walking profile. Particularly the linear decline in walking speed on this test shows a more robust association with subjective fatigue than mean walking speed. Dynamic walking parameters may hence represent valuable clinical features, serving as surrogate measures of motor fatigue. Future studies are needed to verify their prognostic value.

**Keywords:** Multiple sclerosis, Ambulation, Walking, 6 minute walk, 6MW, 12 minute walk, 12MW, Linear trend, U-shape

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## Background

A wide range of tests is available to measure walking performance in patients suffering from Multiple Sclerosis (MS; see Kieseier et al. [1] and Bethoux et al. [2] for recent reviews). Among the most widely used tests are the timed 25 Foot Walk, which measures the time a patient requires to cover a distance of 25 feet at maximum speed, and the 6 min Walk (6MW), which measures the total distance a patient is able to cover walking as fast as possible for six minutes. Particularly the 6MW is commonly administered and has been shown to display external validity, as performance on this test is associated with balance confidence and stair-climbing ability [3].

The application of the 6MW has consistently revealed that MS patients may display considerable walking deficits. Further, abnormal physiologic responses during walking performance were reported. Savci et al. [4] for example observed a significantly lower mean walking speed during the 6MW in MS patients (n = 30, score on the expanded disability status scale [5] EDSS = 1.5 – 6.0) compared to controls (n = 30). The same pattern was observed by Chetta et al. [6], who additionally reported reduced cardiorespiratory fitness, i.e. decreased oxygen pulse and inefficient ventilation, as reflected in an impaired breathing pattern in MS patients (n = 11, EDSS = 1 – 3.5) compared to controls (n = 10). These differences were observed despite normal cardiopulmonary function at rest.

According to Motl et al. [7], even mildly disabled MS patients may differ significantly from healthy controls in their mean walking speed on the 6MW. Besides differences in speed, a differential pattern of oxygen consumption between the first and the second half of the test was observed [8]. The authors concluded that different metabolic systems may be relevant for performance during the first and the second half of the 6MW.

Findings reported by Motl et al. [8] are particularly interesting since parameters which are commonly derived from walking tests (e.g. mean walking speed or total distance covered) are not suitable to examine walking characteristics which may vary during the test. In very few studies, an attempt was made to examine dynamic walking features, such as the progression of walking speed throughout the test duration. In an early study, Schwid et al. [9] reported a significantly lower median walking speed in MS patients measured over a distance of 500 meters. MS patients however did not only walk slower, but also showed a considerable decrease in walking speed towards the end of the test, whereas controls accelerated. Goldman et al. [10] examined velocity profiles of MS patients during the 6MW. Results revealed that MS patients differed from healthy controls in both, the mean walking speed as well as the course of walking speed across the six-minute time span. In case of the control group, a U-shaped velocity profile was observed, with relatively high walking speed at the beginning of the walk, subsequent slowing and acceleration towards the end of the test. In contrast, in MS patients the acceleration toward the end of the test was attenuated [10]. The U-shaped pacing profile has previously been described as a common phenomenon in healthy participants, warranted that the duration of the performed activity is sufficiently long [11]. Hence, the examination of dynamic characteristics, such as the change in walking speed at different stages of the test may provide further, clinically relevant information.

Findings on dynamic walking patterns are also of relevance for the ongoing discourse, whether walking tests could be shortened to provide economically optimized assessment tools for ambulation in MS. Gijbels et al. [12,13] have suggested that an abbreviated version of 2 min duration may suffice to provide an estimate of walking ability. In their study, the authors reported a decline in walking speed during the first three minutes and constant pacing during the consecutive three minutes of the 6MW in a sample of 40 MS patients (EDSS 1.5 – 6.5) [12]. Moreover a separately conducted 2MW showed the same decline in mean walking speed per minute. Nevertheless, findings by Schwid et al. [9], Goldman et al. [10] as well as Motl et al. [8] are not necessarily consistent with this suggestion and imply that shortening of the 6MW might result in the loss of potentially important information of clinical relevance.

In this context, a further exploration of dynamic walking features in MS seems warranted. Even though the observation of a specifically impaired walking profile may be promising for future clinical applications, so far only Goldman et al. [10] have provided information on walking dynamics. The purpose of the current study was to address this issue and to examine the walking dynamics of MS patients more rigorously. In particular, the intention was to replicate results by Goldman et al. [10] and to apply further data analyses for a comparison of walking profiles of MS patients and healthy participants. Based on the suggestion that the duration of walking needs to be sufficiently long to yield a U-shaped pacing profile, in the current study, we examined whether the 6MW, as well as a 12 min Walk (12MW) would reveal distinct dynamics in walking behaviour of MS patients relative to healthy controls. We further collected self-report data with regard to somatic fatigue, in order to verify whether putatively abnormal walking dynamics were related to patient's subjective constraints.

## Methods

A group of 37 MS patients was recruited from the Department of Neurology, Klinikum Bayreuth GmbH, Germany. The comparison group consisted of 25 age-matched healthy participants. Details regarding demographics and clinical characteristics of the sample are displayed in Table 1. All participants provided written informed consent prior to study entry and the study was approved by the ethics committee of the Bavarian Medical Association, Germany. Information about clinical characteristics was extracted from patients' files held by the Department of Neurology. Walking tests (6MW, 12MW) were administered by a single, highly trained clinical examiner during one or two patient visits. Patients completed the two walking tests in randomized order, with at least 3 hours between the assessments. The administration of the 6MW followed standard protocol [14], with modifications suggested by Goldman et al. [10]. For six minutes, participants walked back and forth a distance of 20m, which was divided into 1m segments marked on a wall. Distance covered during each minute was assessed visually, based on the marked segments, by an examiner equipped with a stop-watch. The examiner was seated ten meters away from the midpoint of the walking distance and recorded the distance covered during each minute. This setting was chosen over other methods, such as accompanying the patient with a precise wheel, in order to minimize a putatively confounding influence of the setting on the participants' walking behaviour. The 12MW followed the same procedure, with the only difference that the walking duration was twice as long. Additionally, the Wuerzburger Fatigue Inventory for Multiple Sclerosis (WEIMuS) was implemented prior to the first test as a measure of subjective somatic fatigue [15].

In order to gain information about walking dynamics with regard to MS-related disability, in a first step, patients were sorted into subgroups displaying moderate and mild disability. Group membership was determined based on the EDSS (Moderate MS Group, EDSS > 3.5, n = 18; Mild MS Group, EDSS < 4, n = 19). Scores below 4 refer to patients who are fully ambulatory, while scores between 4 and 5.5 refer with walking impairment who are able to walk at least 100m without assistive devices [5].

Statistical analyses were performed with SPSS 20.0. Differences in mean walking speed (meters/minute) between MS patients and controls were assessed by a two-way repeated measures ANOVA with the within-subjects factor Test (6MW, 12MW) and the between-subjects factor Group (Mild MS, Moderate MS, Controls). Given a

**Table 1 Demographics, clinical information and health behavior**

| | MS Patients (n = 37) | | Controls (n = 25) | | statistic | p-value |
|---|---|---|---|---|---|---|
| **Demographics** | | | | | | |
| Age M(SD) | 39.7 | (12.8) | 38.4 | (11.9) | 0.40[a] | 0.69 |
| Female sex, n (%) | 28 | (75.6) | 18 | (72.0) | 0.11[b] | 0.75 |
| **Health Behavior** | | | | | | |
| Tobacco users, n (%) | 14 | (37.8) | 6 | (24.0) | 1.31[b] | 0.25 |
| Body Mass Index, M(SD) | 22.7 | (5.7) | 23.8 | (3.8) | - 0.89[a] | 0.41 |
| Physical activity/week, n (%) | | | | | | |
| < 1x | 10 | (27.0) | 7 | (28.0) | | |
| 1-2x | 20 | (54.1) | 12 | (48.0) | 0.30[b] | 0.86 |
| > 3x | 7 | (18.9) | 6 | (24.0) | | |
| **Clinical Information** | | | | | | |
| MS course, n (%) | | | | | | |
| Relapsing-remitting | 26 | (70.3) | | | | |
| Secondary progressive | 8 | (21.6) | | | | |
| Clinically isolated syndrome | 3 | (8.1) | | | | |
| MS Duration in years, M(SD) | | | | | | |
| Relapsing-remitting | 6.4 | (7.8) | | | | |
| Secondary progressive | 6.4 | (5.6) | | | | |
| EDSS median (range) | | | | | | |
| Mild MS | 2 | 0 – 3.5 | | | | |
| Moderate MS | 4 | 4 – 5 | | | | |
| MS treatment, n (%) | | | | | | |
| Yes | 25 | (80.6) | | | | |
| No | 12 | (19.4) | | | | |

a t-test.
b chi square test.

sample size of 60 participants, the use of this model yields a detectable effects size of f = 0.2, when relying on levels of α = 0.05 and β = 0.8. The omnibus test was followed up by two-sided t-tests with Bonferroni-corrected p-values to avoid Type I error inflation.

More importantly, linear and quadratic trends in the walking profiles were examined. In the data obtained in the current study, a quadratic trend reflected the degree to which the walking profile of each group approximated a U-shaped pattern. The linear trend served as an estimate of deceleration. The analyses explored, whether the distance covered during each test minute varied throughout the respective test, and whether putative linear and quadratic trends differed between groups. To this end, a repeated measures ANOVA with the within-subjects factor Minute (6MW: 1-6; 12MW: 1-12) and the between-subjects factor Group (Mild MS, Moderate MS, Controls) was conducted separately for each test.a In an additional analysis, Pearson correlations were used to test for an association between subjective somatic fatigue (WEIMuS-Score) and walking parameters.

## Results

### Mean walking speed

Healthy participants walked significantly faster than both groups of MS patients (see Table 2 for the total distance walked). In particular, the examined groups differed in their average walking speed, as revealed by a highly significant main effect of Group [$F(2,59) = 61.65$, $p < 0.001$]. The ANOVA further showed that overall walking speed was affected by walking duration, as indicated by a significant main effect of Test [$F(1,59) = 55.18$, $p < 0.001$]. The Group by Test interaction also reached significance [$F(2,59) = 3.34$, $p < 0.05$].

Post-hoc comparisons indicated that the main effect of Group was due to significant differences in walking speed between controls and the Moderate MS Group as well as significant differences between controls and the Mild MS group in both tests. The pattern of group differences was consistent across tests, albeit more pronounced in the 6MW (Table 3).

### Linear trend component: decline in walking speed

In the 6MW, patients continuously slowed down throughout the test, and this decline in speed was significantly pronounced relative to healthy controls (Figure 1). In particular, the duration of walking affected the walking speed, as revealed by a significant main effect of Minute [$F(5,295) = 57.76$, $p < 0.001$], with a highly significant linear trend [$F(1,59) = 64.26$, $p < 0.001$]. The linear trend, however, was differentially expressed across groups, as revealed by a highly significant Minute by Group interaction [$F(2,59) = 7.00$, $p < 0.01$]. Post hoc comparisons indicated a significantly pronounced decline of walking speed in the Moderate MS Group, relative to controls whereas the difference between controls and the Mild MS Group was not significant (Table 3).

The same pattern of a stronger decline in walking speed in patients, relative to controls, was observed in case of the 12MW (Figure 1). In this case, analyses revealed a significant main effect of Minute [$F(11,649) = 35.13$, $p < 0.001$], with a significant linear trend [$F(1,59) = 46.08$, $p < 0.001$], which was differentially expressed across groups [$F(2,59) = 21.54$, $p < 0.001$]. For both groups of patients, the decline in speed was significantly pronounced, relative to healthy controls (Table 3).

### Quadratic trend component: degree of observed U-shape

Overall, participants' performance approximated a U-shaped velocity profile in the 6MW. However, the U-shape was significantly attenuated in MS patients, relative to healthy controls. In particular, there was a highly significant quadratic trend [$F(1,59) = 129.73$, $p < 0.001$] which was differentially expressed across groups, as indicated by a highly significant Minute by Group interaction [$F(2,59) = 10.82$, $p < 0.001$]. As displayed in Table 3, further testing showed that the quadratic trend was significantly attenuated in both, Mild MS and Moderate MS groups, relative to healthy participants.

The general pacing profile also approximated a U-shaped pattern in the 12MW. In this case the observed U-shape did not vary across groups, and the overall significant quadratic trend [$F(1,59) = 89.82$, $p < 0.001$] was not characterized by a significant Minute by Group interaction [$F(2,59) = 1.90$, $p > 0.05$].

### Obtained walking dynamics and subjective somatic fatigue

Within the MS group, the self-report parameter of somatic fatigue [15] showed significant correlations with mean walking speed [6MW: $r = -0.38$; 12MW: $r = -0.36$, $p < 0.05$, respectively] and highly significant correlations with the linear decline in walking speed [6MW: $r = -0.63$; 12MW: $r = -0.56$, $p < 0.001$, respectively] in both tests.

**Table 2 Total distance covered during the 6MW and the 12MW**

| | Controls (n = 25) | | Mild MS (n = 19) | | Severe MS (n = 18) | |
|---|---|---|---|---|---|---|
| Total distance covered in meters | M | SD | M | SD | M | SD |
| 6MW | 681 | 88 | 586 | 73 | 422 | 69 |
| 12MW | 1305 | 157 | 1151 | 148 | 792 | 134 |

**Table 3 Mean walking speed, derived linear and quadratic trend components of walking dynamics**

| | Controls (n = 25) | | Mild MS (n = 19) | | Statistic | | Severe MS (n = 18) | | Statistic | |
|---|---|---|---|---|---|---|---|---|---|---|
| | M | SD | M | SD | T | p | M | SD | T | p |
| **6MW** | | | | | | | | | | |
| Mean speed m/min | 113.44 | 14.59 | 97.71 | 12.20 | 3.80 | 0.000*** | 70.41 | 11.49 | 10.40 | 0.000*** |
| Linear trend | -0.42 | 0.55 | -0.37 | 0.35 | -0.33 | 0.745 | -1.00 | 0.78 | 2.87 | 0.006** |
| Quadratic trend | 0.52 | 0.22 | 0.32 | 0.23 | 2.90 | 0.006** | 0.19 | 0.26 | 4.50 | 0.000*** |
| **12MW** | | | | | | | | | | |
| Mean speed m/min | 108.75 | 13.10 | 12.37 | 12.37 | 3.31 | 0.002** | 66.01 | 11.16 | 11.21 | 0.000*** |
| Linear trend | -0.00 | 0.25 | -0.22 | 0.33 | 2.52 | 0.016* | -0.73 | 0.51 | 5.63 | 0.000*** |
| Quadratic trend | 0.05 | 0.04 | 0.05 | 0.03 | 0.02 | 0.983 | 0.03 | 0.03 | 1.68 | 0.100 |

Comparisons performed between groups of Mild MS patients and healthy controls, as well as Severe MS Patients and healthy controls.
*p-value < 0.05 ** p-value < 0.01 *** p-value < 0.001.

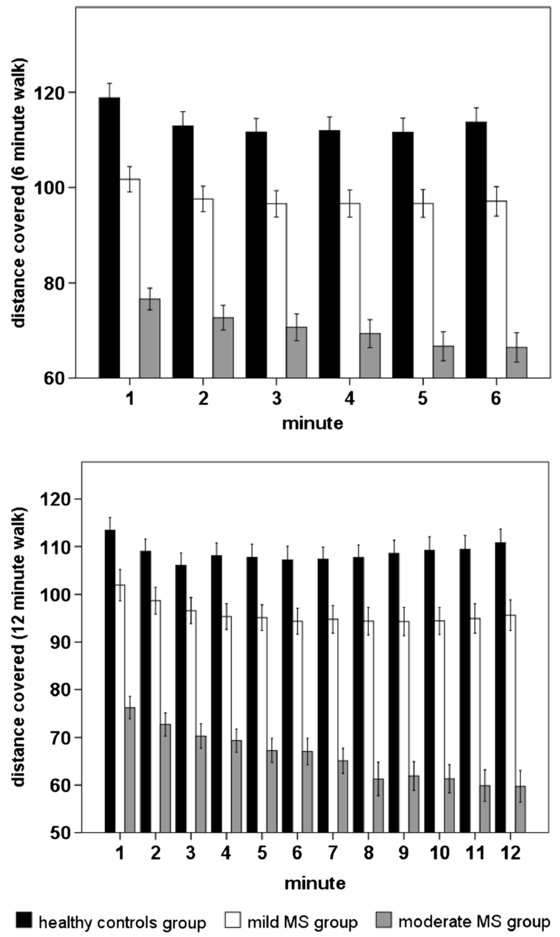


**Figure 1 Velocity profiles of members of the Mild MS, Moderate MS and healthy control group on the 6 min Walking Test (6MW, top) and the 12 min Walking Test (12MW, bottom).** Distance covered is displayed in meters.

In order to verify, whether the association between the linear decline and somatic fatigue was significantly stronger than the association between mean walking speed and somatic fatigue, Steiger's Z-test was used. This revealed that self-reported somatic fatigue was more strongly associated with the decline in speed than with mean walking speed in the 6MW [6MW: $Z = 1.98$, $p < 0.05$]. In the 12MW, the difference between the strength of correlations of self-reported somatic fatigue and walking behavior (mean walking speed, linear decline in walking speed) did not reach statistical significance [12MW: $Z = 1.50$, $p > 0.05$; two-tailed]. For the control group no significant correlations were obtained (all p-values > 0.05). An exploratory analysis further revealed that there were no significant correlations between the self-report parameters and observed quadratic trends (all p-values > 0.05).

## Discussion

Walking tests are frequently used to examine ambulation in MS patients [1,2]. However, analytic procedures applied to data derived from walking tests, with few exceptions [8-10], remained relatively superficial, leaving temporal walking dynamics almost unexplored. We examined three characteristics of walking behavior in two walking tests, comparing MS patients of mild and moderate disability to healthy controls. Besides the common parameter of mean walking speed, velocity profiles included the linear and the quadratic trend of walking speed during a 6 min Walk (6MW) and a 12 Minute Walk (12MW). The linear trend reflected a measure of deceleration over time, while the quadratic trend estimated the degree to which the walking profile of each group approximated a U-shape. With this analysis, we intended to confirm and extend observations made by Goldman et al. [10] who reported distinct patterns in the walking behavior of MS patients and healthy controls during the 6MW.

#### Mean walking speed

Firstly, our results are consistent with findings of Goldman et al. [10], confirming that MS patients walked slower than controls in both tests. In our sample, both, mildly and moderately disabled MS patients displayed attenuated walking speed, relative to controls. As MS commonly affects ambulation, this observation is in line with the extant literature [4,6,9]. The fact that even MS patients with mild disability (Mild MS group) differed significantly from controls in their mean walking speed is noteworthy. This finding hints at an early influence of MS on walking ability in the examined sample and supports previous reports [7,10,16-18].

#### Linear trend in walking speed: mean decline

More importantly, results of the current study indicate that differences in walking behavior between MS patients and controls do not only manifest in mean walking speed, but also in altered dynamic walking parameters.

MS patients with moderate disability slowed down more rapidly than controls on both tests. Complementary, MS patients with mild disability displayed a pronounced deceleration in case of the 12MW. These novel findings indicate that continuous deceleration, as reflected by the linear trend in walking speed, represents an additional, clinically relevant feature of impaired ambulation in MS patients. While for patients with moderate disability, the 6MW represents a test which is sufficient to detect this clinical feature, for patients with mild disability, a considerably longer walking duration, as in the 12MW, seems necessary.

The linear decline in walking speed was significantly pronounced in patients, relative to healthy controls, which indicates that deceleration represents a clinically relevant feature. However, the current study provides further original information on the utility of this parameter. In particular, the linear decline in walking speed was highly correlated with subjective somatic fatigue. This provides convergent evidence, indicating that the pronounced deceleration also represents a good estimate of patients' subjective constraints. It is especially noteworthy that linear deceleration showed *highly* significant correlations with subjective somatic fatigue (all p-values $< 0.001$), whereas the commonly used parameter of mean walking speed showed only *minor* associations with somatic fatigue (all p-values $< 0.05$). Since these correlations differed significantly from each other in the 6MW[b], linear deceleration may in fact represent a more suitable parameter to assess somatic fatigue than mean walking speed. This appears plausible, since the dynamic notion of deceleration seems more congruent with the phenomenon of motor fatigue, than the mean walking speed. In sum, our results indicate that deceleration reflects a potentially useful parameter, which is suitable for the assessment of somatic fatigue. As such, our findings provide strong support for the notion of Goldman et al. [10], who suggested to interpret the decline in walking speed as an indicator of fatigue in MS patients.

#### Quadratic trend in walking speed: degree of observed u-shape

We also found a U-shaped velocity profile (quadratic trend) across both tests in all groups combined. A U-shaped pacing strategy is a known phenomenon in healthy individuals [11]. As hypothesized, the degree of the U-shape was attenuated in MS patients, relative to controls in the 6MW. Even MS patients with mild disability showed an attenuated U-shape relative to controls on this test. This indicates, that the U-shaped profile can also be regarded as a clinically relevant parameter in MS. However, compared to the parameter of linear deceleration, it does not appear to be as informative, since no association with subjective fatigue was obtained and differences in the U-shaped pattern between the studied groups were not found in the 12MW. Nevertheless, since studies in which this dynamic characteristic is utilized are sparse, the current work provides original results on a new, promising clinical feature, worthy to be explored in more detail in the future.

#### Which walking test to use?

Recently, it has been suggested that a brief test including only two minutes of walking (2MW) represents a sufficient measure of walking ability in MS patients [12]. This suggestion was based on a high correlation between the distances covered during the 2MW and the 6MW [12]. Given this correlation, such a suggestion appears feasible when considering the total distance walked. Nevertheless, results of the current study suggest that the choice of which test to use depends on the walking parameter which is supposed to be assessed. For practical reasons, the parameter of mean walking speed, or total distance covered during a given amount of time, has received most attention in research on ambulation in MS. The current study provides novel findings, according to which further parameters can be derived from standard walking tests, which are of high clinical relevance. Particularly the linear trend, as a measure of deceleration, appears to be promising as an estimate of impaired walking ability, since it can be easily derived from a standard walking test. However, since it is not necessarily warranted to derive this measure from a test of only two minutes duration, the current findings do not provide direct support for the suggestion to drastically shorten common tests. In line with this conclusion, Motl et al. [8] have reported that a further putatively relevant parameter, i.e. oxygen consumption, does not reach a steady state within the first two minutes of walking, but remains unaltered only after the third minute. The latter authors suggest that the 2MW functions as a measure of primarily anaerobic and the 6MW as a measure of primarily aerobic performance. Based on our results obtained in case of the 6MW, particularly this test appears to be a feasible measure to capture both, well established parameters, such as the total distance walked, as well as parameters which vary during the walking test. Our findings indicate that an abbreviation of the test duration might result in the loss of potentially important information on dynamic walking behavior, which to date has remained relatively unexplored. Dynamic parameters could serve as a means to increase sensitivity of walking tests to abnormal walking behavior within MS patients.

### Limitations and future directions

In an innovative study Phan-Ba et al. [18] have recently utilized the combination of a timed 500 meter walk (T500MW) and a timed 25 foot walk (T25FW) to assess deceleration in MS. The authors quantified deceleration by computing a *combined* deceleration index, consisting of the ratio of walking speed during the last 100 meters of the T500MW and throughout the T25FW. The authors suggest that such a ratio may be particularly useful to assess ambulation impairment during late stages of MS. Hence, future studies which distinguish between MS subtypes and which explore methodological means to derive further parameters of dynamic walking characteristics may be warranted.

While the current results are in accord with this assumption, they are to be interpreted in the context of few limitations. In particular, it should be noted that the quantification of walking behavior was achieved through visual inspection by an examiner equipped with a stopwatch. This setting was chosen over the one in which a patient is accompanied by an examiner equipped with a precise measurement wheel, to reduce a putatively confounding influence of the setting on walking performance. It is also the approach commonly used in the clinic where the work was carried out. On the other hand, it can be argued that visual inspection may also have an effect on walking performance, and the use of a measurement wheel would have provided a technically more precise measure of walking speed. Hence, the examiner could either have accompanied the patient with the measurement wheel, or the patient could have been equipped with the measurement wheel. Either option may represent a useful alternative to the method implemented in the current study. This fact may be regarded as a caveat to the interpretation of the current results.

Finally, it needs to be noted that the walking parameters explored in the current study imply an alteration of the common nomenclature used in the literature. Performance on walking tests is usually referred to in terms of the total distance covered during a given amount of time. For the use of walking behaviour which changes throughout the test (e.g. deceleration) as a test parameter, a nomenclature involving walking speed appeared more feasible. Nevertheless, when it comes to the interpretation of the current results, it needs to be considered that this nomenclature does not match the one of the extant literature on common walking parameters.

## Conclusions

Our findings highlight the necessity of thoroughly considering the diagnostic goal of a walking test. It is known that the parameter of mean walking speed can be reliably derived from relatively short tests, e.g. the 2MW [12]. However, this parameter might oversimplify the concept of walking impairment, and only tests of longer duration, such as the 6MW, can be used to derive dynamic parameters, which are potentially more informative. As an augmentation to the current standard of measures of walking ability, we contribute a method of quantifying dynamic walking patterns, such as the linear decline in walking speed (linear trend). The linear trend could serve as a surrogate parameter of motor fatigue. It might be better suited than the total distance walked because of its significantly higher correlation with patients' subjective somatic fatigue in the 6MW. Our results support the choice of a longer test duration (12 min) only for MS patients with mild disability (estimated by an EDSS score of less than 4). A shorter test duration (6 min) appears to be sufficient to examine dynamic walking characteristics in MS patients with potentially more moderate deficits (estimated by an EDSS score greater than 3.5). The early registration of changes in walking ability is a key to therapy aimed at minimizing the impairment of mobility. We recommend further research to more thoroughly explore abnormal dynamic walking features in MS, and to establish normative data for these parameters.

## Endnotes

[a] The linear trend (first order polynomial trend component) describes the mean slope of the velocity profile [8]. An example of the calculation: **D1, D2**, . . . **Dn** reflect the distance covered during the **first**, **second**, . . ., **n-th** minute of the walking test. Calculation of the linear trend in the 6MW can be achieved with this formula: $\text{LinearTrend}^{6MW} = ((-5*\mathbf{D1}) + (-3*\mathbf{D2}) + (-1*\mathbf{D3}) + (1*\mathbf{D4}) + (3*\mathbf{D5}) + (5*\mathbf{D6}))/70$ Different formulas were utilized for the 12MW and the quadratic trend [19].

[b] The fact that the difference between the correlation of linear trend of walking speed and subjective somatic fatigue and the correlation of mean walking speed and subjective somatic fatigue reached statistical significance only in the 6MW but not in the 12MW may be a power issue.

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**Author's contributions**
JB conceived of the study, participated in its design, coordination and data acquisition and drafted the manuscript. PK performed the statistical analysis and helped to draft the manuscript. UM participated in the design of the study, reviewed the statistical analysis and revised the manuscript. UH participated in the acquisition of data and revised the manuscript. PO participated in the design of the study. OH participated in the design of the study, reviewed the statistical analysis and revised the manuscript. All authors read and approved the final manuscript.

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Main articles

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# Research on Tai Chi as a sport in health care

## The challenge of complex interventions

**Electronic supplementary material**

The online version of this article (doi: 10.1007/s12662-013-0300-1) contains supplementary material, which is available to authorized users.

## Introduction and background

There is growing scientific interest in the effects of martial arts on health. Most of the research and literature available has an Eastern background. Since the 1990s, Western researchers, too, have increasingly been focusing on martial arts. From a sports science point of view, this research was mainly directed at potential injuries resulting from martial art practice (Burke, Al-Adawi, Lee & Audette, 2007). From a medical point of view, the health benefits of martial arts have been receiving more and more attention especially Tai Chi, which is the most studied martial art by far (Bu et al., 2010; Burke et al., 2007).

### Why study Tai Chi?

In China, the health benefits of Tai Chi are unquestioned as evidenced by the large number of Chinese practicing Tai Chi every morning and by the saying: "Tai Chi helps to gain the pliability of a child, the strength of a lumberjack and the peace of mind of a sage." The majority of scientific studies on Tai Chi focused on the improvement of health deficits in various areas (Field, 2011; Zhu, Guan & Yang, 2010). The results of these studies suggest mainly a positive effect of Tai Chi. However, the mechanisms of inducing change via Tai Chi practice are still unknown, and several methodological difficulties were encountered. The main problem in reviewing studies on Tai Chi is the great variability in the target population, the study design, and the outcome parameters (Field, 2011; Zhu et al., 2010). Bu et al. (2010) suggested that the reason for this variability lies in the inherent property of Tai Chi as a body–mind–spirit exercise (as opposed to being solely a physical exercise), pointing out the multidimensionality of its possible effects. Wayne and Kaptchuk (2008a) elaborated on this idea, presenting a conceptual framework of Tai Chi as a complex multicomponent intervention. They point out that while the effects of Tai Chi practice are researched more and more thoroughly, little attention has been directed at evaluating how this research has been conducted (Wayne & Kaptchuk, 2008b).

### Content and goal of this article

Originally designed as a martial art in ancient China, Tai Chi has been gaining attention in both Eastern and Western health-care research. The reviews found on Tai Chi research focus mainly on the extent of the effects attributed to Tai Chi practice. We face a growing body of evidence in favor of several health benefits in various target populations. However, neither firm conclusions were drawn nor clear recommendations were developed with regard to a well-directed practical application of the concept referred to as Tai Chi. So far, the question of how Tai Chi was scientifically studied has received little attention (Wayne, 2008b). This is striking, since the concept behind the name *Tai Chi* is manifold and variable. This variability poses distinct challenges to the interpretation, generalization, and repetition of original research on Tai Chi interventions, and it may be the key problem impeding the systematic generation of evidence and practical implementations.

Against this background, our aim was to examine the content and methodology of studies on Tai Chi as a sport in health care. We analyzed this issue in a problem-centered article, comprising review-like elaborations in two sections. We did not conduct a systematic review of the health benefits of Tai Chi practice, since this has already been done elsewhere (Zhu et al., 2010). Our intention was to address a fundamental problem within Tai Chi research: complexity. This problem was also encountered in other health-care and behavioral interventions, and remains highly debated in the current literature.

First, we provide an overview of Tai Chi as a sport in general. In this section, we outline the concept behind the rather simple name Tai Chi, referring to the philosophical background, historical development, and principles of Tai Chi practice. Second, we summarize how Tai Chi has been studied as a type of sport in health care to date. This section contains a review-like exploration of the question on how researchers have attempted to study Tai Chi. We include a brief overview of original research as well as a summary of reviews on the therapeutic potential of Tai Chi. We then analyze seven original articles that offer a description of the Tai Chi intervention in order to provide a background for further discussion. To this end, we identified two pluralistic components, namely, Tai Chi itself and the way Tai Chi has been studied scientifically. Third, we provide an overview of the current discussion on complexity within health-care interventions in general. In this section, we focus on the problems inherent to the terminology used in this debate, particularly exploring the terms *complexity, complex intervention, complex system,* and *whole-system research*. Fourth, we discuss the challenge of complexity within Tai Chi itself and within Tai Chi research. In this section, we delineate Tai Chi as a complex intervention and draw conclusions regarding the research methodology in this field.

## What is Tai Chi?

Tai Chi is a living tradition with a long history. The current state of research on the essence and development of the Tai Chi tradition is unlimited and still in progress. In this section, we provide a short outline of the philosophy, historical development, and core principles of Tai Chi. This overview aims to convey the idea of Tai Chi as a multifaceted and variable art of movement albeit with a rather simple name.

### Terminology and philosophy

From a practical point of view, the core of Tai Chi is the performance of defined motions with respect to certain principles (Landmann, 2005, p. 30). In summary, these motions consist of defense and attack techniques, which are carried out rather slowly one after the other in flowing and dance-like chains of motion. Such choreography is called *taolu*, i.e., *form, sequence.* While the core principles of these forms are similar, the movements and dynamics vary with respect to different traditional styles, choice of weapons, and whether they are performed with or without a partner.

The literal translation of Tai Chi means *"supreme ultimate."* In the *Chinese philosophy* of Daoism, the term Tai Chi describes the concept of *yin* and *yang*, which is represented by the Tai Chi symbol (☯). Yin and yang characterize two opposite forces joining and balancing each other in an endless, dynamic interplay. In its original meaning, Tai Chi describes a mountain's summit where the light side and shaded side merge to become one. Similarly, it describes a roof ridge, carrying and uniting both halves of the roof. In Chinese philosophy, Tai Chi (as the concept of yin and yang) is seen as the highest principle of order within the cosmos. A teaching in Daoism *(wuwei)* suggests not to interfere with this natural course of nature by using rough force, but to actively follow its path to reach the destination desired (Anders, Brauner & Zock, 2009, pp. 30–31).

In addition to this philosophic meaning, the term Tai Chi was used to refer to a *Chinese martial art*, which resembles the principle of yin and yang in its fighting technique. The general idea of this technique is self-defense against superior opponents by overcoming differences in strength and speed. Offensive force (yang) is not answered with counterforce (yang), but with drawback (yin) and the intention of unbalancing the offender and then diverting and redirecting his force back to himself (yang). Landmann (2005, pp. 293–294) questioned the belief that the martial art Tai Chi was originally derived from the principle of yin and yang, as suggested by Song and Bohn (1991, p. 45). Landmann (2005, p. 291) assumed that the common knowledge and acceptance of philosophic principles may have served as a suitable aid to explain and justify the martial art Tai Chi and its dynamic principles.

To specify the form of Tai Chi martial art, the type of weapon used is attached to the term Tai Chi. For example, the use of a sword (*jian*) results in the name *Tai Chi Jian*, whereas unarmed Tai Chi is called *Tai Chi Chuan*. The term *chuan* is derived from *shou* (*hand*) and means *fist, fist fight, or boxing* (Landmann, 2005, pp. 57–58). Depending on the system of phonetic translation used, the spelling varies: Tàijíquán (pinyin), T'ai Chi Ch'uan (Wade–Giles system).

### History of Tai Chi Chuan

Tai Chi Chuan is a living tradition and an evolving art. Its original creator remains unknown and its history is controversially discussed. While Chinese history is rich in written information on the life of its governors and direct enemies, written records on the life of the folk are scarce. In its *early phase of development*, Tai Chi Chuan was a secret martial art that was passed down through generations and had not yet been given the name it carries today. The origin of the term "Tai Chi Chuan" itself is not clear and was not established until the 1920s with the first wave of publications on Tai Chi Chuan. Most of what is known today comes from oral traditions in the form of narratives and anecdotes, which were not written down until the nineteenth or twentieth century (Song & Bohn, 1991, p. 25). Since the *mid-nineteenth century* Tai Chi Chuan has been receiving increasing attention. The practice grew with five main traditional styles (Chen, Yang, Wu, Wu, and Sun) and spread beyond the Chinese culture. The main incentive to open originally secret martial arts to the public may have been the invention of firearms, against which even highly developed fighting techniques pose no threat (Filipiak, 2001, p. 147). Most of the early literature on Tai Chi Chuan was written in the late nineteenth century. Beginning with these publications, interest in the health benefits resulting from Tai Chi Chuan practice grew, while the original idea of self-defense became less important (Landmann, 2005, pp. 20–61).

Since the *early twentieth century*, more and more manuscripts and lessons of Tai Chi Chuan have been made available to the public. To increase the suitability of Tai Chi Chuan for the mainstream, the original forms were shortened and simplified and new forms were developed along with the establishment of official martial art competitions (Buss, 2007, pp. 15–18). In China, elements of Tai Chi are included in musical theater performances. Additionally, new forms of motion were invented that carry the term *Tai Chi* in their name, for example, Tai Chi dancing and Tai Chi Bailong Ball (Buss, 2007, p. 21). In this way, Tai Chi Chuan evolved to become both a competitive sport as well as a popular sport and form of health enhancement exercise, earning increasing attention as a subject in sports science.

## Teaching Tai Chi Chuan today

The early manuscripts on Tai Chi Chuan seem to originate from the representatives of three of the main traditional styles (*Chen, Yang, Wu*), having been passed down through generations until the early twentieth century. During the process of traditional teaching, the forms changed along with the Tai Chi masters, each of them aiming to further develop his abilities (Anders et al., 2009, p. 17; Landmann, 2005, p. 61). The change from the direct tradition of Tai Chi Chuan (between a master and his few chosen students) to the dissemination of Tai Chi Chuan to the public via group lessons, led by both masters and students, resulted in an even greater variability in its teaching. Therefore, the expertise of Tai Chi Chuan instructors today is very difficult to assess. Before the 1950s, the criterion of a good teacher was the ability to develop and exert force (*jin force*) achieving high impact without hurting the person being hit (Anders et al., 2009, p. 16). Since the number of instructors who were not able to develop this kind of force increased – while simultaneously the motive behind practicing Tai Chi Chuan changed from martial arts to health promotion – this criterion of expertise became less important (Anders et al., 2009, p. 24; Buss, 2007, p. 21).

Instead, several instructors adopted the Chinese way of legitimation via the traditional lineage, referring to themselves as *personal student of master X* even if they met him only twice a year (Anders et al., 2009, p. 24). Additionally, several terms are now being used to emphasize the quality of the Tai Chi Chuan taught (*original, authentic*) and to imply a specific level of skill (titles like *sifu, master,* and *grand master*) (Kang, 2011). In an attempt to manage the quality of Tai Chi Chuan lessons, several associations were established.

## Tai Chi Chuan principles

Landmann (2005, p. 61) argued that the variability within Tai Chi Chuan practice might be a hint that the core of Tai Chi Chuan is not the form itself, but the principles that are carried within the form. In his analysis of the early manuscripts on Tai Chi Chuan principles, Landmann (2005, p. 306) concluded that a thorough summary of the kinematics of Tai Chi Chuan may never be recovered and may have never even existed.

Landmann (2005) presents four basic concepts to describe the quality of motion within Tai Chi Chuan. The concepts comprise the principles of *yin* and *yang*, *qi*, *jin force,* and *motion.* As argued earlier, well-known philosophic principles (such as *yin* and *yang*) may have served as an aid to describe the characteristics of motion in Tai Chi Chuan in China, but they pose great difficulties to those who are unfamiliar with these concepts (Landmann, 2005, p. 306). The precondition to account for all of the four concepts is *awareness* and the *conscious control* of motion (Landmann, 2005, p. 298). As delineated earlier, *the concept of yin and yang* was used to describe the *dynamic qualities* within Tai Chi Chuan motions.

The term *jin* is used to describe a special way of developing and exerting force in Chinese martial arts. The ways of achieving *jin* vary depending on the type of martial art and its teachings (Anders

**Abstract · Zusammenfassung**

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### Research on Tai Chi as a sport in health care. The challenge of complex interventions

**Abstract**
This article examines the content and methodology of studies on Tai Chi as a sport in health care. We investigate the concept behind the rather simple name "Tai Chi," concluding that this concept is manifold and highly variable. How did researchers deal with this variability when studying the effects of Tai Chi as a health-care intervention? We then explore how scientific research on Tai Chi has been conducted to date and draw the interim conclusion that the variability was barely taken into consideration. Our analysis of seven Tai Chi interventions reveals that two interventions referred to as Tai Chi may differ considerably in their content. The variability poses difficulty in repeating the intervention and drawing causal inferences. This problem is discussed in the current literature under the term "complexity in health-care interventions." On the basis of a summary of this debate, we discuss the challenge of researching Tai Chi from a complex perspective—with the aim of achieving solid results that can be repeated.

**Keywords**
Tai Chi · Health care · Complexity · Complex intervention

### Forschung über Tai Chi im Gesundheitssport. Die Herausforderung komplexer Interventionen

**Zusammenfassung**
Was bedeutet es inhaltlich und methodologisch, Tai Chi als Intervention im Gesundheitssport zu erforschen? Wir untersuchen das Konzept, das sich hinter dem Begriff Tai Chi verbirgt und stellen fest, dass dieses Konzept höchst variabel und vielfältig ist. Auf welche Weise findet diese Variabilität in der Erforschung von Tai Chi als Intervention im Gesundheitssport Berücksichtigung? Wir untersuchen daraufhin, wie Tai Chi bisher wissenschaftlich erforscht wurde und ziehen die Zwischenbilanz, dass die Variabilität der Interventionen kaum Berücksichtigung fand. Unsere beispielhafte Analyse von sieben Interventionen lässt erkennen, dass zwei Interventionen, die beide als Tai Chi bezeichnet werden, inhaltlich sehr unterschiedlich sein können. Die Variabilität stellt uns vor die Schwierigkeit, die Intervention zu wiederholen und kausale Zusammenhänge abzuleiten. Dieses Problem wird aktuell unter dem Begriff Komplexität in der Gesundheitsforschung diskutiert. Auf Basis einer Zusammenfassung dieser Debatte diskutieren wir die Herausforderung, Tai Chi aus einer komplexen Perspektive zu erforschen – mit dem Ziel, zu belastbaren Ergebnissen zu kommen, die replizierbar sind.

**Schlüsselwörter**
Tai Chi · Gesundheitssport · Komplexität · Komplexe Intervention

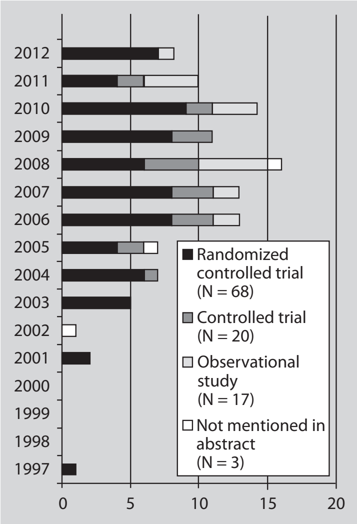


**Fig. 1** ▲ Overview of the longitudinal studies on Tai Chi listed in the PubMed database, with respect to year of publication and study design

et al., 2009, pp. 31–32). In the literature on Tai Chi Chuan, *jin* is translated as *jin force* (Anders et al., 2009; Landmann, 2005) or *elastic force* (Song & Bohn, 1991). In Tai Chi Chuan, the concept of jin describes the *effort of achieving a special organization within the body* (Landmann, 2005, p. 295). The achievement of jin depends mainly on the optimal use of the body's elastic qualities, while the overall effect of jin depends both on one's own bodily structure and the bodily structure of the person hit (Song & Bohn, 1991). In special constellations, this results in spectacular events where the person hit is pushed several meters away from the person exerting jin, who then seems to possess superhuman strength. Anders et al. (2009, p. 24) differentiate two distinct types of Tai Chi practice, depending on whether the development of jin is a specific goal of the practice or not.

The concept of *qi* has been subject to many misunderstandings and mystifications. The Chinese character for qi has been changing over the course of history and was used to describe a variety of microscopic and macroscopic phenomena and concepts. It cannot accurately be defined or translated, and attempts at translation remain vague and ambiguous (Landmann, 2005, p. 80). Even within the context of Tai Chi Chuan, the character for qi is used to describe different matters. Landmann (2005, p. 294) concluded that the term qi is mainly used to describe the *effort of moving the body as a whole* (as opposed to the isolated movement of single parts) with the help of imagination and breathing techniques.

The remaining concept, *motion*, was characterized by the following four approaches: motion as changing the body's position in space, motion as changing the relationship of the body's parts to each other, motion as changing the body's weight ratio, and motion as a counterpart to rest (Landmann, 2005, p. 297).

## Conclusion

Taken together, these findings make it clear that the art of Tai Chi has grown to be a highly pluralistic type of exercise. The practice and dissemination of Tai Chi depend heavily on the fusion of tradition, personal experiences, and development. Moreover, the motives for practicing Tai Chi – e.g., as a martial art, self-defense, meditation, aesthetics, socializing, exploration of a different concept of motion – also play a major role. All the phenomena emerging from this variability are commonly referred to as Tai Chi. However, the term Tai Chi itself does not denote which of these phenomena is meant.

## Researching Tai Chi in health care

Scientific interest in the therapeutic potential of Tai Chi has grown, leading to an increase in the amount of original research being published. The aim of this section is to explore the following question: Which areas has Tai Chi research been directed toward and which way of practicing Tai Chi has been assumed to hold therapeutic potential?

### How has research on Tai Chi been conducted so far?

The database PubMed was searched in March 2012 for longitudinal studies on Tai Chi interventions, using the search terms "Tai," "Chi," "Chuan," "Taiji," and "Taijiquan." All studies that included at least a pretest and posttest design were accepted. The search yielded 108 studies, starting with the year 1997. An overview of these studies was made from the information given in the abstracts, taking into account the following aspects: year of publication, description of the intervention, duration of the intervention, target population, sample size, study design, study arms, and outcome domains (see **Tab. 1** for publications analyzed in Sect. 3.3, and the Appendix for the complete table). The variability within the studies was very high, with the sample size ranging from 6 to 1,200 and the duration of the intervention ranging from 60 min to 12 months. We noted a significant increase in the number of publications from 0 to 10–15 per year (**Fig. 1**). All but three of the studies included in the analysis explored the health benefits of Tai Chi on the basis of a variety of different conditions, focusing to a great extent on elderly persons (**Fig. 2**). The abstract of most studies did not specify the Tai Chi style or forms used (**Fig. 3**).

### How has Tai Chi research been reviewed so far?

The database PubMed was searched in September 2012, using the search term "Tai Chi." The search yielded 871 results. Articles labeled as type "review" were selected, generating 155 results. All articles with the words *Tai Chi* or *Taiji* in their title were selected consecutively, yielding 69 results. Articles not written in English or German were excluded, thus leaving 64 articles for closer analysis (see Appendix for complete table). These 64 articles were published between 1998 and 2012. In the majority of these studies, the health benefits of Tai Chi were reviewed with respect to particular target groups, led by the elderly and persons with cardiovascular problems (see **Fig. 4**). The remaining articles reviewed the health and therapeutic benefits of Tai Chi in general, explored particular aspects of Tai Chi practice, provided information on Tai Chi itself, and reviewed methodological aspects of Tai Chi research (see **Fig. 5**).

To gain insight into the way Tai Chi has been reviewed as an interventional thera-

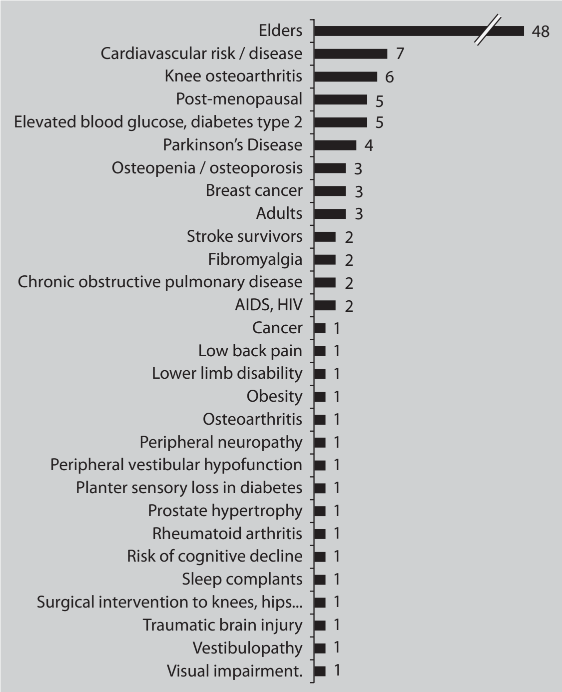


**Fig. 2** ◀ Absolute frequency of longitudinal studies on Tai Chi found in the PubMed database, with respect to target population

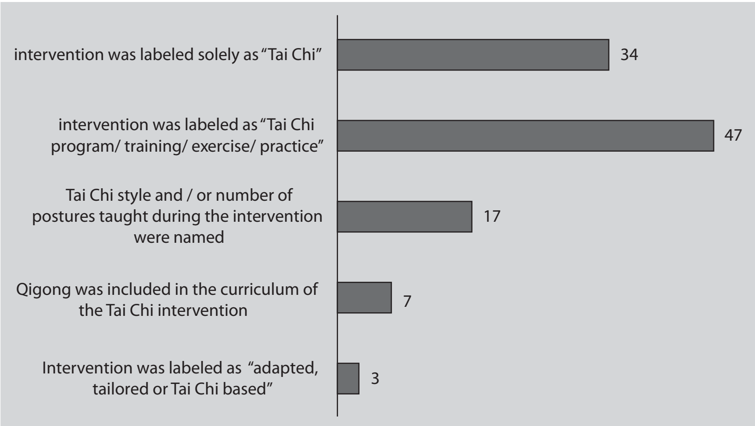


**Fig. 3** ▲ Absolute frequency of longitudinal studies on Tai Chi found in the PubMed database, with respect to description of the intervention provided in the abstract

py, we chose to examine the five reviews focusing on health benefits of Tai Chi in general.[1] In the following section, we provide a summary of these reviews, focusing on their structure and main conclusions.

Klein and Adams (2004) conducted a systematic and well-structured review on the comprehensive benefits of Tai Chi. First, they provided an overview of the whole body of research identified through three databases. They pointed out that the amount and strength of evidence on Tai Chi interventions had increased tremendously from 1985 to 2003 and that a variety of clinical populations were studied. In summary, the literature reviews they cited concluded that, although scientific evidence in favor of the health benefits of Tai Chi was growing, further research was needed. Additionally, in a 2004 review, the methodological approach to researching the effects of Tai Chi on balance was criticized, addressing deficits in what constituted the intervention and the research protocols. Second, Klein and Adams (2004) conducted a systematic review of 17 randomized controlled trials (RCTs) published between 1990 and 2003, comprising a total of 1,035 subjects, intervention durations ranging from 6 weeks to 12 months, and activity duration of less than 15 min to more than 60 min per session. Klein and Adams (2004) reported *Yang style and simplified forms* as the most frequent characterization of the Tai Chi intervention, provided that a description was available at all. In more than 60 % of the over 22 outcome areas examined, statistically significant benefits were reported. Each study reported at least one statistically significant benefit. The most frequent outcome measures were quality of life and physical function. Klein and Adams stated that both measures are complex and multidimensional constructs, comprising a variety of different outcome domains. Further outcomes focused on pain, blood pressure, balance, immune response, flexibility, strength, and kinesthetic sense. Klein and Adams (2004) concluded that evidence supports the potential of Tai Chi benefits in these domains. They also pointed out that the evidence at hand justified Tai Chi being explored in the following domains: cardiac rehabilitation, chronic pain management, fall prevention programs, health and wellness intervention for individuals who are immune suppressed, fitness exercise programs for the elderly, as well as exercise precautions for arthritis-related conditions.

Kuramoto (2006) conducted a research review on the therapeutic benefits of Tai Chi exercise. The review included 14 original articles published between 1991 and 2004. No inclusion or exclusion criteria for the studies reviewed were reported. In this review, Tai Chi interventions were summarized with respect to different outcome domains, including pain reduction, balance and fall prevention, aer-

[1] We did not include the two reviews on methodology in Tai Chi research. Both articles delineated the challenge of complexity within Tai Chi and are referred to in our discussion on this topic in Sect. 5.

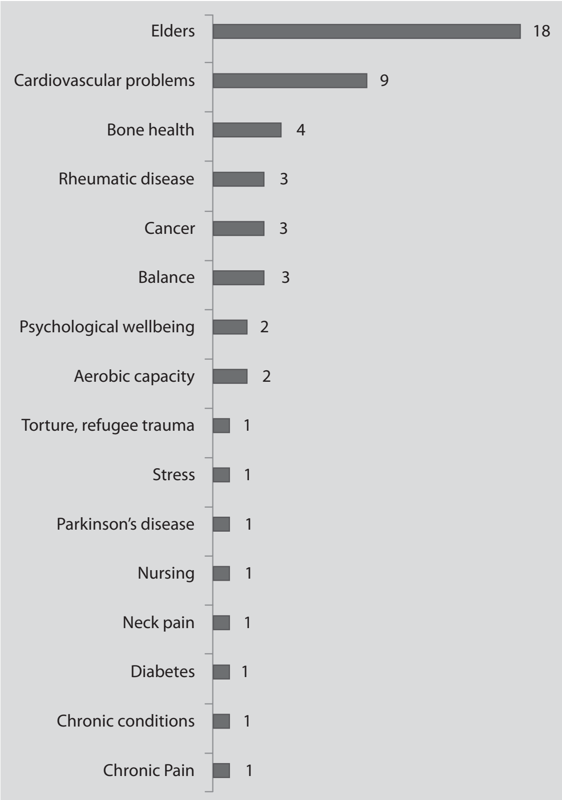


**Fig. 4** ◀ Absolute frequency of review articles on Tai Chi found in the PubMed database, with respect to a selected target population

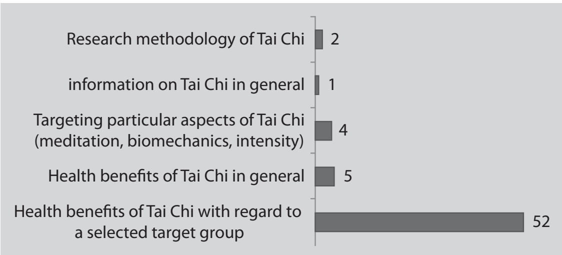


**Fig. 5** ◀ Absolute frequency of review articles on Tai Chi found in the PubMed database, with respect to the topic chosen for review

obic capacity, blood pressure, quality of life, stress, sleep, and strength. A brief summary was provided of the study design, methods, and results of the studies included. No firm conclusion was drawn regarding the strength of evidence. It was concluded that there is a need for better study designs, more longitudinal research, as well as a focus on younger and middle-aged people. Kuramoto (2006, p. 45) stated that "future studies should investigate outcomes associated with Tai Chi training as a function of different instructional techniques, different Tai Chi styles, different groups and different age groups" and that "it is not clear which of the components in Tai Chi makes the exercise especially effective."

Jahnke, Larkey, Rogers, Etnier and Lin (2010) conducted a well-structured, comprehensive review on the health benefits of Qigong and Tai Chi. Using five databases, they included 77 RCTs from 1993 to 2007 that focused either on Qigong or Tai Chi interventions. The studies included comprised 6,410 subjects and 163 different physiological and psychological health outcomes. From these outcomes, nine outcome categories were identified: bone density, cardiopulmonary effects, physical function, falls, balance and related risk factors, quality of life, self-efficacy, patient-reported outcomes, psychological symptoms, and immune- and inflammation-related responses. Consecutively, within each category, the studies included were discussed with respect to control groups, outcome measures, results, and description of intervention as Tai Chi or Qigong. Conclusions were drawn about the strength of evidence for each category. Jahnke et al. (2010) discussed the results with respect to control groups and intervention duration. They found that designs that used an inactive control group mainly resulted in significant differences between treatment groups, while studies that used an active control group mainly found similar improvements in both treatment groups and no significant differences. If the inclusion of an inactive control group did not result in significant differences between treatment groups, the studies mainly included shorter intervention duration (less than 12 weeks) and/or very health-compromised participants. However, Jahnke et al. (2010) also reported on three studies in which significant effects occurred after an intervention duration of only 8 weeks. The authors (2010) concluded that interventions labeled as either Tai Chi or Qigong yielded similar results. While fewer studies focused on Qigong than on Tai Chi, the content of the Tai Chi studies mainly seemed to be simplified Tai Chi forms. Jahnke et al. (2010, p. 12) explained that these simplifications may result in exercise programs that are more similar to Qigong than to Tai Chi and "may be Tai Chi in name only." The authors concluded that these findings justified their claim of the equivalence of Tai Chi and Qigong when researched with regard to therapeutic value. As a main limitation to this conclusion, Jahnke et al. (2010) addressed the lack of detail reported across the studies. A detailed description of the intervention could have helped analyze to what extent the interventions included key elements of meditative movement in their curricula (focus on regulating the body, the breath, and the mind). Moreover, a detailed description was necessary to assess the variations in outcomes achieved. Jahnke et al. (2010) suggested consistent reporting with regard to dosing (frequency, duration and level of intensity, estimate of metabolic equivalents) and motion (speed of execution, muscle groups used, range of motion).

Field (2011) conducted a research review on Tai Chi based on 71 articles (including reviews) published between 1989 and 2010. No inclusion or exclusion criteria were provided for the studies reviewed. The review was structured according to the following outcome domains: empirical support of Tai Chi being an aerobic exercise, other physical benefits, psychological benefits, cardiovascular benefits, pain syndromes, autoimmune conditions, and immune function. Within these domains, the results of different studies were summarized and partly discussed with respect to the intervention duration. However, no conclusions were drawn regarding strength of evidence and future research attempts. Field (2011) drew attention to the following methodological problems: variability in the Tai Chi forms used, the intensity of the Tai Chi protocol, higher amount of prestudy and poststudy designs compared to controlled trials.

Allen and Meires (2011) conducted a brief review of the potential benefits of Tai Chi practice for patients with chronic conditions. Eight original articles published between 2006 and 2009 were included. No inclusion or exclusion criteria were provided for the studies reviewed. The review was addressed at primary care providers and encouraged the prescription of Tai Chi as therapy. Allen and Meires (2011) concluded that Tai Chi could improve the physical and mental well-being of patients with chronic illnesses. They stated that most of the effects in the studies occurred after an intervention duration of 12 weeks with two to three sessions per week.

In summary, the five reviews we analyzed varied in methodological rigor. Klein and Adams (2004) and Jahnke et al. (2010) closely followed a predefined research question, providing conclusions about the strength of evidence identified in the studies reviewed. Kuramoto (2006), Field (2011) and Allen and Meires (2011) summarized a variety of articles on Tai Chi research, but did not draw conclusions about the evidence base. In all five reviews, the presentation of the studies included was oriented toward different outcome domains. We conclude that this seems to be a reasonable way of dealing with the variety of forms that Tai Chi research is directed at. However, the second variability, which is inherent to Tai Chi, was not targeted in any of the five reviews. Yet, the following methodological problems were addressed: lack of description of the intervention (Klein & Adams, 2004; Jahnke et al. 2010), modification of Tai Chi forms (Jahnke et al. 2010), lack of information regarding the intensity of the intervention (Field, 2011), variability in forms used (Field, 2011, Jahnke et al. 2010), lack of association between content and consequences (Kuramoto, 2010), and complexity of outcome domains (Klein & Adams, 2004).

## How have Tai Chi interventions been conducted so far?

In this section, we present an analysis of seven studies reported in original articles that include a detailed description of the Tai Chi intervention conducted (◘ **Table 1**). The goal of this summary is to reflect how Tai Chi has been studied. In particular, the intention was to look into the way the study was organized as well as which components the intervention contained. The seven articles were selected from the 108 original articles analyzed previously (Sect. How has research on Tai Chi been conducted so far?). Selection criteria were sample size, intervention duration, and quality of reporting. The first two criteria were selected with regard to the level of organizational load and the level of explanatory power. The third criterion was aimed at the intervention and was needed because of the poor description of the intervention protocol in most studies (Wayne & Kaptchuk, 2008b). The top seven studies providing the most detailed information on the intervention were chosen.

## Analysis of the study design

**Design** All of the selected articles refer to a *target population* with either a chronic condition, Parkinson's disease (no. 1), fibromyalgia (no. 2), stroke (no. 7), osteopenia (no. 5), or advanced age (nos. 3–4, 6), which is related to chronic conditions and diminishing physical function. This distribution reflects the general distribution of populations targeted by Tai Chi research (◘ **Fig. 2**). The number of participants varied between 28 (no. 7) and 256 (no. 6). All of the studies reviewed were designed as *RCTs*, although this was not a predefined condition to be included in the review. The number of *experimental groups* varied between two (nos. 2–3, 5–7) and three (nos.1, 4). All studies included a Tai Chi group. Control interventions consisted of resistance training, stretching, wellness education, and Western exercise. Noninterventional control groups included attention control and wait-list/standard care control. The *duration of the intervention* was 3 months (nos. 2, 7), 6 months (nos. 1, 3–4, 6), and 9 months (no. 5). The assessment of outcome parameters was conducted two (nos. 2, 7) or three times (nos. 1, 3–6). A postintervention *follow-up* was included in four studies (nos. 1–2, 4, 6).

**Aim and hypothesis** Three articles provided a *hypothesis* (nos. 1–3). They hypothesized that Tai Chi practice would lead to improvements in the following domains: postural stability (no. 1), balance control (no. 3), pain, physical function, psychological function, quality of life, and sleep (no. 2). Study no. 3 also hypothesized that Tai Chi learners would adopt a larger stance width. The remaining four articles stated the *aim of the study* (nos. 4–7). Two studies were aimed at evaluating safety and feasibility of the trial design and the intervention (nos. 5, 7). Study no. 4 was aimed at comparing the effects of Tai Chi practice with Western exercise. Study no. 5 was aimed at exploring the effectiveness as well as the mechanisms through which Tai Chi might exert influence on bone metabolism. Study no. 6 was aimed at assessing the efficacy of Tai Chi on the fall incidence of senior subjects.

**Methods** The *outcome domains* covered physical function (balance, strength, and endurance), cognitive function, condition-specific aspects (number of falls, bone mineral density, questionnaires) as well as questionnaires about habits and psychological constructs. In addition, possible mediators of effectiveness and safety issues about both the intervention and the study design were analyzed. The

## Main articles

**Table 1** Studies chosen for detailed analysis of methodology and Tai Chi intervention

| No. | Reference | Title | Duration (months) | Study population | Sample size | Design | Study arms | Outcome |
|---|---|---|---|---|---|---|---|---|
| 1 | Li, Harmer, Fitzgerald et al. (2012) | Tai Chi and postural stability in patients with Parkinson's disease | 6 | Parkinson's disease | 195 | RCT (3) | TC, resistance training, stretching | Postural control |
| 2 | Wang, Schmid, Rones et al. (2010) | A randomized trial of Tai Chi for fibromyalgia | 3 | Fibromyalgia | 66 | RCT (2) | TC + UC, UC | Fibromyalgia Impact Questionnaire (FIQ), physical and mental components of the SF-36 questionnaire |
| 3 | Yang, Verkuilen, Rosengren et al. (2007) | Effect of combined Taiji and Qigong training on balance mechanisms: an RCT of older adults | 6 | Elderly | 49 | RCT (2) | TC, wait list control | Somatosensory, visual, vestibular ratios of the sensory organization test; quiet stance base of support, feet opening angle |
| 4 | Taylor-Piliae, Newell, Cherin et al. (2010) | Effects of Tai Chi and Western exercise on physical and cognitive functioning in healthy community-dwelling older adults | 6 | Elderly | 133 | RCT (3) | TC, Western exercise, attention-control | Physical and cognitive functioning |
| 5 | Wayne, Kiel, Buring et al. (2012) | Impact of Tai Chi exercise on multiple fracture-related risk factors in post-menopausal osteopenic women: a pilot pragmatic, randomized trial | 9 | Postmenopausal (w) | 86 | RCT (2) | TC + UC, UC | Bone mineral density, serum markers, balance |
| | Wayne, Buring, Davis et al. (2010) | Tai Chi for osteopenic women: design and rationale of a pragmatic randomized controlled trial | 9 | Postmenopausal (w) | 86 | RCT (2) | TC + UC, UC | Bond mineral density, serum markers, balance |
| 6 | Li, Harmer, Fished et al. (2005) | Tai Chi and fall reductions in older adults: an RCT | 6 | Elderly | 256 | RCT (2) | TC, stretching | Number of falls, balance, risk for falling |
| 7 | Taylor-Piliae & Coull (2012) | Community-based Yang-style Tai Chi is safe and feasible in chronic stroke: a pilot study | 3 | Stroke survivors | 28 | RCT (2) | TC, UC | Safety, feasibility, study satisfaction, adequacy of outcome measures |

*TC* Tai Chi, *UC* usual care, *RCT* randomized controlled trials

mediators analyzed were larger stance width (balance control), lumbar and hip mechanical load (bone mineral density), functional ability, and fear of falling (total number of falls). The *process of randomization* was reported with varying details and differed in design. Little information was provided on the *process of the intervention* and how it was monitored or evaluated. The *procedure of tracking and influencing adherence rate* varied considerably. Only two studies included *qualitative measures of program acceptance*, conducting exit interviews and reporting whether the participants enjoyed the intervention (nos. 5, 7). None of the studies reviewed provided an evaluation of the intervention by the participants or the experiences of the Tai Chi instructor(s). None of the studies reported whether the participants intended to continue practicing Tai Chi. Two studies included the *tracking of program fidelity* (nos. 1, 5). Four studies included the *tracking of adverse events* (nos. 1, 2, 5, 7).

**Consequences** Regarding the *tendency of effects observed* in the Tai Chi groups, none of the articles reported the incidence of serious adverse events and all of the effects observed tended to be favorable. In studies comparing the Tai Chi group with a physical active control group, differing effects were reported in the physical and cognitive function measures (nos. 1, 2, 4, 6). In four studies the *amount of improvement* depended on the time of assessment (nos. 1–3, 6). The *maintenance of intervention gains* was reported for the three studies, which included a follow-up period (nos. 1, 2, 4). Five articles provide hints for future research attempts (nos. 3–7). Two articles suggested longer intervention periods, for example, to enable the detection of maintaining function with increasing age rather than showing improvement (nos. 4, 5). Study no. 3 suggested increasing adherence via the inclusion of short Tai Chi forms (positive experiences, self-efficacy) and structured contact with participants. Topics suggested for future research include individual and combined effects of Tai Chi components (no. 3), cost effectiveness of fall prevention through a Tai Chi intervention (no. 5), and mechanisms by which Tai Chi induces effects (no. 5).

### Analysis of the intervention

The selected studies were reviewed according to the following framework, which was developed on the basis of a smaller framework provided by Li, Zhang

**Table 2** Framework used to analyze the intervention

| Topic | No. | Reporting criterion |
|---|---|---|
| Definition | 0–1 | How is Tai Chi defined by the authors? |
| | 0–2 | What was the goal of the intervention? |
| Dose | 1–1[a] | How long was the intervention (weeks)? |
| | 1–2[a] | Was the Tai Chi training center-based or home-based or both? |
| | 1–3[a] | If center-based, how often was the Tai Chi training class held per week and how long did a Tai Chi training class last (minutes)? |
| | 1–4 | How many groups were formed? How many people were in one group? How was the group fitted together? |
| | 1–5 | Were the participants provided with information materials? |
| | 1–6 | Did the participants have previous Tai Chi experience? How much? |
| | 1–7 | How were the rest periods determined during the intervention? |
| | 1–8 | Which was the minimum adherence rate required? |
| | | What attendance rate was achieved? |
| | 1–9 | Did the participants practice at home? |
| Content | 2–1[a] | What style of Tai Chi (Yang, Chen, Sun, etc.) was used in the intervention described? |
| | 2–2[a] | What did a Tai Chi training session consist of in the study? Were there any other non-Tai Chi exercises included in a Tai Chi training session? |
| | 2–3 | Did the content of the class change with time? |
| | 2–4[a] | Were the specific Tai Chi movements used in the training described and illustrated? |
| | 2–5[a] | What were the major components (i.e., slow movements, mental concentration, and deep breathing) of Tai Chi that were emphasized in the training? |
| | 2–6 | Did the participants progress as a group or as individuals? |
| | 2–7 | Did the participants interact within partner tasks or to help each other? |
| | 2–8[a] | Was the description of the control comparable to the description of the Tai Chi training? |
| Teacher(s) | 3[a] | What were the credentials of the Tai Chi instructors in the study? |
| | | Who held the class when the teacher was sick? |

[a]Adopted from Li et al. (2011)

and Smith et al. (2011) (**Table 2**). The main domains analyzed included the intervention's definition, goal, dose, content, and teacher. The extension of the domain *dose* was based on recommendations by Wayne and Kaptchuk (2008b) and by Zhu et al. (2010), who pointed out the vague information on dosage and content provided in original research articles on Tai Chi. The domains were extended focusing on the information deemed necessary to repeat the intervention.

**Definition** The amount of information given about Tai Chi itself varied considerably between the studies. Study no. 6 did not provide any information; study no. 1 limited the description of Tai Chi as being a balance-based exercise. Four articles reported a connection to China (nos. 2–5). Three articles reported that Tai Chi was connected to martial arts but did not report on whether martial arts applications were included in the intervention (nos. 2, 3, 5). The purpose of Tai Chi was reported to be the cultivation of health (nos. 2, 5) and the improvement of physical performance (nos. 3, 4). Four articles reported on the elements of mindfulness, breathing, and relaxation (nos. 2–4, 6). Two articles described the quality of motion as slow and gentle (nos. 2, 3). Two studies were conducted against the background of a specified interventional goal:[2] Study no. 1 tailored a Tai Chi program focusing on weight shifting, the controlled displacement of the center of mass, and stepping in four different directions aiming to tax balance and gait. The instructors were trained in a 2-day workshop, but did not receive any information on the objective of the study and were excluded from data collection tasks. Study no. 3 tailored a Tai Chi program in the same manner, adding range of motion, spinal rotation, and applicability to the elderly. The reduced movement set was justified by the likelihood of positive experiences if the form was accomplished over a short period of time. The program was designed and taught by the principal investigator.

[2] Here, the goal of the Tai Chi intervention itself is meant (as opposed to the aim of the study that was addressed above). Reporting of this criterion may help to distinguish between a Tai Chi intervention as a means to achieving a particular goal (such as balance improvement) versus a Tai Chi intervention aimed at practicing principles of Tai Chi.

**Dose** Only three studies took *previous Tai Chi experience* into account. Study no. 4 reported whether the participants had previous Tai Chi experience. In two studies, eligible participants who had practiced Tai Chi within the last 6 months (no. 2) or 2 years (no. 5) were excluded. Only study no. 7 reported the exact *number and size of Tai Chi groups*. Across selected studies, group size varied between six and 12 participants; two articles did not provide any information about group size (nos. 2, 6). Study no. 5 did not form groups but offered seven pre-screened Tai Chi centers to the participants to choose from. The assigned *practice time* varied between 24 × 60 min (no. 2) and 48 × 60 min + 24 × 60 min + home practice (no. 4). The duration of the intervention ranged from 12 (nos. 2, 7) to 48 weeks (no. 4). In six studies, a center-based class lasted 60 min;

study 6 did not report on class duration. Only studies 4 and 7 (same author) reported on how the *rest periods* during the practice time were determined (chairs available to rest as needed). Three studies include *practice at home* (nos. 2, 4, 5). For two of these, the information materials that participants received as help and incentive were mentioned (nos. 2, 4). Study no. 7 (not including home practice) reported that participants received information material after completion of the study. Study no. 1 forbade participants to practice at home. All of the articles reported the *adherence rate*. Two of them stated an expected adherence rate and mentioned by how many participants it was met (nos. 1, 5). One article reported an exclusion policy for missed classes (no. 1). None of the articles reported whether the participants practiced at home or not.

**Content** The most frequent *style* of Tai Chi was Yang; other styles were Chen and Wu. All studies included short Tai Chi forms of 7–24 figures. All articles provided *information on the Tai Chi form taught*, including text (nos. 1, 3), articles (no. 1), monographs (nos. 2, 4, 6, 7), and a youtube.com link (no. 7) as references. Six articles reported different phases within the class, including warm-up exercises (nos. 1–4, 6, 7) and a cool-down phase (nos. 1, 6, 7). The content of these phases was not reported; only study no. 2 mentioned self-massage as part of the warm-up phase. Four articles reported that the form was taught gradually (nos. 1, 3, 4, 7). Only study no. 3 gave a detailed description of the training schedule, enabling other researchers to repeat the intervention accurately, but did not report whether the teacher and participants were comfortable with the program. Study no. 5 included several Tai Chi centers that were offering Tai Chi classes to the community, and did not provide details of the content of single Tai Chi classes. However, these centers were selected on the basis of predetermined criteria, including essential curricular requirements, acceptable curricular components, and unacceptable curriculum elements, all of which are reported explicitly in the article. Four articles (nos. 3–6) reported Tai Chi-*specific components or principles taught* during the intervention. The elements that were mentioned in more than one article are body alignment or orientation, weight shifting, relaxation, and breathing. Further elements that were mentioned include range of motion, upright position, symmetry, coordination, continuity, slow pace, meditation, concentration, awareness, attention to feeling, inattention to thoughts, attitude/happiness, interaction with the world, and transfer to daily activities. Study no. 5 listed the elemental techniques of Tai Chi motion (e.g., peng, lu, ji, and an). Only study no. 6 mentioned *musical accompaniment* in the Tai Chi classes. None of the analyzed articles reported whether there were *partner or group activities* involved in the Tai Chi lessons. Only study no. 5 mentioned that gentle interactive Tai Chi exercises such as "sensing hands" were allowed. None of the articles reported on *whether participants progressed as a group or individually* and whether *individual tailoring* was allowed or if there was a specific aim of the program. None of the articles mentioned *group dynamics*.

**Teacher** Five of the reviewed articles emphasized the experience of the Tai Chi instructors, reporting the title of "master" (no. 2) and "grand master"(no. 4) and/or several decades of practice time and teaching experience (nos. 3, 5, 7). Study no. 6 described the instructor as "experienced"; study no. 7 reported the choice of a charismatic Tai Chi instructor as a strategy to increase adherence. Exit interviews in this study did not address the relationship between teacher and participants, but revealed that overall satisfaction was high. Study no. 5 allowed classes led by junior instructors supervised by a senior instructor; study no. 1 did not list the credentials of the Tai Chi instructor, but a 2-day training workshop for the instructors was involved. Two studies involved teaching assistants: Study no. 3 involved a different teaching assistant at each location, while study no. 7 involved a registered nurse.

## Conclusion

The aim of this section is to explore how Tai Chi has been researched scientifically, keeping in mind the manifold concept and the variability behind the name Tai Chi, which we outlined in Sect. 2. We asked the question: To which domains has Tai Chi research been directed at and which way of practicing Tai Chi was assumed to hold therapeutic potential?

In the first step, we explored original research on the potential of Tai Chi as a sport in health care, focusing on the abstracts of longitudinal studies only. Our findings confirmed that scientific interest in Tai Chi has been rising. Tai Chi was hypothesized to hold the potential of helping with a wide range of health deficits in a variety of different outcome domains. This pluralistic research into multiple directions was unified by the common goal of pinpointing therapeutic potentials held by a concept that was simply referred to as Tai Chi. However, as shown in Sect. 2, the common ground in the terminology used ("Tai Chi") does not necessarily imply a common ground in the phenomenon researched. To this end, we identified two aspects of Tai Chi research that are highly variable: The first is the manifold concept of Tai Chi itself. The second is the multitude of directions that original Tai Chi research has followed.

In the second step, we explored how original Tai Chi research has been reviewed so far, focusing on the therapeutic benefits of Tai Chi in general. We found that the authors organized their manuscripts according to the different outcome domains of Tai Chi research. In doing so, they dealt with the multitude of domains that Tai Chi research has examined. However, none of the reviews we analyzed targeted the variability within Tai Chi practice itself[3], which may be a result of the poor descriptions of the interventions. Simplified forms of Yang style Tai Chi seemed to be used most frequently.

In the third step, we analyzed seven original articles that provided a detailed description of the intervention. We approached the articles from two perspectives: (a) design of the study and (b) content of the intervention. We found a very high variability in both approaches. Our

[3] A review on the variability within Tai Chi practice could investigate the hypothesis of the study, styles, and forms researched, the intensity of the program, the methodology of teaching, or the reaction of the participants, for example.

aim was to provide an example of how Tai Chi interventions have been conducted. We intended to explore whether the variable concept behind the name Tai Chi has in turn led to a variable interventional implementation. The answer to this question is rather simple: yes.

In conclusion, we show that two interventions that are referred to as Tai Chi are not necessarily the same. In addition to the multitude of directions that Tai Chi research has followed, the way the interventions were conducted may have been (and might prospectively be) just as manifold. This poses distinct challenges to the generalizability and reproducibility of the studies' results. The problem of variability is discussed in the current literature under the term "complex interventions," which is explored in the following section.

## Dealing with complex interventions

Complexity is a phenomenon encountered in the fields of behavioral science and health-care research. The challenges complexity poses to scientific analysis of change induction remain highly debated. The primary aim of the following summary is to provide an overview of this discussion. In particular, the intention is to clarify the meaning behind the terms *complexity*, *complex intervention, complex system, as well as whole-system research* and to highlight the challenges presented by these terms.

### What makes complex interventions complex?

The key feature of complex interventions is their multiple, interacting components (Dieppe, Macintyre, Michie, Nazareth & Petticrew, 2008). In the effort to systematically describe the properties of complex interventions, researchers adopted concepts from the field of systems theory and complexity science (Heng, 2008; Rickles, 2009). Repeatedly, the term *complex intervention* has been used along with the terms *complex systems* and *whole-systems research* (Heng, 2008; Paterson, Baarts, Launsø & Verhoef, 2009; Walach, Falkenberg, Fønnebø, Lewith & Jonas, 2006).

The components of an intervention were characterized with respect to the following properties: *contribution* to the intervention's success, place in the *causal pathways*, *dynamics and interaction*. In their definition, the Medical Research Council emphasized the *contribution* these components make to the intervention's success: Complex interventions comprise

"a number of separate elements which seem essential to the proper functioning of the intervention although the 'active ingredient' of the intervention that is effective is difficult to specify. […] The greater the difficulty in defining precisely what, exactly, are the 'active ingredients' of an intervention and how they relate to each other, the greater the likelihood that you are dealing with a complex intervention." *(Medical Research Council, 2000, p. 1)*

A closer look at the *causal pathway* allows for the differentiation of two distinct qualities of exerting influence: namely, *mediation* and *moderation* of variables or treatment effects. "The term 'mediator' is commonly used for a variable on a causal pathway, and 'moderator' for a variable which modifies the strength of part or all of a causal pathway" (Emsley, Dunn & White, 2010, p. 238). Rickles (2009, pp. 81–82) distinguished *simple causal chains* from *complex causal chains*: Within simple causal chains the effect is so great that no variable is strong enough to change the outcome (e.g., death following a direct shot in the heart). In other words, the causation in simple causal chains is *robust* and *insensitive* to context, whereas within complex causal chains, the effect can be influenced by several cofactors (e.g., death following smoking cigarettes). The causation in complex causal chains is *fragile* and *sensitive* to context.

Blackwood (2006, p. 619) pointed out the *dynamic properties* that are inherent in the components, distinguishing between *constant* components and *variable* components: "Constant components are the components defining the functions (what needs to be done), and the form of these can be adapted to suit the particular context (how it is to be done). Variable components are those which are contextual and intangible." He argued that these need to be identified and operationalized before conducting a definite trial "in order to determine whether the effectiveness of the intervention is due to the measured features of the intervention (constant components) or distinctive features of the site, staff or their interactions (variable components)" (Blackwood, 2006, p. 619).

The *interaction* between the intervention's components is characterized by the differentiation of several dimensions, including interactions, behaviors, group/organizational levels, variability, and flexibility permitted (Dieppe et al., 2008). Shiell, Hawe and Gold (2008) suggested differentiating between complex interventions and interventions into complex systems. According to Shiell et al. (2008, p. 1282), the characteristics of complex systems include: "the tendency to be self-organizing, be sensitive to initial conditions, […] make non-linear phase transitions […]; the existence of emergent properties; […] the importance of interaction effects and feedback" (Rickles, Hawe & Shiell, 2007).

The key question raised in the discussion of complex interventions is how complexity fits into well-established research standards, such as RCTs, and the underlying quest for causal inferences about the intervention strategy (Rickles, 2009; Ritenbaugh, Aickin, Bradley, Caspi, Grimsgaard & Musial, 2010; Verhoef, Lewith, Ritenbaugh, Boon, Fleishman & Leis, 2005). "There is considerable agreement that the classical pharmacological RCT model alone is not sufficient. Yet there does not seem to be universal agreement on what should be done instead" (Boon et al., 2007, p. 283). In this context, the term *whole-system research* was introduced, primarily in the field of studying complementary alternative medicine. According to Ritenbaugh et al. (2010, p. 131), the term *whole-system research* evolved from the attempt to grasp and analyze the mechanisms of holistic health-care approaches, intending to gain "a more holistic idea of the magnitude of impact of these interventions and how they worked," which is difficult to accomplish solely via RCTs.

In the scientific discussion about complexity in health care, several ideas and guidelines about the development, evaluation, and implementation of complex interventions have been published and discussed (Blackwood, 2006; Campbell et al., 2000; Dieppe et al., 2008; Boon et al., 2007).

## What problems evolve from complexity?

The main problem complexity confronts us with is its inherent difficulty to be described, analyzed, understood, and predicted. A key question in this discussion is the applicability of RCTs in evaluating the phenomenon of complexity. RCTs were designed with the intention of eliminating sources of bias within trials in order to allow for causal inferences. Since the RCT is ranked highest on the pyramid of the evidence system (only topped by meta-analysis of RCTs), it has become the gold standard of evaluating medical treatment approaches.

"For the author it is clear that the evidence-based approach has changed the way we do things, not least because every politician now has to slide the phrase 'evidence based' into any policy proposal, but it is much easier to show a direct effect in acute pain than it is in palliative care." *(McQuay, 2011, p. 396)*

As implied by the last clause of this quotation, the evaluation of pharmacological treatments has repeatedly been used as a counterexample in the discussion on the fit between RCTs and complex interventions (Paterson et al., 2009; Shiell et al., 2008; Verhoef et al., 2005; Walach et al., 2006). In a round table discussion on methodological challenges in whole-systems research, Elder et al. (2006, p. 843) emphasized a possible consequence of this exclusionary focus on RCTs: "My impression is that some people who publish in early phase research are trying to make their research look like a phase III randomized clinical trial."

The process of randomization by itself, however, does not necessarily eradicate all sources of bias, allowing for causal conclusions and direct transfer into practice. The basic assumptions and objectives of conducting an RCT should be kept in mind. According to Walach et al. (2006), these assumptions include: (1) It is not known which of the alternative treatments is better. (2) Patient and provider are indifferent to the choice of treatment (equipoise). (3) The goal is to identify specific effects. (4) The goal is to determine a stable effect size independent of context (efficacy). (5) The finding of efficacy in an RCT is readily transferable into clinical practice (effectiveness), if the inclusion and exclusion criteria match the characteristics of a given patient. In their article, Walach et al. (2006, p. 2) drew the conclusion that "all of these assumptions are problematic and sometimes false in complex interventions" and suggested that while being "useful for the evaluation of new pharmacological agents […] even in that situation often only some of the assumptions are met." A significant consequence is the decline in generalizability (external validity).

*Firstly*, the multitude of interacting components found in more complex interventions impedes true *equipoise* prior to the trial (Walach et al., 2006). *Secondly*, the *beliefs, expectations, and preferences* of patients and providers can play an important role in modulating treatment effects. If a trial does not account for this component of an intervention, it cannot provide an accurate estimation of treatment effects in clinical practice (Walach et al., 2006). *Thirdly*, the postulation of a *controlled environment and process* with the aim of increasing internal validity results in a limitation of external validity (Walach et al., 2006). In particular, the standardization of complex interventions may not only be hard to achieve but also compromise the therapeutic process under scrutiny (Bird, Arthur & Cox, 2011; Carter, 2003). *Fourthly*, in an RCT, the inference of the *specific efficacy* of a particular treatment is made upon the comparison with a placebo that is known to have no specific effect (e.g., a sugar pill). However, this procedure cannot simply be transferred to a complex intervention. A complex sham treatment would be necessary, whose inefficacy might be just as hard to prove as the efficacy of the complex intervention under investigation. If no evidence exists on the amount of efficacy of a control treatment, the efficacy measured for the verum treatment can only be understood as *relative efficacy* (EU High Level Pharmaceutical Forum, 2008).

Moreover, the *unspecific effects* evolving from the context of an intervention can be much stronger than the specific effects ascribed to a treatment (Walach et al., 2006). In particular constellations of specific and unspecific effects, the results of RCTs can lead researchers to wrong conclusions about the true impact of a treatment. Walach et al. (2006, pp. 3–4) referred to this constellation as the "*efficacy paradox,*" presenting several examples to explain the phenomenon.

## How could we solve these problems?

In an effort to clarify the property of *complex* matters, the term *simple* is suggested as counterpart, e.g., pharmaceutical treatment versus a rehabilitation program (Paterson et al., 2009). However, objections were raised, stating that these simple matters may also become complex at a closer look (Petticrew, 2011). Glouberman and Zimmerman (2002) distinguished three attributes to a problem: simple, complicated, and complex. In summary, from simple to complicated to complex, there is an increase in the effort necessary for understanding, a decrease in the level of control, as well as a decrease in predictability of the outcome in relation to the input. Prediction of the outcome depending on the input is a key question in the analysis of complex systems. In the effort of learning how a complex system works, what role its elements play in the process, and how it can be manipulated, it is essential to search for universal laws and phenomena (Bar-Yam, 2003).

The question on ways of increasing external validity remains debated: On the one hand, suggestions were made to include alternative trial designs, such as case studies (n −1 trials) and pragmatic[4] trials (Ritenbaugh et al., 2010, Verhoef et al., 2005). A well-structured, thorough review on the issue of preferences within RCTs was conducted by King et al. (2005). Observational studies are a valuable alternative to RCTs in case of strong preferences, ethical objections, or if the analysis includes known confounders of treatment outcome—such as strength of pref-

[4] Pragmatic trials aim to better reflect clinical practice in real life than standardized explanatory trials are able to and they allow for individualized treatment approaches.

erence (King et al., 2005). A way of tracking the potential influence of the *process and context* on the results/outcomes of a trial could be a qualitative arm embedded in the study. On the other hand, the information value of systematic reviews on complex interventions was put up for discussion, asking whether these designs really lead to a better understanding of the evidence at hand and suggesting to rely on the whole bandwidth of evidence creating designs while simultaneously increasing the quality of theory development, planning, conducting, and reporting of complex interventions (Mühlhauser, Lenz & Meyer, 2011).

A helpful comment on the discussion about complexity in health-care research was made by Petticrew (2011). He suggested changing our view of complexity as an *inherent property of a problem* to complexity as *our perspective on the problem*, emphasizing that it can be helpful to treat complex problems "as simple, in order to answer appropriately simple questions" (p. 397). Depending on the question asked, the solution may be more difficult or less difficult to find and might even turn out differently for different perspectives (Petticrew, 2011). A rather simple perspective may be the view of an economist, comparing "the value of what goes in (the resources) with what comes out (the outcomes)," as described by Shiell et al. (2008, p. 1282). Whereas a rather complex question may be posed at the individual level: "What works for whom, in what circumstances, in what respects, and how" (Paterson et al., 2009, p. 7). The question should clarify the goal of the investigation and allow for a discussion about the choice of methods necessary to find a solution.

The bridge between efficacy and effectiveness cannot be built via RCTs. If an intervention works in real life it needs to be evaluated with designs of a higher external validity than RCTs. Patsopoulos (2011, p. 223) recommended sensitizing stakeholders in health care to the "'pragmatic' concept." Simultaneously, he warns that this approach should not be achieved at the expense of experimental trials, because depending on our research question "we need them both" (p. 223). Walach et al. (2006) advocate a circular view of evidence synthesis to replace the traditional hierarchy, indicating that internal validity and external validity need to be balanced by the use of a variety of study designs, which cannot be achieved solely by RCTs. "The important point is not whether a study is randomized or not, but whether it uses a method well suited to answer a question and whether it implements this method with optimal scientific rigor" (Walach et al., 2006, p. 5).

## Conclusion

The discussion about complexity is entangled with the discussion about the limitations of RCTs.[5] This might be because an RCT asks simple questions, even about complex problems. If the perspective and the research question are more complex, different study designs might be better suited than the RCT; however, these designs will not simultaneously be able to give the same answers as RCTs could. Thus, researchers need to choose from which perspective they want to approach their problem. Helpful in this undertaking will be the quality and completeness of previously conducted research and reported data available (Elder et al., 2006; Institut für Qualität und Wirtschaftlichkeit im Gesundheitswesen (IQWiG), 2011; Mühlhauser et al., 2011).

In summary, Tai Chi research may have been studied from a too-simple perspective. In the attempt to gain further information on how to repeat therapeutic effects and on the way Tai Chi works, a more complex perspective is needed. The properties ascribed to complex interventions could also apply to a Tai Chi intervention and could guide the attempt of achieving a more specified and detailed description of the intervention. The problems arising from a complex perspective may then also apply to Tai Chi research. The following section discusses the appropriate requirements.

## Discussion: researching Tai Chi in health care—the challenge of a complex intervention

Tai Chi is an elusive concept with a long history. It is profoundly rooted in philosophic principles and has developed to a variety of styles and teaching traditions with a broad target group. Behind the rather simple name Tai Chi, we found a highly variable and still evolving art of movement. Research on Tai Chi has been conducted in a variety of directions, including health deficits, health benefits, target groups, and outcome domains. Despite the growing body of evidence, no firm conclusions have been drawn. The challenge of processing the information available on Tai Chi research may result from the complexity inherent in Tai Chi. Against this background, we examined the content and methodology of studies on Tai Chi as a sport in health care.

In summary, there is a need for an increasing awareness of the variability and complexity inherent in Tai Chi. The main consequence of this awareness should be the amelioration of the quality of reporting. A better description of the intervention's content could be the first step toward exploring cause–effect relationships. Knowledge of this field could contribute to the generation of recommendations and a systematic implementation of Tai Chi in health care. In order to achieve a systematic description of Tai Chi interventions, there is a need for further methodological research in this direction. Lessons learnt from complexity science in health care could guide the attempt to systematically describe the intervention's content. Additionally, they could contribute to the choice of adequate research questions and trial designs.

In the following section, we provide a complex perspective on the description and scientific analysis of Tai Chi as a sport in health care, transferring the challenges of complex interventions (as defined in Sect. 4) to Tai Chi interventions. The key feature of a *complex intervention* is the composition of *multiple, interacting*

[5] The goal of the summary was to clarify the problems that are addressed with the term complex intervention. Since the limitations of RCTs are tightly connected to the discussion on complexity within healthcare interventions, they form a major part of this summary. As our overview is oriented toward the challenges of complexity, we refrained from summarizing the importance of RCTs for inferential conclusions. We affirm that this section is not intended to question the legitimation and importance of RCTs in general.

*elements*. Wayne and Kaptchuk (2008a) identified the following eight components as an integral part of Tai Chi interventions, providing a detailed description in their manuscript: (1) musculoskeletal strength, flexibility, efficiency, (2) breathing, (3) concentration, attention, mindfulness, (4) imagery, visualization, intention, (5) physical touch, massage, subtle energy, (6) psychosocial interactions, (7) alternative health paradigm, philosophy, spirituality, (8) ritual, icons, environmental effects. These components may differ in emphasis and synergetic interaction depending on the curriculum as well as on the experiences of the Tai Chi instructor and the participants. Many of the components are inseparable and their contribution may change over the duration of practice (Wayne & Kaptchuk, 2008b). The variability of elements and their interactions impedes the allocation of therapeutic effects to the activity of distinct components. This difficulty to pinpoint the components' contribution to the intervention's success characterizes Tai Chi as a complex intervention.

In the attempt to *systematically describe* a Tai Chi intervention, the properties ascribed to the components of complex interventions may be suitable. *Firstly, the dynamic properties* of elements included should be considered. *Constant components* may be those included in the curriculum. They may comprise the number of postures, style, key principles of Tai Chi, key principles of philosophy, breathing techniques, rituals, partner exercises, auxiliary exercises, length and frequency of classes, as well as the length and setting of the intervention. *Variable components* may be the instructor's experience, level of individual progression offered, evolving group dynamics, social interactions, instructor—participant relationship, meaning of the intervention to the participants and to the instructor. In this context, the differentiation between physical presence (*clock time*) and *effective practice time* was suggested, since awareness is a key component in Tai Chi practice (Wayne & Kaptchuk, 2008b).

*Secondly, the interactive properties* of the elements included should be considered. A thorough description may be impossible to achieve, yet there are some anchors that could guide the attempt. A factor influencing the interactive properties could be the level of flexibility permitted. A description might include further information on the intervention's components. It could be estimated to what extent they are actively supported, tolerated, or impeded by the instructor. Addressing *psychosocial interactions* as an example: Were efforts taken to adapt the postures taught to the abilities of the participants? Was individual progression supported? Did the teacher primarily rely on verbal or nonverbal instruction? Were emergent group dynamics particularly favored and supported (e.g., in order to increase social support)? Did the instructor support the transfer of Tai Chi principles to everyday life? Were feelings of achievement and success particularly supported (e.g., in order to increase self-efficacy)? Was the original martial art character of Tai Chi referred to/passed on? Were participants encouraged to reflect and discuss their experiences during the intervention?

*Thirdly, the components' place on the causal pathways* should be considered. A systematic description of the Tai Chi intervention could help to strengthen theories and knowledge about how Tai Chi works. It may help to identify whether particular elements of Tai Chi practice exert influence in a mediating or a moderating way. As an example, the causal connection between Tai Chi practice and balance improvement/falls prevention could be explored. It may be hypothesized that Tai Chi practice can improve balance and reduce the rate of falls in the elderly. It may also be hypothesized that three mediators are located in this causal pathway: strength of lower limbs, coordination, and self-efficacy. In other words, Tai Chi practice may increase the strength of the lower limbs, coordination, and self-efficacy, leading to improved balance. A component of Tai Chi that can moderate the extent to which strength of lower limbs is increased may be the selection of postures included. A component of Tai Chi that can moderate the improvements in coordination may be the extent to which these postures are carried out in different directions. Moreover, improvement in coordination could also be moderated by the level of awareness attributed to the motion. A component of Tai Chi that can moderate the increase in self-efficacy may be the experience of personal mastery. This could be the mastery of postures with single-leg stances. It could also be the mastery of fluently imitating the motion of the instructor or the mastery of learning a Tai Chi form by heart. Components of the Tai Chi program that could moderate the extent of improvements in all three variables may be the dose of Tai Chi, namely, duration and frequency of classes as well as the length of the intervention. However, the dose necessary to achieve significant improvements may vary between these variables. For example, improvement of self-efficacy may be achievable within only a few weeks of practice, while improvement in coordination may take more than a few months.

Besides the challenge of systematically describing the intervention, complexity poses distinct challenges to the scientific analysis of Tai Chi. In the attempt to identify causal connections about the therapeutic potential of Tai Chi practice, the suitability of well-established trial designs should be reconsidered with respect to the research question. Wayne and Kaptchuk (2008b) acknowledged that none of the established research methods is suitable for addressing all the relevant aspects of evidence at once, emphasizing the necessity of a pluralistic approach to generate evidence. They suggested that RCTs should be used in combination with expectancy measures. This suggestion is based on the Tai Chi principle of attributing meaning to the practice of Tai Chi. In this context, Wayne and Kaptchuk (2008a) pointed out that some components of Tai Chi, such as teacher–student interaction, attention, and belief, are an integral part of Tai Chi practice and should thus be treated as specific effects of the intervention. Furthermore, they addressed the choice of the control group. They explained that the interaction of several possibly active components makes it practically impossible to compose a valid form of sham Tai Chi as a placebo control. Apart from RCTs, they proposed and discussed the following designs: pragmatic trials, preference trials, as well as outcome studies, observational studies, and cross-sectional studies. Moreover, Wayne and Kaptchuk (2008b) suggested resorting to simple Tai Chi curricula, pointing out that these are easier to be described, implemented, and replicated. However, as mentioned in Sect. 3, it was clarified that these simplifications may compromise the Tai Chi character of the intervention (Jahnke et al., 2010). Qualitative research was suggested to be included along with quantitative research in an explorative way (Wayne & Kaptchuk, 2008b). In this context, the properties of the interventions components should be addressed (dynamics, interaction, and place in causal pathways).

Taken together, these findings show that a complex perspective in researching Tai Chi as a sport in health care is a challenge. However, to some extent it is a necessary precondition in order to allow for the interpretation, generalization, repetition, and implementation of promising results achieved. To prevent getting lost in complexity, it is essential to keep reflecting on one's own perspective and on the research question. The inclusion of a qualitative study arm and thorough reporting of the methodology and the Tai Chi intervention itself could help to increase comparability and to provide a solid basis for future research attempts.[6] Moreover, researching in this direction may help to formulate theories and increase our understanding of how Tai Chi works. This understanding could be used to provide clear recommendations on which way of practicing Tai Chi is likely to unfold which potential.

The following limitations should be taken into consideration. First, Sect. 2 is mainly based on a single monograph (Landmann, 2005). We did not include further literature on the history and concept of Tai Chi, as we estimate the source cited to be the most elaborate hermeneutic study of ancient documents on Tai Chi available in English or German. Secondly, our exploration of research on Tai Chi was restricted to one database, allowing only a limited view of the data available. Additionally, our analysis of seven original research articles on Tai Chi was partially based on a subjective choice. This approach was necessary because of the poor description of Tai Chi interventions in many of the articles. Thirdly, the summary of the discussion on complexity in health-care interventions (Sect. 3) was not guided by a predefined systematic search of the literature. Instead, we conducted an exploratory analysis guided by the aim of elaborating on the problems addressed in this debate. Fourth, we based the discussion of complexity within Tai Chi research (Sect. 5) on our elaborations on complexity in health-care interventions, presenting a limited set of examples. Further research is required to improve detailed reporting and the generation of a hypothesis on cause–effect relationships in future Tai Chi research.

6 The article "Tai chi and postural stability in patients with Parkinson's disease" by Li, Harmer and Fitzgerald (2012) may serve as guidance for thorough planning and reporting.

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RESEARCH ARTICLE Open Access

# Mindfulness-based interventions in multiple sclerosis: beneficial effects of Tai Chi on balance, coordination, fatigue and depression

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## Abstract

**Background:** Patients suffering from Multiple Sclerosis (MS) experience a wide array of symptoms, including balance problems, mobility impairment, fatigue and depression. Physical exercise has recently been acknowledged as a treatment option complementary to medication. However, information regarding putative effects of structured exercise programs on neurological symptoms is sparse. Tai Chi, a Chinese martial art incorporating physical exercise and mindfulness training, has been shown to yield health benefits in various neurological groups. It seems particularly suitable for patients with motoric deficits as it challenges coordination and balance. The purpose of the current study was to explore the therapeutic value of structured Tai Chi training for coordination, balance, fatigue and depression in mildly disabled MS patients.

**Methods:** A sample of 32 MS patients (Expanded Disability Status Scale, EDSS < 5) was examined. A structured Tai Chi course was devised and a Tai Chi group participated in two weekly sessions of 90 minutes duration for six months, while a comparison group received treatment as usual (TAU). Both groups were examined prior to and following the six-months interval with regards to balance and coordination performance as well as measures of fatigue, depression and life satisfaction.

**Results:** Following the intervention, the Tai Chi group showed significant, consistent improvements in balance, coordination, and depression, relative to the TAU group (range of effect-sizes: partial $\eta^2 = 0.16 – 0.20$). Additionally, life satisfaction improved (partial $\eta^2 = 0.31$). Fatigue deteriorated in the comparison group, whereas it remained relatively stable in the Tai Chi group (partial $\eta^2 = 0.24$).

**Conclusions:** The consistent pattern of results confirms that Tai Chi holds therapeutic potential for MS patients. Further research is needed to determine underlying working mechanisms, and to verify the results in a larger sample and different MS subgroups.

**Keywords:** Multiple Sclerosis, Tai Chi, Mindfulness, Balance, Depression

## Background

Multiple Sclerosis (MS) is the most common neurologic disease of young adults [1]. It is characterized by chronic inflammatory processes affecting the central nervous system, causing neurodegeneration and axonal damage [2]. While the early phase of the disease involves temporary neurologic dysfunctions, the disease course leads to progressive accumulation of disability. In this context, patients suffering from MS may experience a wide array of symptoms, including balance problems, mobility impairment, fatigue and depression [2,3]. Common medical treatment comprises basic immune-modulating medication, cortisol therapy to counter active inflammation during relapses, as well as symptomatic therapy [4].

### Physical therapy for multiple sclerosis

Physical exercise has recently been acknowledged as an essential part of MS therapy [5]. This represents an important extension of treatment options, since traditionally MS patients had been advised not to engage in

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physical activity [6]. There is a growing body of evidence which suggests that exercise is beneficial for MS patients in various domains including muscular strength and aerobic capacity, mobility, mood, fatigue and health-related quality of life [4,7–10]. Additionally, physical exercise may yield potentially adaptive immune-modulating effects [11,12]. Recent findings also suggest that repeated physical exercise may foster neuroplasticity, affecting neurotrophic and neuroprotective mechanisms [13]. However, most MS patients remain physically inactive and information regarding choice, dose and effects of specific exercise programs is sparse [9]. Ellis et al. [14] suggest the inclusion of behavioral interventions into standard MS management, and propose a shift from a rehabilitative model to a preventive approach of physical therapy (for comparison see also Motl et al. [15]). As there is considerable inter-individual variation in the course of symptoms in MS, individually tailored exercise programs may be regarded as most appropriate.

### Mindfulness and its clinical applications

Recently, such programs have successfully been implemented in combination with mindfulness based interventions (for recent review see Simpson et al. [16]). The term mindfulness is rooted in Buddhist philosophy [17]. Its key element is the attempt to focus on the present moment experience while maintaining and open, non-judgemental attitude [18,19]. Mindfulness has repeatedly been incorporated into secular clinical interventions. In this context, mindfulness training was shown to yield beneficial effects in a variety of conditions including chronic pain, fibromyalgia, psoriasis, as well as depressive and eating disorders, and to attenuate maladaptive cognitive patterns [20–26]. Further studies indicate that mindfulness training may yield adaptive neurophysiologic effects, including altered immune functioning [27–29].

While the exact working mechanisms of mindfulness continue to be explored, integrative models have been devised. In their two-component model of mindfulness, Bishop et al. [30] defined an attentional and a motivational component. A conceptual outline of this model is provided in Figure 1. According to the authors, self-regulated attention involves focusing on experience in the here and now. The resulting ability to sustain attention and switch its focus intentionally is assumed to enable non-elaborative awareness. The latter is characterized by observing, acknowledging and releasing arising thoughts, sensations and emotions without further, secondary cognitive elaboration. Since attentional resources are limited, non-elaborative awareness increases access to information on current experience, as attentional capacity is not allocated to further elaborative processing [31]. In mindfulness exercises, commonly the breath is used as an object of orientation to return back to the present moment experience.

The second component, orientation to experience, implies a curious and accepting attitude towards the stream of consciousness (*beginner's mind*, *see* Bishop et al. [30]). This observant, non-judging perspective and the open receptivity to new experience are assumed to reduce avoidant behavior patterns [29]. In this context, particularly the familiarisation with distressing emotions is believed to increase affect tolerance. Moreover, body awareness and emotional awareness are fostered.

### Tai Chi training and mindfulness

To date, there are only few structured interventions which incorporate both, physical and mindfulness exercises for MS patients. Grossman et al. [32] implemented a structured eight-week mindfulness-based intervention including Yoga exercises and observed improved quality of life, as well as depression and fatigue. Complementary to such pioneering work, we suggest that Tai Chi may be particularly suited to integrate physical and mindfulness training in MS. Tai Chi is a Chinese martial art, representing a multicomponent intervention, addressing musculoskeletal strength, flexibility, and mindfulness [33,34].

It should be noted that the concept of mindfulness is compatible with contents of Tai Chi practice. As illustrated in Figure 1, its first component, regulation of attention, is addressed by Tai Chi practice, as Tai Chi involves purposeful direction of attention. Attention needs to be directed during the process of imitating a choreography (called *form*) as demonstrated by the instructor. To this end, it is necessary to constantly switch attention between exteroception (observing the instructor and the own body) and interoception (bodily sensations involving proprioception, balance, breathing). During exercises, attention is also directed at the Tai Chi principles (see Additional file 1: Supplement 1), which require a high amount of resources and receptivity to interoceptive information, fostering body awareness.

The second component of mindfulness is addressed as Tai Chi training implies the maintenance of a curious and open attitude. The perpetual aim in Tai Chi practice is a friendly attitude towards oneself and others, respecting the own person and the own abilities, without judgement or competition (see Additional file 1: Supplement 1). Non-elaborative awareness is a prerequisite to stay on track while playing the form. During this process, personal boundaries such as limits of stability, flexibility and endurance, as well as habits to cope with these limitations are explored, fostering body awareness. Emotional awareness is developed by consciously observing and accepting arising emotions during Tai Chi practice (e.g. fear of embarrassment, fear of falling, self-criticism, motivational issues).

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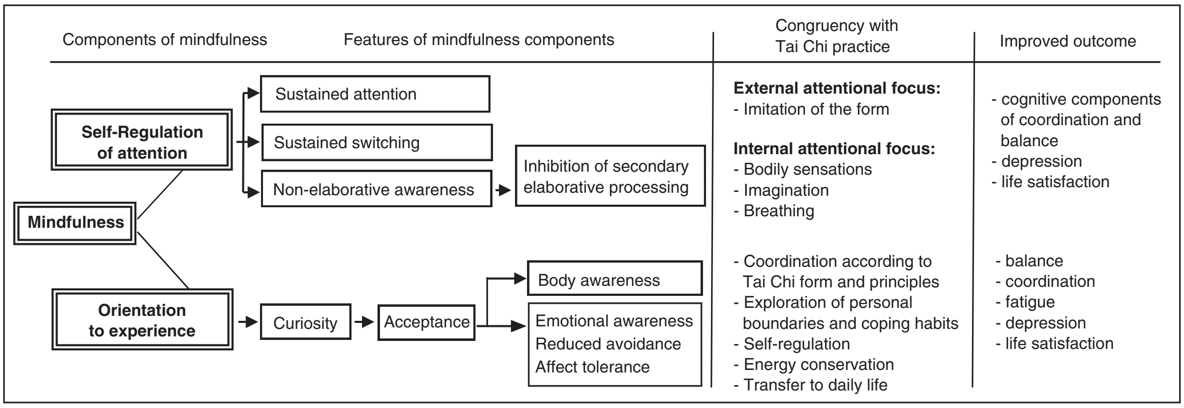


**Figure 1 Conceptual outline of the two-component model of mindfulness, adapted from Bishop et al. (2004) and its relevance for Tai Chi practice.**

### Purpose of the current work: structured Tai Chi training for MS patients

Tai Chi has been shown to yield health benefits in various neurological groups, including Parkinson's Disease [35], Fibromyalgia [36], chronic stroke [37], and peripheral neuropathy [38]. Currently there are three studies available on Tai Chi and MS. Husted et al. [39] reported improvements in walking distance, hamstring flexibility and psychological well-being, following a Tai Chi intervention. Mills et al. [40,41] observed improvements in balance and symptom management. Finally, Tavee et al. [42] reported improvements in perceived physical and mental health, as well as pain, but not in mobility.

In the indicated studies, the intervention duration did not exceed 2 months. This is noteworthy, since the benefits of Tai Chi practice are believed to increase with time [43]. As a consequence, short intervention periods could lead to an underestimation of the full potential of Tai Chi [43]. Compatible with this assumption, recent findings suggest that the effect of mindfulness training on cognitive control and its underlying neural mechanisms is modulated by practice adherence [44].

For the current study, a standardized Tai Chi program was designed, details of which are made available to other research groups (Additional file 1: Supplement 1). The purpose of this standardized intervention was to provide a basis for a structured empirical evaluation of putative effects of Tai Chi in MS.

The goal of the current study was to explore the effects of this intervention program on balance, fatigue, depression and quality of life in mildly disabled MS patients. Furthermore, the intention was to examine the safety and feasibility of this intervention for MS patients.

## Methods

### Study design and participants

The study was designed as a two-arm trial to examine the effects of a six-month mindfulness-based Tai Chi intervention versus treatment as usual (TAU). It was approved by the ethics committee of the Bavarian Medical Association, Germany, and all participants provided written informed consent. Participants were recruited from the Department of Neurology, Klinikum Bayreuth. Invitations were given orally or via mail to patients who were or had been in out-patient care. Additionally, study invitations were distributed via local support groups. Information about clinical characteristics was extracted from patients' files held by the Department of Neurology. Inclusion criteria were a diagnosis of any MS type, being able to walk without a walking aid, an Expanded Disability Status Scale (EDSS) score < 5, and being relapse-free for the past four weeks. Severe cognitive impairment which would interfere with the ability to take part in weekly Tai Chi classes was ruled out, based on reports of the neurological examinations in patients' files.

Between December 2010 and November 2011, the files of a total of 400 MS patients were screened for eligibility criteria. Since the site of the study (Klinikum Bayreuth) is located in a rural area of Germany, a substantial portion of these candidates (approximately 250) were discarded beforehand due to the distance of their home to the study site, which made a weekly appearance impossible. Out of the remaining candidates, 38 met inclusion criteria and were willing to participate in the study. Outcome measures were assessed during a patient visit at baseline and following an interval of six months. In this context, all patients participated in assessments addressing balance, fatigue, depression, and quality of life. Potential alterations in balance and coordination were defined as primary endpoints, alterations in fatigue, depression and quality of life as secondary endpoints of the study. During the six-months interval between pre (baseline) and post assessments, 15 patients received structured Tai Chi training (Tai Chi group), and 17 patients received treatment as usual (TAU group), i.e. they were instructed to consult their medical professionals as they usually would. In a pilot phase, implemented with the intention to raise awareness about the possibility to participate in Tai Chi courses in the study centre, members of the latter group had previously taken part in Tai Chi classes. However, during the six-months interval, members of this group did not participate in a structured intervention. Due to the length of the intervention and to enable patients to participate regularly, group assignment occurred based on patients' availability for the weekday on which the Tai Chi course took place.

Six Patients from the Tai Chi group withdrew from the study due to time issues (N = 5) and health problems (N = 1) and were lost to follow-up. Consequently a total of 32 patients was included in the final analysis (Tai Chi N = 15; TAU N = 17). As indicated in Table 1, there were no significant differences with regards to basic demographics between the Tai Chi group and the TAU group. Further, there were no clinical differences regarding MS course, disease duration and MS treatment.

**Table 1 Demographics, clinical information, health behavior**

| | TAU (n = 17) | | Tai Chi (n = 15) | | Statistic | p-value |
|---|---|---|---|---|---|---|
| **Demographics** | | | | | | |
| Age M (SD) | 43.6 | (8.0) | 42.6 | (9.4) | 0.32[a] | 0.753 |
| Female sex, n (%) | 12 | (71) | 10 | (67) | 0.06[b] | 0.811 |
| **Health Behavior** | | | | | | |
| Tobacco users, n (%) | 2 | (12) | 3 | (20) | 0.42[b] | 0.645 |
| Body Mass Index, M (SD) | 25.5 | (5.5) | 24.2 | (3.7) | 0.79[a] | 0.438 |
| Phys. activity/week, n (%) | | | | | | |
| < 1x | 6 | (35) | 2 | (13) | 0.17[b] | 0.338 |
| 1-2x | 6 | (35) | 8 | (53) | | |
| > 3x | 5 | (30) | 5 | (33) | | |
| **Clinical Information** | | | | | | |
| MS course, n (%) | | | | | | |
| Relapsing-remitting | 13 | (77) | 14 | (93) | 4.93[b] | 0.085 |
| Secondary progressive | 4 | (24) | 0 | (0) | | |
| Clinically isolated syndrome | 0 | (0) | 1 | (7) | | |
| MS Duration in years, M (SD) | 7.8 | (6.8) | 6.0 | (4.7) | 0.86[a] | 0.395 |
| MS treatment, n (%) | | | | | | |
| Yes | 16 | (94) | 12 | (80) | 0.45[b] | 0.228 |

[a]t-test.
[b]chi square test.
Note: M = mean, SD = standard deviation, TAU = treatment as usual.

However, the EDSS was elevated in the TAU group (range: 1–4.5, median = 4), relative to the Tai Chi group (range: 1–4, median = 2). Adherence varied between 15 and 44 (median = 30) attended classes out of 50 classes offered in total.

### Assessment of balance and coordination

An established balance test, comprising 14 tasks with an increasing level of difficulty, including both static and dynamic balance was utilized [45]. It included a series of one leg stances in different conditions as well as walking across a wooden board in different conditions (forwards, backwards, including turns). The test was previously shown to display sufficient metric qualities (test-retest reliability: r = .78, Chronbach's alpha = .92) [45]. In this context, its convergent validity was also shown referring to posturographic measures [45].

Additionally, a coordination test was implemented, comprising 10 tasks with an increasing level of difficulty [45]. As was the case for the balance test, the coordination test was previously shown to involve sufficient metric properties (test-retest reliability: r = .60, Chronbach's alpha = .72) [45].

In both tests, each task achieved equalled one point, accumulating to a maximum of 14 points in the balance test and 10 points in the coordination test. A detailed description of both tests is provided in Additional file 2: Supplement 2. To our knowledge, the tests have not been used in MS previously. However, they were developed for functional evaluation of patients during neurologic rehabilitation [45]. Since the tests were designed to cover a broad spectrum of ability/disability within ambulatory patients, they may be regarded as particularly suitable for MS patients with considerable variance in motoric deficits.

### Assessment of depression, fatigue and life satisfaction

Additionally, self-reports measures in the domains depression, fatigue and life satisfaction were included. For the assessment of depressive symptoms, a 15-item questionnaire was used (Allgemeine Depressionskala, ADS-K; English: Center for Epidemiological Studies Depression Scale, CES-D); [46]), which addresses the severity of depressive symptoms during the last two weeks. Items are rated on a scale from 0–3 and the sum of all items represents the depression parameter. Further, the Fatigue Scale of Motor and Cognitive Functions (FSMC [47]) was administered, which consists of 20 items, scored on a scale from 1–5, and accumulating to a maximum score of 80 points. The Questionnaire of Life Satisfaction (QLS [48]) consists of 6 domains, including health, finances, leisure time, self, sexuality and friends, comprising 7 items each, on a 1–7 rating scale, accumulating to a maximum score of 420 points.

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### Tai Chi intervention

A structured, compact Tai Chi program was developed based on the Yang-style 10-form (see Additional file 1: Supplement 1 for details and Martin [49] or Sinclair [50] for a video link). Exercises were structured so that during each session of the course, the same essential elements were repeated. The advantage of this design was that patients who missed out on an occasion could rejoin the training without difficulties. Further, continuously repeating the exercises may be regarded as supportive for a long-term learning process and automaticity, potentially fostering neuroplasticity [13]. The intervention was centre-based and did not include home assignments. The Tai Chi instructor was a highly trained exercise therapist with 4 years of Tai Chi experience. No classes were cancelled and no adverse events were noted.

Throughout the intervention period of six months, weekly sessions of 90 minutes duration took place. During the first month of the course, the Tai Chi form was played 4–5 times per session. A break of a few minutes during which participants could relax and ask questions occurred after each completion of the form. During the consecutive 5 months the form was played 6–8 times per session. In this case, breaks usually occurred after two completions of the form, respectively, albeit they were not always necessary or enforced. The increase in repetitions following the first month was attributable to arising automaticity. In context of the relation between Tai Chi training and mindfulness (Figure 1), this arising automaticity may be associated with an attentional shift from an external focus (imitating the form) to an internal focus (e.g. bodily sensations, breathing). On the occasion with the highest amount of repetitions without a break, 8 repetitions were completed. In general, the instructor organized the class with respect to the energy level and current capability of participants.

### Statistical analysis

Scores on all parameters were normally distributed according to Saphiro-Wilk tests (all $p$-values > 0.05). Differences in outcome parameters between the Tai Chi group and the TAU group were assessed by a two-way repeated measures ANOVA with the within-subjects factor Time (pre vs. post) and the between-subjects factor Group (Tai Chi vs. TAU), separately for each parameter. Post-hoc comparisons were conducted via Bonferroni-corrected two-sided t-tests.

To ensure systematic progression of variance across pre and post measures, in a secondary analysis, test-retest reliability was determined. To this end, Pearson correlations were computed for each test parameter between values obtained at pre and post assessments.

## Results

### Balance and coordination

In case of balance performance, a significant Time by Group interaction emerged [$F(1,30) = 5.70$, $p < 0.05$, partial $\eta^2 = 0.16$]. Post-hoc comparisons revealed that performance in the Tai Chi group improved, while it remained relatively stable in the TAU group (Figure 2a, Table 2). For coordination, there was a significant main effect of Time [$F(1,30) = 4.89$, $p < 0.05$, partial $\eta^2 = 0.14$] and a significant Time by Group interaction [$F(1,30) = 6.57$, $p < 0.05$, partial $\eta^2 = 0.18$]. Post-hoc comparisons indicated that the increase in coordination performance scores was significant in the Tai Chi group whereas scores remained relatively stable in the TAU group (Figure 2b, Table 2).

### Depression, fatigue and life-satisfaction

In case of depression, a significant main effect of Time [$F(1,27) = 6.61$, $p < 0.05$, partial $\eta^2 = 0.19$] and a significant Time by Group interaction emerged [$F(1,27) = 6.55$, $p < 0.05$, partial $\eta^2 = 0.20$]. Post-hoc comparisons revealed that depression scores significantly decreased in the Tai Chi group, whereas they remained relatively stable in the TAU group (Figure 2d, Table 2).

For Fatigue, a significant Time by Group interaction [$F(1,25) = 7.83$, $p = 0.01$, partial $\eta^2 = 0.24$] and a significant main effect of Group emerged [$F(1,25) = 5.91$, $p < 0.05$, partial $\eta^2 = 0.19$]. Post-hoc comparisons indicated a significant increase in fatigue scores in the TAU group from pre to post assessments. Scores in the Tai Chi group remained relatively stable. At pre-treatment assessments the groups did not differ significantly in fatigue. In contrast, fatigue differed following the six-months interval (Figure 2c, Table 2).

In case of life satisfaction, a significant Time by Group interaction [$F(1,24) = 8.64$, $p < 0.01$, partial $\eta^2 = 0.27$] and a significant main effect Group emerged [$F(1,24) = 8.64$, $p < 0.01$, partial $\eta^2 = 0.19$]. Post-hoc comparisons indicated a significant rise in the life-satisfaction score in the Tai Chi group relative to the TAU group. At pre-treatment assessments the groups did not differ significantly in life satisfaction. In contrast, life satisfaction differed following the six-months interval (Figure 2e, Table 2).

### Test-retest reliability

In consideration of the relatively small sample size, estimates of test-retest reliability were computed to derive information on the reliability of all implemented measures. This analysis was implemented separately for the Tai Chi and the TAU group, as well as for both groups combined, and tested whether the progression of variance of each parameter was systematic across assessments [51,52]. Test-retest reliability was reasonable

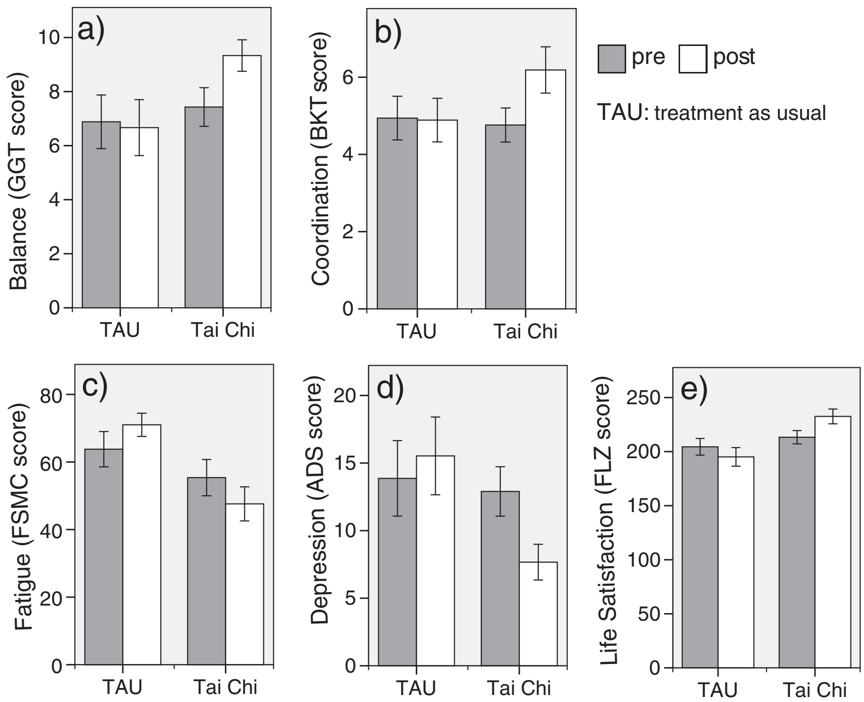


**Figure 2 Mean scores on outcome parameters compared between the Tai Chi and the TAU group.** Error bars represent standard errors. See Methods section for a detailed description and references of each test.

for each parameter in both groups (Table 3; range of Pearson r: .56 - .92).

## Discussion

Physical exercise has recently been acknowledged as an essential part of MS therapy [5]. However, information with regards to putative effects of structured exercise programs on neurological symptoms is sparse. Similarly, mindfulness training, which is known to be beneficial for various clinical groups [53,27], was suggested to increase quality of life in MS patients [54]. Nevertheless, to date the body of studies on this topic remains limited [16]. Previous work has indicated that Tai Chi, which incorporates a combination of physical exercises and mindfulness training, might yield health benefits in MS [16,39–42]. In the current study, the therapeutic value of a newly devised structured Tai Chi course (Additional file 1: Supplement 1) for coordination, balance, fatigue and depression in mildly disabled MS patients was examined.

The obtained results are in accordance with previous suggestions and extend the body of related literature [55,56,10,16,4]. During the Tai Chi intervention, objective parameters including balance and coordination (i.e. the primary study endpoints) as well as subjective measures of depression and life satisfaction (secondary endpoints) improved. In contrast, these measures were not altered in the TAU group. Additionally, a maintenance effect on fatigue was observed, as fatigue in the Tai Chi

**Table 2 Differences in mean scores on outcome parameters in the Tai Chi group and the TAU group**

| | TAU (N = 17) | | | | | Tai Chi (N = 15) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pre | | Post | | Statistic | Pre | | Post | | Statistic |
| | M | SD | M | SD | p | M | SD | M | SD | p |
| **Balance** | 6.88 | 4.09 | 6.53 | 4.49 | 0.439 | 8.00 | 2.83 | 9.33 | 2.26 | 0.031 |
| **Coordination** | 4.94 | 2.33 | 4.82 | 2.46 | 0.814 | 5.00 | 1.89 | 6.60 | 1.80 | 0.003 |
| **Fatigue** | 63.79 | 19.55 | 70.47 | 14.04 | 0.025 | 51.23 | 22.55 | 47.6 | 19.54 | 0.182 |
| **Depression** | 13.87 | 10.82 | 16.13 | 11.99 | 0.951 | 12.21 | 6.66 | 7.67 | 5.12 | 0.007 |
| **Lifesatisfaction** | 204.46 | 27.77 | 193.81 | 36.2 | 0.290 | 215.77 | 25.55 | 232.57 | 25.62 | 0.012 |

Note: M = mean; SD = standard deviation; TAU = treatment as usual.

**Table 3 Test-retest reliability**

| | Tai Chi & TAU | | Tai Chi | | TAU | |
|---|---|---|---|---|---|---|
| **Parameter** | **r** | **p** | **r** | **p** | **r** | **p** |
| **Balance** | 0.835 | 0.000 | 0.660 | 0.007 | 0.913 | 0.000 |
| **Coordination** | 0.573 | 0.001 | 0.565 | 0.028 | 0.642 | 0.005 |
| **Fatigue** | 0.877 | 0.000 | 0.917 | 0.000 | 0.878 | 0.000 |
| **Depression** | 0.822 | 0.000 | 0.653 | 0.011 | 0.936 | 0.000 |
| **Life satisfaction** | 0.697 | 0.000 | 0.660 | 0.014 | 0.757 | 0.003 |

Test-retest reliability as determined by Pearson correlations between values obtained at pre and post assessments (Tai Chi group N = 15, TAU group N = 17). See Methods section for a detailed description of each test parameter.

group remained relatively stable whereas it deteriorated in the TAU group. In sum, this consistent pattern of beneficial alterations in the examined outcome parameters provides support for the utility of structured Tai Chi training in the context of MS treatment. While the exact working mechanisms remain to be explored, the current findings allow the suggestion that Tai Chi enhances balance performance and coordination and may exert beneficial effects on mood and fatigue. Observed compliance rates indicated that the implemented Tai Chi form (10-form) was appropriate in the context of a structured intervention of six months duration. We recommend using the 10-form in future studies as it is a well-known standard form and provide extensive information on the intervention in Additional file 1: Supplement 1.

### Limitations and future directions

While our results extend the current literature on beneficial effects of mindfulness training and physical exercise in MS patients, they need to be interpreted in the context of several limitations. On the one hand, the length of the intervention made it necessary to ensure that a sufficient number of patients could participate in the Tai Chi course regularly. Therefore, assignment to Tai Chi and TAU groups occurred based on patients' weekday preference. The lack of formal random assignment is to be regarded as a major limitation of the current work. Moreover, group assignment based on patients' weekday preference represents a selection bias and may have been affected by patients' general motivation. In this context, it is also necessary to point out that while some of the clinical characteristics were similar in both groups (MS-subtype, disease duration, medical treatment), the EDSS score was higher in the TAU group than in the Tai Chi group. Despite its relatively broad classification system, the EDSS is a widely used and accepted tool for monitoring overall disease progression in MS patients [57]. Even though functional domains reflected by the EDSS are not congruent with all parameters implemented in the current work, it cannot be ruled out that the difference in EDSS scores of the two groups affected the obtained results. It also needs to be considered that only a small sample was examined and that the intervention and evaluation procedures were implemented by the same person (JB), involving a potential bias. Moreover, the dose of Tai Chi training was not recorded in detail. However, the total dose of Tai Chi cannot easily be measured as it depends on multiple components and personal commitment of the participants.

On the other hand, it is noteworthy that the pattern of beneficial effects was consistent across outcome variables and that patients' compliance was sufficient. Moreover, despite the small sample size and the relatively long intervention period of six months, test-retest reliability of all test parameters was sufficient. This is particularly important since the implemented tests were not instruments which are widely used in the MS literature. Consequently, it could be argued that they might have involved low validity in MS patients. Contradicting this assumption, the observation of sufficient test-retest reliability of all test parameters in the current work indicates that rank ordering of subjects' values in outcome parameters changed systematically during the six months period. Hence, the progression of variance was systematic and employed measures provided reliable information. We suggest that it is warranted for future studies to verify results of the current work using a randomized design, a larger sample and different MS subgroups. Such future studies may also include further comparison groups, besides TAU, especially in consideration of non-specific effects which might manifest in improved depression symptoms and quality of life due to social support, as well as self-efficacy.

Analyzing different components of Tai Chi interventions, such as motion, mindfulness and breathing, may help to form theories about underlying working mechanisms. In this context, the effects of Tai Chi training on neural plasticity with respect to motor and sensory abilities in MS patients seem worth investigating as recent findings showed alterations of cortical representations of interoceptive attention following mindfulness meditation [58]. Improved interoception may also enhance the quality of feedback loops during coordination, enhancing confidence and reliability of movement. Apart from this, it has been shown that breathing practices by themselves have beneficial autonomic regulatory effects [59]. This is of particular interest in stress-exacerbated diseases like MS, as it has been reported that stress management therapy seems to reduce inflammation and enhance neuroprotection [60]. Based on the working mechanisms of different components, possible interactions and synergetic effects need to be explored. This understanding might provide the opportunity of creating clear recommendations on which way of practicing Tai Chi is likely to unfold most beneficial effects [34].

## Conclusions

The Tai Chi 10-form is safe and feasible for a six-months intervention period with MS patients. Tai Chi may have beneficial effects on balance, coordination and psychological well-being in patients with MS.

## Additional files

**Additional file 1:** Supplement 1.

**Additional file 2:** Supplement 2.

**Competing interests**

The authors declare that they have no competing interests. The study was supported by Novartis Pharma GmbH. The corresponding author received an expense allowance for presenting the study on a symposium of Novartis Pharma GmbH. This publication was funded by the German Research Foundation (DFG) and the University of Bayreuth in the funding program Open Access Publishing.

**Authors' contributions**

JB conceived of the study, participated in its design, coordination and data acquisition, held all Tai Chi classes and drafted the manuscript. PKe performed the statistical analysis and helped to draft the manuscript. UH supported the patient recruitment and clinical assessments. PO participated in the design of the study, supervised the study and reviewed the manuscript. PKu participated in the design of the study, co-conceptualized and supervised the Tai Chi intervention and revised the manuscript. All authors read and approved the final manuscript.

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# Appendix

| Year | Authors | Title | Target group | Topic |
|---|---|---|---|---|
| 1998 | Kessenich, C. R. | Tai Chi as a method of fall prevention in the elderly | elders | intervention |
| 1998 | Ross, M. C.; Presswalla, J. L. | The therapeutic effects of Tai Chi for the elderly | elders | intervention |
| 1999 | Chen, K. M.; Snyder, M. | A research-based use of Tai Chi/movement therapy as a nursing intervention | nursing | intervention |
| 2000 | Lewis, D. E. | T'ai chi ch'uan | general | general |
| 2001 | Chen, K. M.; Snyder, M.; Krichbaum, K. | Clinical use of tai chi in elderly populations | elders | intervention |
| 2001 | Li, J. X.; Hong, Y.; Chan, K. M. | Tai chi: physiological characteristics and beneficial effects on health | cardiovascular | intervention |
| 2001 | Yalden, J.; Chung, L. | Tai Chi: towards an exercise program for the older person | elders | intervention |
| 2002 | Lan, Ching; Lai, Jin-Shin; Chen, Ssu-Yuan | Tai Chi Chuan: an ancient wisdom on exercise and health promotion | elders | intervention |
| 2002 | Wu, Ge | Evaluation of the effectiveness of Tai Chi for improving balance and preventing falls in the older population--a review | elders | intervention |
| 2003 | Taylor-Piliae, Ruth E. | Tai Chi as an adjunct to cardiac rehabilitation exercise training | cardiovascular | intervention |
| 2004 | Chu, Dennis A. | Tai Chi, Qi Gong and Reiki | methodology | research |
| 2004 | Han, A.; Robinson, V.; Judd, M.; Taixiang, W.; Wells, G.; Tugwell, P. | Tai chi for treating rheumatoid arthritis | rheumatic disease | intervention |
| 2004 | Klein, Penelope J.; Adams, William D. | Comprehensive therapeutic benefits of Taiji: a critical review | therapy | research |
| 2004 | Verhagen, Arianne P.; Immink, Monique; van der Meulen, Annemieke; Bierma-Zeinstra, Sita M. A. | The efficacy of Tai Chi Chuan in older adults: a systematic review | elders | intervention |
| 2004 | Wang, Chenchen; Collet, Jean Paul; Lau, Joseph | The effect of Tai Chi on health outcomes in patients with chronic conditions: a systematic review | chronic conditions | intervention |
| 2004 | Wayne, Peter M.; Krebs, David E.; Wolf, Steven L.; Gill-Body, Kathleen M.; Scarborough, Donna M.; McGibbon, Chris A.; Kaptchuk, Ted J.; Parker, Stephen W. | Can Tai Chi improve vestibulopathic postural control? | balance | intervention |

| Year | Authors | Title | Target group | Topic |
|---|---|---|---|---|
| **2005** | Wayne, Peter M.; Scarborough, Donna Moxley; Krebs, David E.; Parker, Stephen W.; Wolf, Steven L.; Asmundson, Lara; McGibbon, Chris A. | Tai Chi for vestibulopathic balance dysfunction: a case study | balance | intervention |
| **2006** | Adler, Patricia A.; Roberts, Beverly L. | The use of Tai Chi to improve health in older adults | elders | intervention |
| **2006** | Kuramoto, Alice M. | Therapeutic benefits of Tai Chi exercise: research review | therapy | research |
| **2006** | Mansky, Patrick; Sannes, Tim; Wallerstedt, Dawn; Ge, Adeline; Ryan, Mary; Johnson, Laura Lee; Chesney, Margaret; Gerber, Lynn | Tai chi chuan: mind-body practice or exercise intervention? Studying the benefit for cancer survivors | cancer | intervention |
| **2007** | Cheng, Tsung O. | Tai Chi: the Chinese ancient wisdom of an ideal exercise for cardiac patients | cardiovascular | intervention |
| **2007** | Hong, Youlian; Li, Jing Xian | Biomechanics of Tai Chi: a review | Biomechanics of Tai Chi | particular |
| **2007** | Lee, M. S.; Pittler, M. H.; Ernst, E. | Tai chi for rheumatoid arthritis: systematic review | rheumatic disease | intervention |
| **2007** | Lee, Myeong Soo; Pittler, Max H.; Ernst, Edzard | Is Tai Chi an effective adjunct in cancer care? A systematic review of controlled clinical trials | cancer | intervention |
| **2007** | Lee, Myeong Soo; Pittler, Max H.; Taylor-Piliae, Ruth E.; Ernst, Edzard | Tai chi for cardiovascular disease and its risk factors: a systematic review | cardiovascular | intervention |
| **2007** | Taylor-Piliae, Ruth E.; Haskell, William L. | Tai Chi exercise and stroke rehabilitation | cardiovascular | intervention |
| **2007** | Wayne, Peter M.; Kiel, Douglas P.; Krebs, David E.; Davis, Roger B.; Savetsky-German, Jacqueline; Connelly, Maureen; Buring, Julie E. | The effects of Tai Chi on bone mineral density in postmenopausal women: a systematic review | bone health | intervention |
| **2008** | Grodin, Michael A.; Piwowarczyk, Linda; Fulker, Derek; Bazazi, Alexander R.; Saper, Robert B. | Treating survivors of torture and refugee trauma: a preliminary case series using qigong and t'ai chi | torture, refugee trauma | intervention |
| **2008** | Harmer, Peter A.; Li, Fuzhong | Tai Chi and falls prevention in older people | elders | intervention |
| **2008** | Lan, Ching; Chen, Ssu-Yuan; Lai, Jin-Shin | The exercise intensity of Tai Chi Chuan | exercise intensity of Tai Chi | particular |
| **2008** | Lan, Ching; Chen, Ssu-Yuan; Wong, May-Kuen; Lai, Jin-Shin | Tai Chi training for patients with coronary heart disease | cardiovascular | intervention |

| Year | Authors | Title | Target group | Topic |
|---|---|---|---|---|
| 2008 | Lee, M. S.; Pittler, M. H.; Kim, M-S; Ernst, E. | Tai chi for Type 2 diabetes: a systematic review | diabetes | intervention |
| 2008 | Lee, M. S.; Pittler, M. H.; Shin, B-C; Ernst, E. | Tai chi for osteoporosis: a systematic review | bone health | intervention |
| 2008 | Lee, Myeong Soo; Lam, Paul; Ernst, Edzard | Effectiveness of tai chi for Parkinson's disease: a critical review | parkinsons | intervention |
| 2008 | Lee, Myeong Soo; Pittler, Max H.; Ernst, Edzard | Tai chi for osteoarthritis: a systematic review | bone health | intervention |
| 2008 | Lui, Pauline Po Yee; Qin, Ling; Chan, Kai Ming | Tai Chi Chuan exercises in enhancing bone mineral density in active seniors | bone health | intervention |
| 2008 | Thornton, Everard W. | Tai Chi exercise in improving cardiorespiratory capacity | aerobic capacity | intervention |
| 2008 | Wall, Robert B. | Teaching Tai Chi with mindfulness-based stress reduction to middle school children in the inner city: a review of the literature and approaches | stress reduction | intervention |
| 2008 | Wayne, Peter M.; Kaptchuk, Ted J. | Challenges inherent to t'ai chi research: part II-defining the intervention and optimal study design | methodology of Tai Chi research | research |
| 2008 | Wayne, Peter M.; Kaptchuk, Ted J. | Challenges inherent to t'ai chi research: part I--t'ai chi as a complex multicomponent intervention | methodology of Tai Chi research | research |
| 2008 | Wong, Alice M. K.; Lan, Ching | Tai Chi and balance control | balance | intervention |
| 2008 | Yeh, Gloria Y.; Wang, Chenchen; Wayne, Peter M.; Phillips, Russell S. | The effect of tai chi exercise on blood pressure: a systematic review | cardiovascular | intervention |
| 2009 | Hall, Amanda; Maher, Chris; Latimer, Jane; Ferreira, Manuela | The effectiveness of Tai Chi for chronic musculoskeletal pain conditions: a systematic review and meta-analysis | chonic pain | intervention |
| 2009 | Lee, M. S.; Lee, E-N; Ernst, E. | Is tai chi beneficial for improving aerobic capacity? A systematic review | aerobic capacity | intervention |
| 2009 | Low, Serena; Ang, Li Wei; Goh, Kiat Sern; Chew, Suok Kai | A systematic review of the effectiveness of Tai Chi on fall reduction among the elderly | elders | intervention |
| 2009 | Posadzki, Paul; Jacques, Samantha | Tai chi and meditation: A conceptual (re)synthesis? | Tai Chi and meditation | particular |
| 2009 | Rogers, Carol E.; Larkey, Linda K.; Keller, Colleen | A review of clinical trials of tai chi and qigong in older adults | elders | intervention |
| 2009 | Wang, Wei Chun; Zhang, Anthony Lin; Rasmussen, Bodil; Lin, Li-Wei; Dunning, Trisha; Kang, Seung Wan; Park, Byung-Joo; Lo, Sing Kai | The effect of Tai Chi on psychosocial well-being: a systematic review of randomized controlled trials | psychological well-being | intervention |

| Year | Authors | Title | Target group | Topic |
|---|---|---|---|---|
| 2009 | Yeh, Gloria Y.; Wang, Chenchen; Wayne, Peter M.; Phillips, Russell | Tai chi exercise for patients with cardiovascular conditions and risk factors: A SYSTEMATIC REVIEW | cardiovascular | intervention |
| 2010 | Chang, Yu-Kai; Nien, Yu-Hsiang; Tsai, Chia-Liang; Etnier, Jennifer L. | Physical activity and cognition in older adults: the potential of Tai Chi Chuan | elders | intervention |
| 2010 | Jahnke, Roger; Larkey, Linda; Rogers, Carol; Etnier, Jennifer; Lin, Fang | A comprehensive review of health benefits of qigong and tai chi | therapy | research |
| 2010 | Lee, Myeong Soo; Choi, Tae-Young; Ernst, Edzard | Tai chi for breast cancer patients: a systematic review | breast cancer | intervention |
| 2010 | Lee, Myeong Soo; Lee, Eun-Nam; Kim, Jong-In; Ernst, Edzard | Tai chi for lowering resting blood pressure in the elderly: a systematic review | elders | intervention |
| 2010 | Liu, Hao; Frank, Adam | Tai chi as a balance improvement exercise for older adults: a systematic review | elders | intervention |
| 2010 | Maciaszek, Janusz; Osinski, W. | The effects of Tai Chi on body balance in elderly people--a review of studies from the early 21st century | elders | intervention |
| 2010 | Wang, Chenchen; Bannuru, Raveendhara; Ramel, Judith; Kupelnick, Bruce; Scott, Tammy; Schmid, Christopher H. | Tai Chi on psychological well-being: systematic review and meta-analysis | psychological well-being | intervention |
| 2010 | Wooton, Angela Conrad | An integrative review of Tai Chi research: an alternative form of physical activity to improve balance and prevent falls in older adults | elders | intervention |
| 2011 | Allen, Jennifer; Meires, Jan | How to prescribe Tai chi therapy | therapy | research |
| 2011 | Dalusung-Angosta, Alona | The impact of Tai Chi exercise on coronary heart disease: a systematic review | cardiovascular | intervention |
| 2011 | Field, Tiffany | Tai Chi research review | therapy | research |
| 2011 | Leung, Daniel P. K.; Chan, Carol K. L.; Tsang, Hector W. H.; Tsang, William W. N.; Jones, Alice Y. M. | Tai chi as an intervention to improve balance and reduce falls in older adults: A systematic and meta-analytical review | elders | intervention |
| 2011 | Plastaras, Christopher T.; Schran, Seth; Kim, Natasha; Sorosky, Susan; Darr, Deborah; Chen, Mary Susan; Lansky, Rebecca | Complementary and alternative treatment for neck pain: chiropractic, acupuncture, TENS, massage, yoga, Tai Chi, and Feldenkrais | neck pain | intervention |
| 2011 | Wang, Chenchen | Tai chi and rheumatic diseases | rheumatic disease | intervention |
| 2012 | Blake, Holly; Hawley, Helen | Effects of Tai Chi exercise on physical and psychological health of older people | elders | intervention |

| Year | Authors | Title | Duration in months | Study population | Sample size (n) | Design (number of study arms) | Study arms | Outcome domains |
|---|---|---|---|---|---|---|---|---|
| **1997** | Wolf, S. L.; Barnhart, H. X.; Ellison, G. L.; Coogler, C. E. | The effect of Tai Chi Quan and computerized balance training on postural stability in older subjects. Atlanta FICSIT Group. Frailty and Injuries: Cooperative Studies on Intervention Techniques | 3,75 | elders | 72 | RCT (3) | TC, computerized balance training, education | postural sway |
| **2001** | Li, Fuzhong; Harmer, Peter; McAuley, Edward; Fisher, K. John; Duncan, Terry E.; Duncan, Susan C. | Tai Chi, Self-Efficacy, and Physical Function in the Elderly | 6 | elders | 94 | RCT (2) | TC, wait list control | self-efficacy and physical function |
| **2001** | Wolf, S. L.; Sattin, R. W.; O'Grady, M.; Freret, N.; Ricci, L.; Greenspan, A. I.; Xu, T.; Kutner, M. | A study design to investigate the effect of intense Tai Chi in reducing falls among older adults transitioning to frailty | 12 | elders | N/A | RCT (2) | TC, wellnes education | variables related to function, behavior, and the biomechanics of movement. |
| **2002** | Taggart, Helen M. | Effects of Tai Chi exercise on balance, functional mobility, and fear of falling among older women | 3 | elders (female) | N/A | N/A | TC, N/A | falls, fear of falling, balance, functional mobility |
| **2003** | Irwin, Michael R.; Pike, Jennifer L.; Cole, Jason C.; Oxman, Michael N. | Effects of a behavioral intervention, Tai Chi Chih, on varicella-zoster virus specific immunity and health functioning in older adults | 3,75 | elders | 36 | RCT (2) | TC, wait list control | VZV specific immunity, health functioning |
| **2003** | Song, Rhayun; Lee, Eun-Ok; Lam, Paul; Bae, Sang-Cheol | Effects of tai chi exercise on pain, balance, muscle strength, and perceived difficulties in physical functioning in older women with osteoarthritis: a randomized clinical trial | 3 | osteoarthritis (female) | 72 | RCT (2) | TC, controls | physical functioning, balance, stength, flexibility, pain, stiffness |
| **2003** | Tsai, Jen-Chen; Wang, Wei-Hsin; Chan, Paul; Lin, Li-Jung; Wang, Chia-Huei; Tomlinson, Brian; Hsieh, Ming-Hsiung; Yang, Hung-Yu; Liu, Ju-Chi | The beneficial effects of Tai Chi Chuan on blood pressure and lipid profile and anxiety status in a randomized controlled trial | 3 | adults with elevated blood pressure | 76 | RCT (2) | TC, sedentary | blood pressure, lipid profile, anxiety status |
| **2003** | Wolf, Steven L.; Barnhart, Huimnan X.; Kutner, Nancy G.; McNeely, Elizabeth; Coogler, Carol; Xu, Tingsen | Selected as the best paper in the 1990s: Reducing frailty and falls in older persons: an investigation of tai chi and computerized balance training | 3,75 | elders | 200 | RCT (3) | TC, computerized balance training, education | biomedical, functional and psychosocial indicators of fraility, occurence of falls |

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| Year | Authors | Title | Duration in months | Study population | Sample size (n) | Design (number of study arms) | Study arms | Outcome domains |
|---|---|---|---|---|---|---|---|---|
| **2003** | Wolf, Steven L.; Sattin, Richard W.; Kutner, Michael; O'Grady, Michael; Greenspan, Arlene I.; Gregor, Robert J. | Intense tai chi exercise training and fall occurrences in older, transitionally frail adults: a randomized, controlled trial | 12 | elders | 291 | RCT (N/A) | TC, N/A | functional measures, fall occurence, adherence, falls efficacy, sickness, balance confidence |
| **2004** | Chan, Kaiming; Qin, Ling; Lau, Mingchu; Woo, Jean; Au, Szeki; Choy, Wingyee; Lee, Kwongman; Lee, Shiuhung | A randomized, prospective study of the effects of Tai Chi Chun exercise on bone mineral density in postmenopausal women | 12 | post-menopausal | 132 | RCT (2) | TC, sedentary | bone mineral density, fracture rates |
| **2004** | Hart, Jacob; Kanner, Hava; Gilboa-Mayo, Ronit; Haroeh-Peer, Osnat; Rozenthul-Sorokin, Naomi; Eldar, Reuben | Tai Chi Chuan practice in community-dwelling persons after stroke | 3 | stroke survivors | 18 | RCT (2) | TC, physiotherapy | social and general functioning, balance, walking speed |
| **2004** | Hass, Chris J.; Gregor, Robert J.; Waddell, Dwight E.; Oliver, Alanna; Smith, Dagan W.; Fleming, Richard P.; Wolf, Steven L. | The influence of Tai Chi training on the center of pressure trajectory during gait initiation in older adults | 12 | elders | 28 | N/A (2) | TC, wellness education | postural control, center of pressure trajectory during gait initiation |
| **2004** | Li, Fuzhong; Fisher, K. John; Harmer, Peter; Irbe, Dainis; Tearse, Robert G.; Weimer, Cheryl | Tai chi and self-rated quality of sleep and daytime sleepiness in older adults: a randomized controlled trial | 6 | elders | 118 | RCT (2) | TC, low impact exercise | sleep quality, daytime sleepyness |
| **2004** | Li, Fuzhong; Harmer, Peter; Fisher, K. John; McAuley, Edward | Tai Chi: improving functional balance and predicting subsequent falls in older persons | 6 | elders | 256 | RCT (2) | TC, exercise stretching | functional balance, falls reduction |
| **2004** | McGibbon, Chris A.; Krebs, David E.; Wolf, Steven L.; Wayne, Peter M.; Scarborough, Donna Moxley; Parker, Stephen W. | Tai Chi and vestibular rehabilitation effects on gaze and whole-body stability | 2,5 | peripheral vestibular hypofunction | 26 | RCT (2) | TC, vestibular rehabilitation | ganze stability, whole body stability, footfall stability during locomotion |
| **2004** | Tsang, William W. N.; Hui-Chan, Christina W. Y. | Effect of 4- and 8-wk intensive Tai Chi Training on balance control in the elderly | 2 | elders | 49 | RCT (2) | TC, general education | balance control |
| **2005** | Choi, Jung Hyun; Moon, Jung-Soon; Song, Rhayun | Effects of Sun-style Tai Chi exercise on physical fitness and fall prevention in fall-prone older adults | 3 | elders | 68 | N/A (2) | TC, control | physical fitness, fall avoidance efficacy, fall episodes |

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| Year | Authors | Title | Duration in months | Study population | Sample size (n) | Design (number of study arms) | Study arms | Outcome domains |
|---|---|---|---|---|---|---|---|---|
| 2005 | Galantino, Mary Lou; Shepard, Kay; Krafft, Larry; Laperriere, Arthur; Ducette, Joseph; Sorbello, Alfred; Barnish, Michael; Condoluci, David; Farrar, John T. | The effect of group aerobic exercise and t'ai chi on functional outcomes and quality of life for persons living with acquired immunodeficiency syndrome | 2 | AIDS | 38 | RCT (3) | TC, aerobic exercise, control | strategies and exercise guidelines, functional outcomes, quality of life |
| 2005 | Jones, Alice Y.; Dean, Elizabeth; Scudds, Rhonda J. | Effectiveness of a community-based Tai Chi program and implications for public health initiatives | 3 | adults | 100 | CT | TC, cross-sect control | lung function and physical activity, Resting heart rate, blood pressure, oxygen saturation, handgrip strength, flexibility, balance |
| 2005 | Li, Fuzhong; Harmer, Peter; Fisher, K. John; McAuley, Edward; Chaumeton, Nigel; Eckstrom, Elizabeth; Wilson, Nicole L. | Tai Chi and fall reductions in older adults: a randomized controlled trial | 6 | elders | 256 | RCT (2) | TC, stretching | number of falls, balance, risk for falling |
| 2005 | McGibbon, Chris A.; Krebs, David E.; Parker, Stephen W.; Scarborough, Donna M.; Wayne, Peter M.; Wolf, Steven L. | Tai Chi and vestibular rehabilitation improve vestibulopathic gait via different neuromuscular mechanisms: preliminary report | 2,5 | elders with vestibulopathy | 36 | RCT (2) | TC, vestibular rehabilitation | time-distance measures, physical performance |
| 2005 | Sattin, Richard W.; Easley, Kirk A.; Wolf, Steven L.; Chen, Ying; Kutner, Michael H. | Reduction in fear of falling through intense tai chi exercise training in older, transitionally frail adults | N/A | elders | N/A | N/A | TC, wellness education | fear of falling |
| 2005 | Thomas, G. Neil; Hong, Athena W. L.; Tomlinson, Brian; Lau, Edith; Lam, Chris W. K.; Sanderson, John E.; Woo, Jean | Effects of Tai Chi and resistance training on cardiovascular risk factors in elderly Chinese subjects: a 12-month longitudinal, randomized, controlled intervention study | 12 | elders | 207 | RCT (3) | TC, resistance training, control | cardiovascular risk factors |
| 2006 | Audette, Joseph F.; Jin, Young Soo; Newcomer, Renee; Stein, Lauren; Duncan, Gillian; Frontera, Walter R. | Tai Chi versus brisk walking in elderly women | 3 | elders (female) | 19 | RCT (3) | TC, brisk walking, sedentary | aerobic capacity, heart rate variability, strength, flexibility, balance, psychological status, quality of life |

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|---|---|---|---|---|---|---|---|---|
| **2006** | Faber, Marjan J.; Bosscher, Ruud J.; Chin A Paw, Marijke J.; van Wieringen, Piet C. | Effects of exercise programs on falls and mobility in frail and pre-frail older adults: A multicenter randomized controlled trial | 5 | elders | 278 | RCT (2) | TC, functional walking | falls, functional performance, disability |
| **2006** | Lee, Hea-Young | [Comparison of effects among Tai-Chi exercise, aquatic exercise, and a self-help program for patients with knee osteoarthritis] | N/A | knee ostoarthritis | 50 | N/A (3) | TC, aquatic exercise, self-help program | arthritis, muscle strength, balance, difficulty of performing activities |
| **2006** | Lin, Mau-Roung; Hwang, Hei-Fen; Wang, Yi-Wei; Chang, Shu-Hui; Wolf, Steven L. | Community-based tai chi and its effect on injurious falls, balance, gait, and fear of falling in older people | 1 | elders | 1200 | CT (2) | TC, control | falls, falance, gait, fear of falling |
| **2006** | Mustian, Karen M.; Katula, Jeffrey A.; Zhao, Hongwei | A pilot study to assess the influence of tai chi chuan on functional capacity among breast cancer survivors | 3 | breast cancer | 21 | RCT (2) | TC, psychosocial therapy | functional capacity |
| **2006** | Nnodim, Joseph O.; Strasburg, Debra; Nabozny, Martina; Nyquist, Linda; Galecki, Andrzej; Chen, Shu; Alexander, Neil B. | Dynamic balance and stepping versus tai chi training to improve balance and stepping in at-risk older adults | 2,5 | elders | 213 | N/A (2) | TC, combined balance and step training | balance, stepping |
| **2006** | Orr, Rhonda; Tsang, Tracey; Lam, Paul; Comino, Elizabeth; Singh, Maria Fiatarone | Mobility impairment in type 2 diabetes: association with muscle power and effect of Tai Chi intervention | 5 | diabetes type 2 | 37 | RCT (2) | TC, western exercise | mobility, balance, physiologic capacity, health status |
| **2006** | Robins, Jo Lynne W.; McCain, Nancy L.; Gray, D. Patricia; Elswick, R. K.; Walter, Jeanne M.; McDade, Elizabeth | Research on psychoneuroimmunology: tai chi as a stress management approach for individuals with HIV disease | N/A | HIV | N/A | RCT | N/A | psychosocial variables |
| **2006** | Taylor-Piliae, Ruth E.; Haskell, William L.; Stotts, Nancy A.; Froelicher, Erika Sivarajan | Improvement in balance, strength, and flexibility after 12 weeks of Tai chi exercise in ethnic Chinese adults with cardiovascular disease risk factors | 3 | elders | 39 | OS (1) | TC | balance, strength, endurance, flexibility |

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| Year | Authors | Title | Duration in months | Study population | Sample size (n) | Design (number of study arms) | Study arms | Outcome domains |
|---|---|---|---|---|---|---|---|---|
| 2006 | Taylor-Piliae, Ruth E.; Haskell, William L.; Waters, Catherine M.; Froelicher, Erika Sivarajan | Change in perceived psychosocial status following a 12-week Tai Chi exercise programme | 3 | cardiovascular risk | 39 | OS (1) | TC | psychosocial status (mood, stress, self-efficacy to overcome barriers to Tai Chi, confidence to perform Tai Chi, perceived social support) |
| 2006 | Wolf, Steven L.; O'Grady, Michael; Easley, Kirk A.; Guo, Ying; Kressig, Reto W.; Kutner, Michael | The influence of intense Tai Chi training on physical performance and hemodynamic outcomes in transitionally frail, older adults | 12 | elders | 311 | RCT (2) | TC, wellnes education | variables related to function, behavior, and the biomechanics of movement. |
| 2006 | Zeeuwe, Petra E. M.; Verhagen, Arianne P.; Bierma-Zeinstra, Sita Ma; van Rossum, Erik; Faber, Marjan J.; Koes, Bart W. | The effect of Tai Chi Chuan in reducing falls among elderly people: design of a randomized clinical trial in the Netherlands [ISRCTN98840266] | 3,25 | elders | 270 | RCT (2) | TC, control | fall prevention, physical and psychosocial function |
| 2006 | Zhang, Jian-Guo; Ishikawa-Takata, Kazuko; Yamazaki, Hideo; Morita, Takae; Ohta, Toshiki | The effects of Tai Chi Chuan on physiological function and fear of falling in the less robust elderly: an intervention study for preventing falls | 2 | elders | 49 | RCT (2) | TC, control | physiological function, fear of falling |
| 2007 | Brismée, Jean-Michel; Paige, Robert L.; Chyu, Ming-Chien; Boatright, Julie D.; Hagar, James M.; McCaleb, Joseph A.; Quintela, Mauricio M.; Du Feng; Xu, Ke T.; Shen, Chwan-Li | Group and home-based tai chi in elderly subjects with knee osteoarthritis: a randomized controlled trial | 3 | knee osteoarthritis | 41 | RCT (2) | TC, health education | knee pain, knee range of motion, physical function |
| 2007 | Cheung, Siu Yin; Tsai, Eva; Fung, Lena; Ng, Judy | Physical benefits of Tai Chi Chuan for individuals with lower-limb disabilities | 3,75 | lower limb disability | 39 | N/A (2) | TC, control | cardiavascular function, pulmonary function, shoulder range of motion |
| 2007 | Gatts, Strawberry K.; Woollacott, Marjorie Hines | How Tai Chi improves balance: biomechanics of recovery to a walking slip in impaired seniors | 0,75 | elders with surgical intervention to knees, hips and back | 22 | RCT (2) | TC, wait list control | kinematics, center of pressure, center of mass |

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|---|---|---|---|---|---|---|---|---|
| **2007** | Greenspan, Arlene I.; Wolf, Steven L.; Kelley, Mary E.; O'Grady, Michael | Tai chi and perceived health status in older adults who are transitionally frail: a randomized controlled trial | 12 | elders | 269 | RCT (2) | TC, wellness education | perceived health |
| **2007** | Irwin, Michael R.; Olmstead, Richard; Oxman, Michael N. | Augmenting immune responses to varicella zoster virus in older adults: a randomized, controlled trial of Tai Chi | 4 | elders | 112 | RCT (2) | TC, health education | vaccine-stimulated immune response |
| **2007** | Li, Fuzhong; Harmer, Peter; Fisher, K. John; Xu, Junheng; Fitzgerald, Kathleen; Vongjaturapat, Naruepon | Tai Chi-based exercise for older adults with Parkinson's disease: a pilot-program evaluation | 5 days | Parkinson's Disease | 17 | OC (1) | TC | feasibility, safety, efficacy (physical performance |
| **2007** | Li, Yuhua; Devault, Cheri N.; van Oteghen, Sharon | Effects of extended Tai Chi intervention on balance and selected motor functions of the elderly | 12 | elderly with osteopenia or osteoporosis (male) | 47 | N/A (2) | TC, control | static and dynamic balance, choice reaction time, heel rise strength, ankle flexibility |
| **2007** | Maciaszek, J.; Osiński, W.; Szeklicki, R.; Stemplewski, R. | Effect of Tai Chi on body balance: randomized controlled trial in men with osteopenia or osteoporosis | 4,5 | elderly with osteopenia or osteoporosis (male) | 49 | RCT (2) | TC, control | body balance, posturagraphy |
| **2007** | Richerson, Samantha; Rosendale, Kyle | Does Tai Chi improve plantar sensory ability? A pilot study | 6 | diabetes and plantar sensory loss | 18 | OS (1) | TC | balance, plantar sensory perception |
| **2007** | Voukelatos, Alexander; Cumming, Robert G.; Lord, Stephen R.; Rissel, Chris | A randomized, controlled trial of tai chi for the prevention of falls: the Central Sydney tai chi trial | 4 | elders | 702 | RCT (2) | TC, waitlist control | balance |
| **2007** | Woo, Jean; Hong, Athena; Lau, Edith; Lynn, Henry | A randomised controlled trial of Tai Chi and resistance exercise on bone health, muscle strength and balance in community-living elderly people | 4 | elders | 180 | RCT (2) | TC, control | bone mineral density, muscle strength |
| **2007** | Yang, Yang; Verkuilen, Jay V.; Rosengren, Karl S.; Grubisich, Scott A.; Reed, Michael R.; Hsiao-Wecksler, Elizabeth T. | Effect of combined Taiji and Qigong training on balance mechanisms: a randomized controlled trial of older adults | 6 | elders | 49 | RCT ( (2) | TC, wait list control | somatosensory, visual, vestibular ratios of the sensory organisation test; quiet stance base of support, feet opening angle |

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|---|---|---|---|---|---|---|---|---|
| **2007** | Yang, Yang; Verkuilen, Jay; Rosengren, Karl S.; Mariani, Rachel A.; Reed, Michael; Grubisich, Scott A.; Woods, Jeffrey A. | Effects of a Taiji and Qigong intervention on the antibody response to influenza vaccine in older adults | 5 | elders | 50 | N/A (2) | TC, wait list control | immune response to influenza vaccine |
| **2008** | Chang, Rei-Yeuh; Koo, Malcolm; Yu, Zer-Ran; Kan, Chung-Ben; Chu, I-Tseng; Hsu, Chen-Tung; Chen, Cheng-Yun | The effect of t'ai chi exercise on autonomic nervous function of patients with coronary artery disease | 9 | coronary artery disease | 61 | N/A (2) | TC, control | heart rate variability |
| **2008** | Chen, Kuei-Min; Lin, Jong-Ni; Lin, Huey-Shyan; Wu, Hui-Chuan; Chen, Wen-Ting; Li, Chun-Huw; Kai Lo, Sing | The effects of a Simplified Tai-Chi Exercise Program (STEP) on the physical health of older adults living in long-term care facilities: a single group design with multiple time points | 6 | elders | 51 | OS (1) | TC | cardio-respiratory function, blood pressure, balance, hand-grip strength, lower body flexibility, and physical health actualization |
| **2008** | Cho, Kee-Lee | Effect of Tai Chi on depressive symptoms amongst Chinese older patients with major depression: the role of social support | 3 | elders | 14 | RCT (2) | TC, wait list control | depressive symptoms |
| **2008** | Hackney, Madeleine E.; Earhart, Gammon M. | Tai Chi improves balance and mobility in people with Parkinson disease | 3 | Parkinson's Disease | 33 | RCT (2) | TC, control | balance, gait, mobility |
| **2008** | Irwin, Michael R.; Olmstead, Richard; Motivala, Sarosh J. | Improving sleep quality in older adults with moderate sleep complaints: A randomized controlled trial of Tai Chi Chih | 6 | elders with sleep complaints | 112 | RCT (2) | TC, health education | sleep quality |
| **2008** | Lee, Hea-Young; Lee, Keum Jae | [Effects of Tai Chi exercise in elderly with knee osteoarthritis] | 3 | knee osteoarthritis | 46 | N/A (2) | TC, control | pain, stiffness, disability, knee joint motion, mobility, balance, falling |
| **2008** | Li, Jing Xian; Xu, Dong Qing; Hong, Youlian | Effects of 16-week Tai Chi intervention on postural stability and proprioception of knee and ankle in older people | 4 | elders | N/A | N/A | N/A | postural stability, proprioception |
| **2008** | Matthews, Margaret M.; Williams, Harriet G. | Can Tai chi enhance cognitive vitality? A preliminary study of cognitive executive control in older adults after A Tai chi intervention | 2,5 | elders | 20 | OS (1) | TC | cognitive executive function |

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|---|---|---|---|---|---|---|---|---|
| **2008** | Murphy, Lori; Singh, Betsy B. | Effects of 5-Form, Yang Style Tai Chi on older females who have or are at risk for developing osteoporosis | 3 | osteoporosis | 31 | OS (1) | TC | balance, functional strength, fall occurence |
| **2008** | Shen, Chwan-Li; James, C. Roger; Chyu, Ming-C; Bixby, Walter R.; Brismée, Jean-Michel; Zumwalt, Mimi A.; Poklikuha, Glen | Effects of Tai Chi on gait kinematics, physical function, and pain in elderly with knee osteoarthritis--a pilot study | 1,5 | knee osteoarthritis | 40 | OS (1) | TC | knee pain and stiffness, gait kinematics, physical function, pain, pain self-efficacy |
| **2008** | Tsang, William W. N.; Hui-Chan, Christina W. Y. | Sensorimotor control of balance: a Tai Chi solution for balance disorders in older subjects | 1 | elders | N/A | N/A (2) | TC, general education | balance, limb joint proprioception, motor output at the level of knee muscles, integration of neural signals in the centra nervous system for balance control |
| **2008** | Wang, Chenchen; Schmid, Christopher H.; Hibberd, Patricia L.; Kalish, Robert; Roubenoff, Ronenn; Rones, Ramel; Okparavero, Aghogho; McAlindon, Timothy | Tai Chi for treating knee osteoarthritis: designing a long-term follow up randomized controlled trial | 3 | knee osteoarthritis | 40 | RCT (2) | TC, wellness education and stretching | WOMAC pain, function and stiffness, global assessment, lower extremity function, knee proprioception, depression, self-efficacy, social support, quality of life, adherence, adverse events |
| **2008** | Wang, Jing Hao | Effects of Tai Chi exercise on patients with type 2 diabetes | 2 | diabetes type 2 | 12 | OS (1) | TC | blood glucose, serum insulin, insulin receptor activity |
| **2008** | Yang, Yang; Verkuilen, Jay; Rosengren, Karl S.; Mariani, Rachel A.; Reed, Michael; Grubisich, Scott A.; Woods, Jeffrey A.; Schlagal, Bob | Effects of a traditional Taiji/Qigong curriculum on older adults' immune response to influenza vaccine | 5 | elders | 50 | N/A (2) | TC, controls | immune response to influenza vaccine |
| **2008** | Yeh, Gloria Y.; Mietus, Joseph E.; Peng, Chung-Kang; Phillips, Russell S.; Davis, Roger B.; Wayne, Peter M.; Goldberger, Ary L.; Thomas, Robert J. | Enhancement of sleep stability with Tai Chi exercise in chronic heart failure: preliminary findings using an ECG-based spectrogram method | 3 | heart failiure | 18 | RCT (2) | TC, usual care | sleep spectrogram (EEG based) |
| **2008** | Zhang, Ying; Fu, Frank H. | Effects of 14-week Tai Ji Quan exercise on metabolic control in women with type 2 diabetes | 3,5 | diabetes type 2 (female) | 20 | RCT (2) | TC, control | metabolic control, lipid metabolism |

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|---|---|---|---|---|---|---|---|---|
| **2009** | Blake, H.; Batson, M. | Exercise intervention in brain injury: a pilot randomized study of Tai Chi Qigong | 2 | traumatic brain injury | 20 | RCT (2) | TC, social control | mood, self-esteem, flexibility, coordination, physical activity, social support |
| **2009** | Dechamps, Arnaud; Gatta, Blandine; Bourdel-Marchasson, Isabelle; Tabarin, Antoine; Roger, Patrick | Pilot study of a 10-week multidisciplinary Tai Chi intervention in sedentary obese women | 2,5 | sedentary obese (female) | 21 | RCT (2) | TC, conventional exercise | weight, body composition, heart rate, blood pressure, mobility, mood, eating, self-efficacy |
| **2009** | Hackney, Madeleine E.; Earhart, Gammon M. | Health-related quality of life and alternative forms of exercise in Parkinson disease | 3,25 | Parkinson's Disease | 75 | RCT (4) | TC, Tango, Walz/Foxtrott, control | mobility,social support, quality of life, PDQ-39 |
| **2009** | Hall, Amanda M.; Maher, Chris G.; Latimer, Jane; Ferreira, Manuela L.; Lam, Paul | A randomized controlled trial of tai chi for long-term low back pain (TAI CHI): study rationale, design, and methods | 2,5 | low back pain | 160 | RCT (2) | TC, wait list control | symptoms, pain related disability, quality of life, perceived effect of treatment |
| **2009** | Hall, Courtney D.; Miszko, Tanya; Wolf, Steven L. | Effects of Tai Chi intervention on dual-task ability in older adults: a pilot study | 3 | elders | 15 | N/A (2) | TC, health education | dual-task ability |
| **2009** | Hui, S. S. C.; Woo, J.; Kwok, T. | Evaluation of energy expenditure and cardiovascular health effects from Tai Chi and walking exercise | 3 | middle-aged | N/A | N/A (2) | TC, walking | body composition, aerobic fitness, muscular fitness, fasting blood glucose, resting metabolic rate, perceived health |
| **2009** | Lee, Hwa-Jin; Park, Hi-Joon; Chae, Younbyoung; Kim, Song-Yi; Kim, Seung-Nam; Kim, Seung-Tae; Kim, Je-Ho; Yin, Chang-Shik; Lee, Hyejung | Tai Chi Qigong for the quality of life of patients with knee osteoarthritis: a pilot, randomized, waiting list controlled trial | 2 | knee osteoarthritis | 44 | RCT (2) | TC, wait list contnrol | quality of life, symptoms, physical function |
| **2009** | Li, Jing Xian; Xu, Dong Qing; Hong, Youlian | Changes in muscle strength, endurance, and reaction of the lower extremities with Tai Chi intervention | 4 | elders | 40 | RCT (2) | TC, general education | muscle strength, endurance, reaction time of the lower extremities |

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|---|---|---|---|---|---|---|---|---|
| **2009** | Logghe, Inge H. J.; Zeeuwe, Petra E. M.; Verhagen, Arianne P.; Wijnen-Sponselee, Ria M. T.; Willemsen, Sten P.; Bierma-Zeinstra, Sita M. A.; van Rossum, Erik; Faber, Marjan J.; Koes, Bart W. | Lack of effect of Tai Chi Chuan in preventing falls in elderly people living at home: a randomized clinical trial | 3,25 | elders | 269 | RCT (2) | TC, usual care | falls, balance, fear of falling, cardiopulmonary funtion, physical activity, functional status |
| **2009** | Shen, Chwan-Li; Chyu, Ming-Chien; Yeh, James K.; Felton, Carol K.; Xu, Ke T.; Pence, Barbara C.; Wang, Jia-Sheng | Green tea polyphenols and Tai Chi for bone health: designing a placebo-controlled randomized trial | 6 | post-menopausal | 140 | RCT (4) | Placebo, green tea polyphenols, TC + placebo, TC + green tea polyphenols | oxidative DNA damage markers, bone formation biomarkers, bone resorption biomarkers |
| **2009** | Song, Rhayun; Ahn, Sukhee; Roberts, Beverly L.; Lee, Eun Ok; Ahn, You Hern | Adhering to a t'ai chi program to improve glucose control and quality of life for individuals with type 2 diabetes | 6 | diabetes type 2 | 99 | CT (2) | TC 80% adherence, TC less than 80% adherence | glucose control, diabetic self care activities, quality of life |
| **2010** | Chang, Rei-Yeuh; Koo, Malcolm; Kan, Chung-Ben; Yu, Zer-Ran; Chu, I-Tseng; Hsu, Chen-Tung; Chen, Cheng-Yun | Effects of Tai Chi rehabilitation on heart rate responses in patients with coronary artery disease | 6 | coronary artery disease | 54 | N/A (2) | TC + usual care, usual care | prognostic factors of cardiac events, rate-pressure product and -reserve |
| **2010** | Dechamps, Arnaud; Diolez, Philippe; Thiaudière, Eric; Tulon, Aurore; Onifade, Chérifa; Vuong, Tuan; Helmer, Catherine; Bourdel-Marchasson, Isabelle | Effects of exercise programs to prevent decline in health-related quality of life in highly deconditioned institutionalized elderly persons: a randomized controlled trial | N/A | elders | N/A | RCT (N/A) | N/A | quality of life, ADL |
| **2010** | Huang, Hui-Chi; Liu, Chieh-Yu; Huang, Yu-Tai; Kernohan, W. George | Community-based interventions to reduce falls among older adults in Taiwan - long time follow-up randomised controlled study | 5 | elders | 163 | RCT (4) | TC, education, TC + education, control | falls and risk factors of falls, gait balance |
| **2010** | Lee, Linda Y. K.; Lee, Diana T. F.; Woo, Jean | The psychosocial effect of Tai Chi on nursing home residents | 6,5 | elders | 139 | CT (2) | TC, usual care | psychosocial wellbeing in nursing home |
| **2010** | Lelard, Thierry; Doutrellot, Pierre-Louis; David, Pascal; Ahmaidi, Said | Effects of a 12-week Tai Chi Chuan program versus a balance training program on postural control and walking ability in older people | 3 | elders | 28 | RCT (2) | TC, balance training | postural control, walking ability |

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| Year | Authors | Title | Duration in months | Study population | Sample size (n) | Design (number of study arms) | Study arms | Outcome domains |
|---|---|---|---|---|---|---|---|---|
| **2010** | Li, Li; Manor, Brad | Long term Tai Chi exercise improves physical performance among people with peripheral neuropathy | 6 | peripheral neuropathy | 25 | OS (1) | TC | plantar pressure detection, strength and standing balance |
| **2010** | Liu, X.; Miller, Y. D.; Burton, N. W.; Brown, W. J. | A preliminary study of the effects of Tai Chi and Qigong medical exercise on indicators of metabolic syndrome, glycaemic control, health-related quality of life, and psychological health in adults with elevated blood glucose | 3 | adults with elevated blood glucose | 11 | OS (1) | TC | indicators of methabolic syndrome, glucose control, quality of life, stress and ddepressive symptoms |
| **2010** | Peppone, Luke J.; Mustian, Karen M.; Janelsins, Michelle C.; Palesh, Oxana G.; Rosier, Randy N.; Piazza, Kenneth M.; Purnell, Jason Q.; Darling, Tom V.; Morrow, Gary R. | Effects of a structured weight-bearing exercise program on bone metabolism among breast cancer survivors: a feasibility trial | 3 | breast cancer survivors | 16 | RCT (2) | TC, usual care | bone loss biomarkers |
| **2010** | Taylor-Piliae, Ruth E.; Newell, Kathryn A.; Cherin, Rise; Lee, Martin J.; King, Abby C.; Haskell, William L. | Effects of Tai Chi and Western exercise on physical and cognitive functioning in healthy community-dwelling older adults | 6 | elders | 133 | RCT (3) | TC, western exercise, attention-control | physical and cognitive functioning |
| **2010** | Uhlig, Till; Fongen, Camilla; Steen, Eldri; Christie, Anne; Ødegård, Sigrid | Exploring Tai Chi in rheumatoid arthritis: a quantitative and qualitative study | 3 | rheumatoid arthritis | 15 | OS (1) | TC | disease activity, self-reported health status, physical performance |
| **2010** | Wang, Chenchen; Schmid, ChristopherH; Rones, Ramel; Kalish, Robert; Yinh, Janeth; Goldenberg, DonL; Lee, Yoojin; McAlindon, Timothy | A randomized trial of tai chi for fibromyalgia | 3 | fibromyalgia | 66 | RCT (2) | TC + usual care, usual care | Fibromyalgia Impact Questionanire (FIQ), physical and mental components of the SF-36 questionaire |
| **2010** | Wayne, Peter M.; Buring, Julie E.; Davis, Roger B.; Connors, Ellen M.; Bonato, Paolo; Patritti, Benjamin; Fischer, Mary; Yeh, Gloria Y.; Cohen, Calvin J.; Carroll, Danette; Kiel, Douglas P. | Tai Chi for osteopenic women: design and rationale of a pragmatic randomized controlled trial | 9 | post-menopausal | N/A | RCT (2) | TC + usual care, usual care | bonde mineral density, serum markers, balance |

**Legend:** N/A = not available, TC = Tai Chi, RCT = randomized controlled trial, CT = controlled trial, OS = observational study

| Year | Authors | Title | Duration in months | Study population | Sample size (n) | Design (number of study arms) | Study arms | Outcome domains |
|---|---|---|---|---|---|---|---|---|
| **2010** | Wu, Ge; Keyes, Lawrence; Callas, Peter; Ren, Xiaolin; Bookchin, Bea | Comparison of telecommunication, community, and home-based Tai Chi exercise programs on compliance and effectiveness in elders at risk for falls | 3,75 | elders | 64 | RCT (3) | TC via telecommunication, via community center, via video | exercise compliance, falls, fear of falling, balance, self-reported health |
| **2010** | Yeh, Gloria Y.; Roberts, David H.; Wayne, Peter M.; Davis, Roger B.; Quilty, Mary T.; Phillips, Russell S. | Tai chi exercise for patients with chronic obstructive pulmonary disease: a pilot study | 3 | chronic obstructive pulmonary disease | 10 | RCT (2) | TC + usual care, usual care | quality of life, exercise capacity |
| **2011** | Barbat-Artigas, Sébastien; Filion, Marie-Eve; Dupontgand, Sophie; Karelis, Antony D.; Aubertin-Leheudre, Mylène | Effects of tai chi training in dynapenic and nondynapenic postmenopausal women | 3 | post-menopausal | 62 | OS (1) | TC | body composition, handgrip strength, functional capacity, cardiorespiratory functions |
| **2011** | Caminiti, Giuseppe; Volterrani, Maurizio; Marazzi, Giuseppe; Cerrito, Anna; Massaro, Rosalba; Arisi, Arianna; Franchini, Alessio; Sposato, Barbara; Rosano, Giuseppe | Tai chi enhances the effects of endurance training in the rehabilitation of elderly patients with chronic heart failure | 3 | elderly with cronic heart failiure | 60 | RCT (2) | TC + endurance training, endurance training | exercise tolerance, quality of life |
| **2011** | Carbonell-Baeza, Ana; Romero, Alejandro; Aparicio, Virginia A.; Ortega, Francisco B.; Tercedor, Pablo; Delgado-Fernández, Manuel; Ruiz, Jonatan R. | Preliminary findings of a 4-month Tai Chi intervention on tenderness, functional capacity, symptomatology, and quality of life in men with fibromyalgia | 4 | fibromyalgia (male) | 6 | OS (1) | TC | tenderness, functional capacity, symtomatology, quality of life |
| **2011** | Chan, Aileen W. K.; Lee, Albert; Suen, Lorna K. P.; Tam, Wilson W. S. | Tai chi Qigong improves lung functions and activity tolerance in COPD clients: a single blind, randomized controlled trial | 3 | chronic obstructive pulmonary disease | 206 | RCT (3) | TC, walking, control | respiratory functions, activity tolerance |
| **2011** | Chang, Rei-Yeuh; Koo, Malcolm; Ho, Meng-Ying; Lin, Zi-Zi; Yu, Zer-Ran; Lin, Yen-Fen; Wang, Be-Jen | Effects of Tai Chi on adiponectin and glucose homeostasis in individuals with cardiovascular risk factors | 60min | cardiovascular risk | 26 | OS (1) | TC | adiponectin, glucose homeostasis |

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| **Year** | **Authors** | **Title** | **Duration** in months | **Study population** | **Sample size** (n) | **Design** (number of study arms) | **Study arms** | **Outcome domains** |
|---|---|---|---|---|---|---|---|---|
| **2011** | Fujimoto, Satoshi; Yamazaki, Sachiko; Wakabayashi, Akitsu; Matsuzaki, Yumi; Yasumura, Seiji | The effects of Tai-chi exercise for the prevention of long-term care in community-dwelling frail elderly people -New care-need certification and mortality- | 3,5 | elders | 118 | CT (2) | TC, control | New care-need certification , motor fitness scale, maximum walking speed over 10 meters, functional reach test, ability to stand after a long period of sitting, and maximum one step width. |
| **2011** | Huang, Tzu-Ting; Yang, Lin-Hui; Liu, Chia-Yih | Reducing the fear of falling among community-dwelling elderly adults through cognitive-behavioural strategies and intense Tai Chi exercise: a randomized controlled trial | N/A | elders | N/A | RCT (3) | TC + cognitive-behavioural, cognitive-behavioural, control | fear of falling |
| **2011** | Janelsins, Michelle C.; Davis, Paul G.; Wideman, Laurie; Katula, Jeffrey A.; Sprod, Lisa K.; Peppone, Luke J.; Palesh, Oxana G.; Heckler, Charles E.; Williams, Jacqueline P.; Morrow, Gary R.; Mustian, Karen M. | Effects of Tai Chi Chuan on insulin and cytokine levels in a randomized controlled pilot study on breast cancer survivors | 3 | breast cancer survivors | 19 | CT (2) | TC, control | insulin and cytokine levels |
| **2011** | Lam, Linda C. W.; Chau, Rachel C. M.; Wong, Billy M. L.; Fung, Ada W. T.; Lui, Victor W. C.; Tam, Cindy C. W.; Leung, Grace T. Y.; Kwok, Timothy C. Y.; Chiu, Helen F. K.; Ng, Sammy; Chan, W. M. | Interim follow-up of a randomized controlled trial comparing Chinese style mind body (Tai Chi) and stretching exercises on cognitive function in subjects at risk of progressive cognitive decline | 12 | adults at risk of cognitive decline | 389 | RCT (2) | TC, stretching | cognitive function |
| **2011** | Toda, Masahiro; Den, Rei; Hasegawa-Ohira, Masako; Morimoto, Kanehisa | Influence of personal patterns of behavior on the effects of Tai Chi: a pilot study | 20min | healthy (female) | 22 | OS | TC | Profile of Mood States (POMS) score |
| **2012** | Chen, Ellen W.; Fu, Amy S. N.; Chan, K. M.; Tsang, William W. N. | The effects of Tai Chi on the balance control of elderly persons with visual impairment: a randomised clinical trial | N/A | elders with visual impairment. | 40 | RCT (2) | TC, control | (i) passive knee joint repositioning to test knee proprioception; (ii) concentric isokinetic strength of the knee extensors and flexors and (iii) a sensory organisation test to quantify an individual's ability to maintain balance in a variety of complex sensory conditions |

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| Year | Authors | Title | Duration in months | Study population | Sample size (n) | Design (number of study arms) | Study arms | Outcome domains |
|---|---|---|---|---|---|---|---|---|
| **2012** | Jung, Seil; Lee, Eun-Nam; Lee, Sook-Ryon; Kim, Mi-Sook; Lee, Myeong Soo | Tai chi for lower urinary tract symptoms and quality of life in elderly patients with benign prostate hypertrophy: a randomized controlled trial | 3 | patients with benign prostate hypertrophy | 56 | RCT (2) | TC, usual care | lower urinary tract symptoms (LUTSs), quality of life (QoL), and sex hormone levels |
| **2012** | Li, Fuzhong; Harmer, Peter; Fitzgerald, Kathleen; Eckstrom, Elizabeth; Stock, Ronald; Galver, Johnny; Maddalozzo, Gianni; Batya, Sara S. | Tai chi and postural stability in patients with Parkinson's disease | 6 | Parkinson's Disease | 195 | RCT (3) | TC, resistance training, stretching | postural control |
| **2012** | Lu, Xi; Hui-Chan, Christina Wy; Tsang, William Wn | Effects of Tai Chi training on arterial compliance and muscle strength in female seniors | 4 | elders (female) | 31 | RCT (2) | TC, education | arterial compliance, muscle strength |
| **2012** | Reid-Arndt, Stephanie A.; Matsuda, Sandy; Cox, Cathy R. | Tai Chi effects on neuropsychological, emotional, and physical functioning following cancer treatment: a pilot study | 2,5 | cancer survivors (female) | 23 | OS (1) | TC | neuropsychology, balance, self-report (neuropsychology, stress and mood, fatigue |
| **2012** | Taylor-Piliae, RuthE; Coull, BruceM | Community-based Yang-style Tai Chi is safe and feasible in chronic stroke: a pilot study | 3 | stroke survivors | 28 | RCT (2) | TC, usual care | safety, feasibility, recruitment rates, intervention adherence, adverse events, study satisfaction, dropouts, adaequacy of outcome measures |
| **2012** | Tousignant, Michel; Corriveau, Helene; Roy, Pierre-Michel; Desrosiers, Johanne; Dubuc, Nicole; Hebert, Rejean; Tremblay-Boudreault, Valerie; Beaudoin, Audree-Jeanne | The effect of supervised Tai Chi intervention compared to a physiotherapy program on fall-related clinical outcomes: a randomized clinical trial | N/A | elders | 152 | RCT (2) | TC + physiotherapy | fall related variables (balance, gait, fear of falling, functional autonomy, self-actualisation, self-efficacy) |
| **2012** | Wayne, Peter M.; Kiel, Douglas P.; Buring, Julie E.; Connors, Ellen M.; Bonato, Paolo; Yeh, Gloria Y.; Cohen, Calvin J.; Mancinelli, Chiara; Davis, Roger B. | Impact of Tai Chi exercise on multiple fracture-related risk factors in post-menopausal osteopenic women: a pilot pragmatic, randomized trial | 9 | post-menopausal | 86 | RCT (2) | TC + usual care, usual care | bonde mineral density, serum markers, balance |

**Legend:** N/A = not available, TC = Tai Chi, RCT = randomized controlled trial, CT = controlled trial, OS = observational study

**Appendix 3:** Detailed analysis of seven Tai Chi studies. (Legend: * This criterion was suggested by Li et al. (2011) , "?" This criterion was not mentioned in the manuscript)

| Topic | # | Reporting criterion | Li et al. (2012) Parkinson # 1 | Wang et al. (2010) Fibromyalgia # 2 | Yang et al (2007) Seniors, (TC + QG) # 3 | Taylor-Piliae et al. (2010) Seniors # 4 | Wayne et al. (2010/2012) Osteopenic Women # 5 | Li et al. (2005) Seniors # 6 | Taylor-Piliae et al. (2012) Stroke # 7 |
|---|---|---|---|---|---|---|---|---|---|
| Design | D-1 | **Study design** | RCT | RCT | RCT | RCT | RCT | RCT | RCT |
| | D-2 | **Study groups** | 1. Tai Chi<br>2. Resistance training<br>3. stretching | 1. Tai Chi<br>2. wellness education and stretching | 1. Tai Chi<br>2. wait list control | 1. Tai Chi<br>2. Western exercise<br>3. Attention control | 1. Tai Chi + standard care<br>2. standard care (waitlist) | 1. Tai Chi<br>2. stretching | 1. Tai Chi<br>2. standard care |
| | D-3 | **Sample size** | N = 195 | N = 66 (men) | N = 49 | N = 133 | N = 86 (women) | N = 256 | N = 28 |
| | D-4 | **Target population** | Parkinson's Disease | Fibromyalgia | Seniors | Seniors | Osteopenia | Seniors | Chronic stroke |
| | D-5 | **Total duration of the intervention in months** | 6 | 3 | 6 | 6 | 9 | 6 | 3 |
| | D-6 | **Times of assessment (Months)** | 0, 3, 6 | 0, 3<br>1 variable was assessed weekly | 0, 2, 6 | 0, (3), 6 | 0, 3, 9 | 0, 3, 6<br>1 variable was assessed daily | 0, 3 |
| | D-7 | **Was a follow up measure included?** | 9 | 6 | No | 12 | No | 12<br>1 variable was assessed daily | No |
| | D-8 | **Did the authors build on previously conducted research?** | Previous research 3, study rationale included as attachment | | | Yes, 2 | Yes, study rationale | Yes, implementation research | No |
| | D-9 | **What was the hypothesis?**<br><br>**What was the aim of the study?** | **We hypothesized** that tai chi would be more effective in improving postural stability in limits-of-stability tasks than a resistance-based exercise regimen or low-impact stretching (control). | **We hypothesized** that at the end of the 12-week intervention period, patients in the Tai Chi group would have greater reduction in musculoskeletal pain and greater improvements in sleep quality, physical and psychological function, and health related quality-of-life scores than those in the control group. | **We hypothesized** that Tai Chi and Qigong (TQ) training would improve older adult's ability to effectively use perceptual information relevant for balance control. It was also hypothesized that TQ learners would adopt a larger stance width. | The aim was<br><br>to evaluate the effects of Tai Chi versus a standard program of western exercise consisting of cardiorespiratory-endurance, strength and flexibility training on physical and cognitive functioning in healthy, community-dwelling adults age 60 and older. | The aim was<br><br>1) To assess the feasibility of conducting a RCT of Tai Chi exercise for post-menopausal osteopenic women (recruitment, administering the intervention and outcome measurements, eliciting subject compliance, and retaining subjects in the trial)<br>2) to collect preliminary data on the effectiveness of Tai Chi in reducing rates of BMD loss in osteopenic women<br>3) to collect preliminary data evaluating the biomechanical, physiological, and psychological mechanisms through which Tai Chi may reduce rates of decline in BMD and fracture risks associated with osteopenia.<br>**A key feature of this study is** the use of a network of screened Tai Chi schools to provide Tai Chi interventions in a naturalistic setting and manner. | The aim was<br><br>1) to evaluate the efficacy of a 6-month Tai Chi intervention on falls in a sample of adults aged 70 and older.<br>2) to assess functional ability (balance, physical performance) and fear of falling<br>3) to determine, during a 6-month post-intervention follow up, whether intervention gains obtained during the 6-month intervention could be maintained | The aim was<br><br>1) to assess the safety and feasibility of a 12-week program (36 one-hour sessions) of Yang style 24-posture short form of Tai Chi in adult stroke survivors at + three months post-stroke, compared to Usual Care;<br>2) to describe within group changes in physical functioning and quality of life. |
| | D - 10 | **Which outcome domains were included?** | 1) Limits of stability:<br>a) maximum excursion,<br>b) directional control (Balance Master System)<br>2) Muscle Strength (knee, ankle) (Biodex System, isokinetic dynamometer)<br>3) Functional reach<br>4) Timed Up and Go<br>5) Unified Parkinson's Disease Rating Scale<br>6) Falls<br>7) Other<br>a) Participant characteristics<br>b) Habitual physical activity (PASE)<br>c) medication use (MCQ)<br>d) Quality of life(SF-36)<br>e) fear of falling (SAFFE) | 1) Fibromyalgia Impact Questionnaire (FIQ)<br>2) Global pain status (via VAS)<br>3) Number of tender sites<br>4) Pittsburgh Sleep Quality Index (PSIQ)<br>5) Depression scale of the center of epidemiologic studies (CES-D)<br>6) Outcome expectations for exercise scale<br>7) Chronic pain self efficacy scale<br>8) Quality of life (SF-36) | 1) Sensory Organisation Test (EquiTest)<br>2) Base of support and feet opening angle | 1) Physical functioning<br>a) balance: single leg stance, functional reach test<br>b) muscle strength and endurance: timed arm curl and chair-stand test<br>c) flexibility: back-scratch, sit and reach tests<br>d) cardiorespiratory endurance: treadmill test<br>2) Cognitive functioning<br>60s animal naming, forward and backward digit span tests<br>3) Additional measures<br>a) class attendance<br>b) physical activity (CHAMPS) | 1) Bone turnover markers<br>2) DXA measures of BMD<br>3) Quality of life<br>4) Tai Chi class attendance and home practice compliance<br>5) Non-Tai Chi and physical activity<br><br>6) Substudy: biomotion<br>a) assessment of balance control during quiet standing<br>b) changes in joint kinetics and dynamic balance control during chair rise<br>c) changes in joint kinetics and dynamic balance control during gait | 1) Daily fall calendar<br>2) Balance<br>a) Berg balance scale<br>b) Dynamic Gait Index<br>c) Functional reach<br>d) single leg standing tests<br>3) Physical performance<br>a) 50-foot speed walk<br>b) Up & Go Test<br>4) Fear of falling (SAFFE) | 1) Short physical performance battery to assess balance, gait speed, lower body strength<br>2) Aerobic endurance:<br>2minute step-in-place test<br>3) Quality of life<br>a) (SF-36)<br>b) Pittsburgh Sleep Quality Index (PSIQ)<br>c) Depression scale of the center of epidemiologic studies (CES-D) |

**Appendix 3:** Detailed analysis of seven Tai Chi studies.. *(Legend: * This criterion was suggested by Li et al. (2011) , "?" This criterion was not mentioned in the manuscript)*

| Topic | # | Reporting criterion | Li et al. (2012) Parkinson # 1 | Wang et al. (2010) Fibromyalgia # 2 | Yang et al (2007) Seniors, (TC + QG) # 3 | Taylor-Piliae et al. (2010) Seniors # 4 | Wayne et al. (2010/2012) Osteopenic Women # 5 | Li et al. (2005) Seniors # 6 | Taylor-Piliae et al. (2012) Stroke # 7 |
|---|---|---|---|---|---|---|---|---|---|
| Design | D-11 | **Was there a qualitative arm embedded in the study?** | Yes:<br>tracking of program fidelity, drop outs received an exit interview to determine the reasons for leaving the study | No | Yes: Qualitative statistical interview conducted on select Tai Chi/Qigong participants | No | Yes:<br>feasibility,<br>Tracking of program fidelity,<br>exit interviews,<br>Attendance and Compliance (wallet size attendance card and home practice logs sent by participants at the end of each month + non-compliant participants were contacted immediately to identify and overcome barriers) | No | Yes,<br>**several retention strategies** e.g. establishing a tracking method during recruitment, providing personalized feedback, using the same location for all aspects of the study, personal attention and encouragement, monitoring attendance, utilizing a charismatic Tai Chi instructor, providing appropriate incentives, and maintaining good communication.<br><br>**several strategies to provide adequate subject safety** e.g. small class size, TC classes in outpatient rehabilitation facilities equipped with automated external defibrillators, all subjects had a chair nearby to allow for rest periods and were allowed to use walkers or canes if needed, the Tai Chi instructor continuously monitored subjects for correct foot placements, a registered nurse was in attendance at all sessions |
| | D-12 | **In RCTs: Which randomization method was used and was preference an issue?** | Randomization assignments were generated by permuted block randomization with an allocation of 1:1:1. Randomization was conducted after baseline assessment.<br><br>3 of 309 eligible patients refused randomization and withdrew from the study<br><br>Preference:<br>Participants only received the information that the aim of the study was to compare three different types of exercise. aiming to minimize preexisting beliefs and expectations about Tai Chi. However, positive expectations about exercise in general were reported by the authors. | Participants were allocated in 3 randomization cycles, using computer-generated numbers.<br>Randomization was conducted after baseline assessment.<br><br>Preference:<br>Participants only received information that the aim of the study was to compare two different forms of exercise aiming to minimize preexisting beliefs and expectations about Tai Chi. | Participants were allocated using cluster randomization (for 3 sites separately) with the third generator of www.randomization.com by a random permutation of integers. Anticipating drop outs, a greater number of participants were assigned to the Tai Chi group (last 70% of the numbers) than to the control group (first 30% of the numbers). One couple received only one number in order to be assigned to the same group.<br>Randomization was conducted after baseline assessment.<br><br>19 of the eligible 68 participants were not randomized due to choice, scheduling or convenience and were excluded from the data analysis | Participants were randomized in a disproportionate manner with approximately 30% assigned to each of the two exercise groups and 40% to control. (The larger control group was needed for subsequent supplemental study.)Randomization was conducted after baseline assessment.<br><br>21 of the 383 eligible participants refused randomization and withdrew from the study | Randomization assignments were generated by a computer program using a permuted block design with a variable block size. Randomization was conducted after baseline assessment. | Randomization assignments were generated by computer-allocated random numbers with an allocation ratio of 1:1. Randomization was conducted after baseline assessment. | Participants were recruited in cohorts of 10-12 and allocated via special method of randomization aiming to reduce drop outs: each subject drew a slip of paper to be allocated a study arm. |
| | | | | | | | | | |
| Results | R-1 | **Primary Outcome** | Tai Chi group performed consistently better than both control groups in the **limits of stability test** | Tai Chi group higher improvement in **Fibromyalgia Impact Questionnaire** than controls did. Improvements were maintained for 24 weeks. | | Tai Chi group showed greater improvement in **single leg stance** than attention control group.<br><br>Western exercise group showed greater improvement in upper body flexibility than Tai Chi group and attention control group.<br><br>TC group showed greater improvement in a **cognitive functioning** test (digits backwards) than western exercise group and attention control group. | Tai Chi group showed greater improvements in **bone metabolism** than controls. | Tai Chi group showed greater improvements in **total number of falls, proportion of fallers and injurious falls** than stretching control group.. | The dose of Tai Chi was well tolerated, adherence was high, there were no adverse events and overall study satisfaction within participants was high.<br><br>By trend, the Tai Chi group showed greater improvements in balance, endurance and quality of life than usual care controls.<br><br>By trend, usual care controls showed greater improvement in gait speed and strength than Tai Chi group. |
| | R-2 | **Secondary outcomes** | Tai Chi group performed better than stretching control in **all secondary outcomes.**<br><br>Tai Chi group performed better than resistance training group in **stride length and functional reach.**<br><br>Ta Chi group and resistance training group **lowered the incidence of falls**. | Tai Chi group higher improvement in **Quality of Life Questionnaire** than controls did. | Tai Chi group performed consistently better than waitlist controls in **Sensory Organization Test** and quiet stance **Base of Support**. Within Tai Chi group Improvement was greatest within the first 2 months. Tai Chi group adopted a wider stance width. | | Tai Chi group greater improvements in **quality of life** questionnaire and **balance** measures than controls. | Tai Chi group showed greater improvements **in all measures of functional balance, physical performance and fear of falling** than stretching control group.<br><br>These Improvements were maintained for 6 months. | |
| | R-3 | **Adverse Events** | No serious adverse events | No adverse events | Not mentioned | Not mentioned | No serious adverse events, 9 minor adverse events (mainly musculoskeletal related). | No adverse events | No adverse events. |

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|---|---|---|---|---|---|---|---|---|---|
| Experi-ences | E-1 | **(How) Was the process of the intervention monitored?** | Standardized intervention protocol and process evaluation checklist:<br>a) instructor qualification and training<br>b) teaching distribution of the individual forms and movements<br>c) exercise intensity and consistency in training dosage across different sites<br>e) weekly class attendance | Number of missed sessions were tracked, subjects were asked to complete daily logs about their training,<br>subjects who missed a class were asked to attend a makeup class | The content of the intervention was predetermined and described in a detailed schedule.<br><br>No information is given about further evaluation or monitoring. | ? | a) Number of attended sessions and additional practice time was tracked in both groups<br>b) Tracking of program fidelity | Number of attended sessions were tracked | ? |
| | E -2 | **Which barriers to participation were encountered?** | ? | ? | ? | ? | ?<br>qualitative arm addressed this issue, but did not report results | ? | ? |
| | E -3 | **How were adverse events monitored and reported?** | Adverse events were documented in an adverse log and, in the event of observing a major adverse event, reported immediately.<br>A summary is provided in form of a table for "in class" and "out of class" separately. | Throughout the entire intervention period, we monitored adverse events, using a standard adverse-event case report form at each visit. This form included a description of all unanticipated benefits and undesirable experiences, particularly falls and exacerbations of fibromyalgia symptoms. | ? | ? | Adverse events were tracked both through instructors and participants through the use of a AE policy, report forms and monthly safety calls to participants (2 in the 1st month) through the study staff<br><br>serious AEs: 0<br>minor AEs: 9<br>(7 in TC group, none attributed directly to TC training, musculoskeletal related) | ?<br>No intervention related injuries or falls were observed during the course of the study. | We examined recruitment rates of potential subjects, adherence to the intervention along with safety issues (i.e. falls or adverse events during Tai Chi), study satisfaction, drop-outs, and adequacy of the outcomes measures; as indicators of study safety and feasibility.<br>There were no falls or other adverse events during Tai Chi classes. |
| | E -4* | **Was the evaluation of the Tai Chi training and/or the instructor by study subjects available?** | No | No | No | No | Yes<br>(exit interviews of participants) | No | Yes<br>(overall satisfaction with being in the study, gain of personal benefits, would recommend the study to others) |
| | E -5 | **Did the participants like the intervention?<br>Were the participants interested in continuing with the activity?** | ? | ? | ? | ? | Participant reported satisfaction with their TC intervention was very high | ? | The majority of subjects reported that they gained personal benefits (71%, n=18), would recommend the study to others (86%, n=22), and reported their overall satisfaction as high (8.3 (SD=1.9); 1=not satisfied, 10=most satisfied) |
| | E -6 | **Are the reasons for Drop Outs reported?** | Yes (in a flowchart) | Yes (in a flowchart) | Yes (in a flowchart) | Yes (in a flowchart) | Yes (in the text) | Yes (in a flowchart) | Yes (in a flowchart) |
| | E -7 | **Do authors give any information or hints for future research attempts?** | No,<br>but their article poses a good example of reporting Tai Chi interventions | No | **suggestion of 3 topics for future studies:**<br>a) importance of core strength,<br>b) neuromuscular activity,<br>c) individual and combined effects of the different components of traditional Tai Chi<br>**suggestion of short Tai Chi forms:**<br>observed in this study are derived primarily from the static and dynamic Qigong and early form choreography. In other words, it is not important whether 12, 24, or 108 movement forms are taught in an intervention (indeed, longer forms may discourage older adults and decrease participation). | **Suggestion of longer observation intervals:**<br>For an exercise regimen to be "successful" for this population, it may not need to improve significant increases in functioning but simply prevent or slow decline so that independence and quality of life are maintained. To test such hypothesis, specific interventions will need to be tested for years, not just weeks or months. | Suggestion of longer observation intervals, suggestion of more structured contact with study participants to improve adherence | a) The way in which Tai Chi improved physical deficits occasioned by senescence<br>b) Question of costs (e.g. costs per fall prevention)<br>c) Targeting frail elders with specific disease risks | In a full-scale study, 52 subjects / group are needed to detect statistically significant between group differences..<br>The adequacy of outcome measures is discussed and improvements are suggested. |
| Quality of repor-ting | Q - 1 | **How many items of the modified CONSORT statement provided by Li et al (2011) were reported?** | 38/40 | 32/40 | 32/40 | 29/40 | 37/40 | 33/40 | 35/40 |

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|---|---|---|---|---|---|---|---|---|---|
| Defini-tion | 0-1 | **How is Tai Chi defined by the authors?** | a balance based exercise. | Tai Chi is a mind-body practice that originated in China as a martial art. It combines meditation with slow, gentle, graceful movements, as well as deep breathing and relaxation, to move vital energy (or *qi*) throughout the body. | Tai Chi (commonly spelled "T'ai Chi" or "Tai Chi") is a centuries- old exercise that is a fusion of Chinese philosophy and martial and healing arts. Tai Chi has received increasing attention within both the public and scientific communities, because<br>a) the art is a holistic form of exercise that was designed to improve, among other things, balance strength, coordination, agility, reaction time, flexibility, and postural control [ref],<br>b) anecdotal stories of the health benefits of Tai Chi practice have been widely disseminated in China for over a century,<br>c) Western culture has increasingly embraced nontraditional forms of exercise and medical treatment,<br>d) the relatively slow and gentle movements of the art are especially well suited to the elderly, and<br>e) Tai Chi exercise is relatively safe and inexpensive | Tai Chi is an Eastern form of exercise. It is a gentle. Low-impact exercise that has been practiced in China for hundreds of years. During the performance of Ta Chi Exercise, individuales are taught to be mindful of what their bodies are doing and how it feels. The goal is for the whole body to remain relaxed while practicing Tai Chi, integrating mental concentration and breathing control. | Tai Chi, also known as Tai Chi Chuan and Tai Chi Chuan, has its roots in the martial arts; yet for centuries millions of Chinese have practiced its flowing, meditative movements to cultivate and maintain health. Tai Chi employs detailed regimens of physical movement, breathing techniques, and cognitive tools (both visualization and focused internal awareness) to strengthen, relax and integrate the body and mind. | None specified. | Tai Chi […] is a low-cost, low-impact, moderate-intensity exercise that appeals to older adults […] combining physical movements with mental concentration and relaxation.<br>During Tai Chi, the slow, rhythmic movements are linked together in a continuous sequence, while body weight is shifted from leg to leg. This challenges the balance control system to maintain its center within a changing base of support and enhances better balance, […] individuals are taught to be mindful of what their bodies are doing and how it feels while performing Tai Chi. |
| | 0-2 | **What was the goal of the intervention?** | To **maintain balance through postural control** through a tailored Tai Chi program to tax balance and gait by having participants perform symmetric and diagonal movements, such as weight shifting, controlled displacement of the center of mass over the base of support, ankle sways, and anterior-posterior and lateral stepping. | None specified. | A ***traditional*** curriculum that emphasized both forms and standing and sitting Qigong meditation was intentionally examined.<br>The form movements were chosen to focus on **basic mobility skills**:<br>**weight shifting** to both sides (stepping and pivoting forward, backward, sideways, diagonally), **range of motion** (emphasis to spinal rotation to both sides, bilateral upper extremity elevation and reaching forward, backward, sideways), and **coordination**.<br>They were also selected for their **adaptability and use with an older population**.<br>A reduced movement set was utilized to reduce memorization requirements and **increase feelings of accomplishment** over a short period. | None specified. | None specified. | None specified. | None specified. |

**Appendix 3:** Detailed analysis of seven Tai Chi studies. *(Legend: * This criterion was suggested by Li et al. (2011) , "?" This criterion was not mentioned in the manuscript)*

| Topic | # | Reporting criterion | Li et al. (2012) Parkinson # 1 | Wang et al. (2010) Fibromyalgia # 2 | Yang et al (2007) Seniors, (TC + QG) # 3 | Taylor-Piliae et al. (2010) Seniors # 4 | Wayne et al. (2010/2012) Osteopenic Women # 5 | Li et al. (2005) Seniors # 6 | Taylor-Piliae et al. (2012) Stroke # 7 |
|---|---|---|---|---|---|---|---|---|---|
| Dose | 1-1* | How long was the intervention (weeks)? | 24 | 12 | 24 | 48 | 36 | 24 | 12 |
| | 1-2* | Was the Tai Chi training center-based or home-based or both? | Center-based | both | Center based: 3 senior centers | both | Both | center | Center based |
| | 1-3* | If it is center-based, how often was the Tai Chi training class per week and how long did a Tai Chi training class last (minutes)? | 2x / week, 60 minutes | 2x / week, 60 minutes | 3x / week, 60minutes (30min Qigong, 30min Tai Chi) | 1st 24 weeks: center: 2x / week, 60min home: 3x / week 2nd 24 weeks: center: 1x / week , 60min home: 3x / week | Minimum requirement: 1st 4 weeks: center: 2x / week, 60min home/center: 2x / week, 30min 2nd 32 weeks: center: 1x / week , 60min home/center: 3x / week, 30min | 3x / week practice time not reported | 3x / week, 60min |
| | 1-4 | How many groups were built? How many people were in one group? How was the group fitted together? | ?, 8-12, ? | ? | 3 groups adding to N = 33 | 8-10 | Participants weren't organized in groups, there were 6 TC schools involved | ? | 2 groups with 6 participants each |
| | 1-5 | Where the participants provided with information materials? | No | Yes: Printed materials on its (TCs) principles and techniques | ? | Yes: a) individual counseling session by class instructor about program schedule, safety issues, intervention procedures b) written instructions, illustrations of the postures, videotape | ? | ? | Yes, after the end of the study period (DVD and TC workbook) |
| | 1-6 | Did the participants have previous Tai Chi experience? How much? | ? | Having practiced Tai Chi within the last 6 months was an exclusion criterion. | ? | Yes: TC: 19%, western exercise: 26%, attention control: 25% | Rurrent regular practice of Tai Chi or within the past 2 years was an exclusion criterion. | ? | ? |
| | 1-7 | How were the rest periods determined during the intervention? | ? | ? | ? | Chairs available for participants to rest as needed | ? | ? | Chairs available for participants to rest as needed, in addition participants were allowed to use canes or walkers as needed |
| | 1-8 | Which was the minimum adherence rate required? What attendance rate was achieved? | Expected adherence rate: 75%, exclusion with 4 consecutive classes missed | Expected adherence rate: ?, Achieved attendance rate: TC: 77%, Control: 70% | ? | 1st 24 weeks: achieved adherence rate TC: 77%, western exercise: 68%, attention control: 67% 2nd 24 weeks: achieved adherence rate TC: 65%, western exercise: 53%, attention control: ? | 26 (60%) of the TC participants met the attendance rate asked (99,5h) average attendance rate achieved was 83,2h, range = 0-226h (lower attendance rate than in other studies was attributed to the missing component of a peer group sharing the same medical condition) | 92 (80%) of the TC participants attended 50 sessions or more (of 78), 87 (81%) od stretching control attended 50 sessions or more median = 61 for both groups | TC: 92%, (33 of 36 sessions) usual care: 99%, (12 of 12 sessions) |
| | 1-9 | Did the participants practice at home? | forbidden | ?, They were encouraged to practice at least 20min per day | ? | ?, Participants were assigned 3 home-based exercise sessions per week. Tai Chi students were encouraged to practice daily. | ?, Participants were assigned 2-3 home-based exercise sessions per week. | ? | ? |

**Appendix 3:** Detailed analysis of seven Tai Chi studies. *(Legend: * This criterion was suggested by Li et al. (2011) , "?" This criterion was not mentioned in the manuscript)*

| Topic | # | Reporting criterion | Li et al. (2012) Parkinson # 1 | Wang et al. (2010) Fibromyalgia # 2 | Yang et al (2007) Seniors, (TC + QG) # 3 | Taylor-Piliae et al. (2010) Seniors # 4 | Wayne et al. (2010/2012) Osteopenic Women # 5 | Li et al. (2005) Seniors # 6 | Taylor-Piliae et al. (2012) Stroke # 7 |
|---|---|---|---|---|---|---|---|---|---|
| Content | 2-1* | **What style of Tai Chi (Yang, Chen, Sun, etc.) was used in the intervention described?** | Tailored 8-Form | Yang, 10-Form | Chen,<br>a) tailored 7-Form adapted from 48-form<br>b) one single figure "golden cock stands on one leg" | Yang, 24- form | fist forms of Yang (41%), Wu (59%), Chen, Sun style | Yang, 24-form | Yang, 24-form |
| | 2-2* | **What did a Tai Chi training session consist of in the study? Were there any other non-Tai Chi exercises included in a Tai Chi training session?** | 5-10min warm-up, core activities, 5min cool down | Warm-up and self-massage, review of principles, movements, breathing techniques and relaxation in tai chi | static Qigong, dynamic Qigong, Tai Chi Form, Instructor demonstration, Tai Chi Principles discussed (detailed schedule provided by the authors) | 45min instruction including warm-up exercises | **Essential curricular requirements** included: Tai Chi training emphasizing on determined principles (see 2-5*).<br>**Non-Tai Chi components** were allowed if they were conducted in the spirit of Tai Chi: such as balance, flexibility, continuity and self-awareness training, meditation, self-massage, gentle interactive Tai Chi exercises. **Excluded** was training with weapons, sparring, aerobic demand, ancillary equipment or martial arts. | 5-10min warm up, TC practice, 5-10min cool down,<br>instruction covered learning new movements and reviewing movements learned in previous sessions.<br>musical accompaniment | 20min warm up, 30 min TC, 10min cool down |
| | 2-3 | **Did the content of the class change with time?** | The first 10 weeks emphasized the mastery of single forms through multiple repetitions; later weeks focused on repetitions to enhance balance and increase locomotion. | ? | The seven individual movements were gradually connected by transitions until they could be executed continuously, from start to finish, by the end of the forth month.<br>(see schedule provided by the authors) | A new posture was taught each week during the first 12 weeks, with the entire sequence of postures practiced together during the following 12 weeks. During the consecutive 24 weeks 12 additional postures were taught, with participants learning a total of 24 postures during the study. | ? | ? | The TC form was gradually taught over the 12 weeks |
| | 2-4* | **Were specific Tai Chi movements used in the training described and illustrated?** | Yes<br>(text + reference: 3 articles) | Yes<br>( 1 monograph) | Yes<br>(the figures' names were reported) | Yes<br>(reference: 3 monographs) | No | Yes,<br>( 1 monograph) | Yes,<br>(inventor of the form: Dr Pi-Lu Fei,<br>1 monograph, youtube link) |
| | 2-5 | **What were the major components (i.e. slow movements, mental concentration and deep breathing) of Tai Chi that were emphasized in the training?** | Natural breathing | ? | Relaxation, range of motion, breathing, weight shifting, awareness, body alignment, carrying relaxation to Qigong and form, carrying Tai Chi principles to daily activities, interaction with the world and importance of attitude/happiness | Body orientation, relaxation, breathing, attention to feeling. Inattention to thoughts, upright and relaxed posture, symmetry, weight shifting, a slow and relaxed pace | 1) Relaxed continuous movement<br>2) Vertical skeletal alignment<br>3) Meditative intention to promote self-awareness, relaxation and concentration<br>4) Instruction on breathing techniques | Multidirectional weight shifting, awareness of body alignment, multisegmental (arms, legs, trunk) movement coordination | **Basic TC elements:**<br>This short form contains no difficult or strenuous postures, yet contains all of the 13 key elements of Tai Chi that are essential for good health and emotional balance. The key elements include: Ward Off (Peng), Roll Back (Lu), Press (Ji), Push (An), Pull (Cai), Slap (Lie), Elbow (Zhou), Shoulder (Kao), Step Forward (Qian), Step Back (Kun), Look Right (Kan), Look left (Li), and Centering (Ding). |
| | 2-6 | **Did the participants progress as a group or as individuals?** | ? | ? | ? | ? | ? | ? | ? |
| | 2-7 | **Did the participants interact within partner tasks or to help each other?** | ? | ? | ? | ? | ? | ? | ? |
| | 2-8* | **Was the description of the control comparable to the description of the Tai Chi training?** | Mit der Frage bin ich unglücklich, da beide gleich schlecht berichtet werden könnten. Gefragt werden müsste nicht nach der Beschreibung sondern nach der Art der Durchführung…? | | Wait-list control group | Yes | Yes,<br>Usual care (wait list) control group,<br>description of components of usual care provided | Yes<br>(Stretching, mainly seated) | Yes<br>usual care: description of components of usual care provided |
| Teacher | 3* | **What were the credentials of the Tai Chi instructors in the study?**<br><br>**Who held the class when the teacher was sick?** | **TC instructors** (N = ?) were trained and certified during a 2-day workshop.<br>**Stretching and Resistance instructors** (N = ?) had at least 10 years of community teaching experience with adults and were certified by a recognized organization<br>**All instructors** were CPR certified and able to follow the research protocol | **TC instructor:**<br>One single Tai Chi master at a single center | **TC instructor:**<br>The principal investigator, a nationally recognized Tai Chi instructor with more than 30 years of experience of traditional training and 20 years of teaching experience both in China and the US.<br>The instructor was supported by a different teaching assistant at each location. | **TC instructor:**<br>a Tai Chi grand master<br>**western exercise instructors:**<br>certified exercise leaders at a YMCA facility<br>**attention control instructors:**<br>experienced professionals | Long lasting Tai Chi school, open to the public for a minimum of 5 years,<br>Senior instructor with a minimum of 10 years of training,<br>classes led by junior instructors supervised by a senior instructor | Experienced TC instructors | **Tai Chi instructor:**<br>a long-term practitioner of the Yang Style of Tai Chi, certified to teach the Yang Style of Tai Chi with over 30 years of teaching experience, including older adults with chronic diseases<br><br>**Registered nurse** experienced in exercise testing/supervision and possessing advanced cardiac life support certification |

## 4 Description of the Tai Chi Intervention

The 10-form Tai Chi protocol is a simple concept, adaptable to the abilities and needs of participants. The primary aim of each lesson is to provide the participants with an opportunity to employ in a self-determined exploration of the body and its abilities. Each lesson consists of four elements: warm-up, form, consolidation, cool-down. The warm-up phase includes two weight shifting exercises and is split in a time for conversation and a time in silence. Any further exercises are to be excluded to keep the intervention as simple as possible. The complete 10-form is practised several times each lesson. The number of repetitions varies depending on the mood of the participants. There may be several repetitions without a break in between. The time to complete the form once takes about 5 to 6 minutes. Additionally, each lesson contains a technique consolidation phase on specific elements of the form, based on the questions and needs of the participants. The lessons are concluded with a cool-down phase, comprising breathing and relaxation techniques which focus on body awareness and abdominal breathing in a sitting or lying position. This curricular concept allows for a ritualized course of Tai Chi training with a focus on the Tai Chi movements and principles. Included principles are body-alignment, moving the body slowly as a whole, staying balanced and aware of the body's centre of gravity as well as of the body's connection to the ground, awareness to weight-shifting and not falling into the step, mindful movement, relaxation and abdominal breathing. The training may be accompanied by music. We used the audiobook Shaolin Qi Gong - Energy in Motion (Energie in Bewegung) by Sayama and Shi Xinggui (2007).

**Warm-up (10-20min)**

The first exercise comprises rhythmic weight shifting from one leg to the other while swinging the relaxed arms from one side to the other via a rotation in the trunk and hip. The heel may be lifted from the floor when the body is turning away from it. The instructor should coach the participants regarding physiologic movement of the knees if necessary. During this activity, there is room for conversation.
The second exercise consists in shifting the body's weight to different directions in a relaxed and upright, standing position, feet hip-width apart. First, awareness is directed on a grounded, balanced and upright position, relaxed shoulders and comfort. Second, participants start slowly shifting their weight in different directions like a tree in the wind. They are encouraged to shifting within the comfort zone as well as beyond their comfort zone to explore their limits of stability. Third, the movements are reduced until the participants reach their centre, standing almost still.

**10-Form**

The 10-form is played in a symmetric way. While the figures commencement, cross hands and conclusion are played once, the remaining figures are played twice in opposite directions. The 10 figures are: commencement, reverse reeling forearms, brush knee and push, part the wild horse's mane, wave hands like clouds, rooster stands on one leg, kick with heel, grasp the peacock's tail, cross hands, conclusion. Depending on the way of counting, the 10-form is sometimes also called the 8-form (not counting the commencement and the conclusion). A video of the form can be found here: http://www.youtube.com/watch?v=P4Z4sQNQtJM or here http://www.youtube.com/watch?v=n_nfD5O15bk.

### Consolidation

The consolidation phase is used to pick specific elements from the form or principles for more detailed explanation and practice. The content of the consolidation phase is variable, depending on the participants' questions and needs. The aim of this phase is to help the participants to get more comfortable with the Tai Chi form. The accuracy of the Tai Chi movements according to the standard version are supported but not demanded. During the first two months of the intervention, the one leg stances are practised with the free foot touching the ground with the toes (rooster stands on one leg) or heel (kick with heel). After two months, the teacher starts demonstrating the single leg stance version. Participants are encouraged to choose their preferred way of playing the positions. The teacher emphasizes that the relaxed stability of the position (even with the help of the free foot) is more important than barely managing a single leg stance.

### Cool-down (15min)

During the cool-down phase, the attention is directed to the inside. The aim is mindful body awareness and abdominal breathing. First, the attention is directed to the body's contact to the ground and a feeling of being supported. Trusting this support, participants let go of weight and tension. Second, the attention is consecutively drawn to the breath—how and where it can be felt. Third, the hands are placed on the belly and try to feel the breathing. Forth, the incoming air is directed towards the hands to motivate abdominal breathing. Fifth, active engagement to breathing turns to simple awareness of the flowing movements of breathing and the alternation of expansion and release. Sixth, the attention is directed to the ground and further into the room, leading the participants back to the outside world. Seven, there is time for gentle movement, stretching and yawning. Eighth, in an upright position, the participants wake themselves up by tapping their body.

**Balance Test Description**[1]

| | | |
|---|---|---|
| 1. | aim | Quantitative measure of balance ability |
| 2. | tools | 1 balance beam (10cm in width, 4m in length, 1cm in height)<br>2 cones<br>1 volleyball |
| 3. | content | 14 Items, rated dichotomously (1 = achieved task, 0 = failed task) |
| 4. | course | test abortion after two consecutive fails |

**Coordination Test Description**

| | | |
|---|---|---|
| 1. | aim | Quantitative measure of balance ability |
| 2. | tools | 1 balance beam (10cm in width, 4m in length, 1cm in height)<br>2 cones<br>1 volleyball<br>1 gymnastics ball<br>1 gymnastics stick<br>3 target marks (20cm in diameter, 70cm apart, two in the height of 1.18m, one in the height of 1.74m), 1 target mark (1m in diameter, in the height of 3m) |
| 3. | content | 10 Items, rated dichotomously (1 = achieved task, 0 = failed task) |
| 4. | course | test abortion after two consecutive fails |

**Conduction of the balance test and the coordination test combined**

| Coordination | Balance | # | task | description |
|---|---|---|---|---|
| | | | The Test is comprised of 24 tasks in a rising level of difficulty. Try to complete as many tasks as possible. It is important that you keep up your concentration even when you failed to complete a task. The test is going to take this course: We do one task after the other. At first, I'm going to demonstrate the task for you and explain its rules. While I'm doing that you are not allowed to try the task yourself, instead you just watch and listen. When it's your turn, I'm going to repeat the aim of the task for you. Consecutively, you try to complete the task. You only have one single try for each of the tasks. | |
| | x | 1 | One leg stance | As soon as you're ready, you lift one knee up to the front.[2] Your free foot mustn't touch your standing leg and should be placed between the ankle and knee of you standing leg. The aim of this task is to keep standing on one leg for 15 seconds (s) without leaving the initial position of your standing foot. The time starts as soon as your foot left the ground. |
| | x | 2 | One leg stance, moving the free leg forth and back | As soon as you're ready, you start swinging one leg forth and back. The aim of this task is to stand 15s on one leg, while swinging the other. Your standing foot may not leave its initial position during the task. The time starts as soon as your foot left the ground. |
| | x | 3 | One leg stance after 360° turn | As soon as you're ready, you turn 360 degrees. Right after turning, you lift one knee up to the front. Your free foot mustn't touch your standing leg and should be placed between the ankle and knee of you standing leg. The aim of this task is to keep standing on one leg for 15s without leaving the initial position of your standing foot. The time starts as soon as you completed your turn and your foot left the ground. |

[1] While the original balance test is comprised of 12 tasks, we included eyes-open conditions for two tasks involving only eyes-closed conditions (jumping jack and moving a foot around two poles in the figure of eight). We chose this procedure for safety reasons, as eyes-closed conditions are very difficult for some MS patients.

[2] In tasks involving one-legged stances, participants were instructed to stand on the leg which in their opinion was best capable to complete the task successfully. We chose this method for economic reasons: First, using only one leg for all tasks might have induced motor fatigue in some participants. Second, testing both legs for each task would have taken too much

| Coordination | Balance | # | task | Description |
|---|---|---|---|---|
| x | x | 4 | Jumping Jack | Stand on this line with both feet touching each other and your arms relaxed beside your body. From this position, you jump into a wider stance and lift your arms sideways into the air simultaneously. Consecutively, you jump back into your initial position. The aim of this task is to do 5 jumping jacks, touching the line with at least one foot each time you land. As soon as you leave the line with both feet, you fail the task. |
| | x | 5 | One leg stance with eyes closed | As soon as you're ready, you lift one knee up to the front. Your free foot mustn't touch your standing leg and should be placed between the ankle and knee of you standing leg. Then you close your eyes. The aim of this task is to keep standing on one leg for 15s without leaving the initial position of your standing foot. The time starts as soon as you closed your eyes. |
| | x | 6 | One leg stance with eyes closed after 360° turn | As soon as you're ready, you turn 360 degrees. Right after turning, you lift one knee up to the front. Your free foot mustn't touch your standing leg and should be placed between the ankle and knee of you standing leg. Then you close your eyes. The aim of this task is to keep standing on one leg for 15s without leaving the initial position of your standing foot. The time starts as soon as you closed your eyes. |
| | x | 7 | One leg stance, moving the free leg forth and back with eyes closed | As soon as you're ready, you start swinging one leg forth and back. Then you close your eyes. The aim of this task is to stand 15s on one leg, while swinging the other. Your standing foot may not leave its initial position during the task. The time starts as soon as you closed your eyes |
| x | x | 8 | One leg stance, drawing the figure 8 around two cones | With one foot, you step between these cones, your feet should be about 15cm apart. The aim of this task is to draw the figure 8 around these cones with your leg. Keep this leg as straight as possible. You start drawing the figure 8 moving it sideways and then so the front around the front cone. After that, you move your leg between the cones and around the back cone and place it on its initial position between the cones. Try not to touch the cones on your way. Please do the task once with your eyes open and a second time with your eyes closed. If you don't feel comfortable closing your eyes, you may refrain from trying the task with your eyes closed. |
| x | | 9 | Touch three targets with a stick | You stand sideways to the wall with your dominant hand facing the wall holding the stick. The aim of this task is to touch these 3 target marks consecutively with the stick. At first, you touch them with your eyes open. After that, you close your eyes and try to hit them again. Please do this task slowly and concentrated. |
| x | | 10 | Moving pattern along the wall | The aim of this task is to move sideways to the right along the wall in a specific pattern. In the initial position, you are standing face to the wall with your hands touching the wall at about the height of your shoulders. Your feet are touching each other. Your hands are touching each other. Then you start the movement with your right foot and your left hand. Your right foot takes a step to the right. Simultaneously, your left hand crosses your right arm and is placed to the right of your right hand. After that, your left foot crosses your right leg and is placed to the right of it. Simultaneously your right hand crosses your left arm and is placed to the right of your left hand. After each step either your arms or your legs are crossed. Do the task in a slow and concentrated manner. As soon as you move a limb that does not have its turn, you fail the task. The aim of the task is to complete 10 steps in this pattern. I'm going to count for you. Please go into the initial position. You start with your right foot and your left hand. |

| Coordination | Balance | # | task | Description |
|---|---|---|---|---|
| x | | 11 | Jumping pattern | The aim of this task is to jump in a specific pattern while rotating your arms in backward circles. You stand with your arms straight behind your back, then you make a step with one leg, jump in the air with this leg while lifting the knee of your other leg. Your arms move upwards together with your free leg. Then you land on the leg you jumped from and make a step with the leg, repeating the same pattern. You complete the task when you manage to do 5 jumps of this pattern in a row. |
| x | | 12 | Catch a ball between the knees | In the initial position, you bend forward, holding the ball between your knees with both hands. One hand is holding the ball from the front and the other hand is holding the ball from the back. In this position, your arms are placed around one of your legs. The aim of the test is to let go of the ball and switch the position of your hands without dropping the ball on the ground. The hand that held the ball from the front should then be holding it from the back and the hand that held the ball from the back is holding it from the front. Now, your arms are placed around your other leg. You complete the task if you manage to switch the position of your hands 3 times without dropping the ball. |
| | x | 13 | cross the balance beam walking forwards | For your starting position, place one foot on the beam and the other foot next to the beam on the ground. As soon as you're ready, walk across the beam. At the end of the beam, you stop walking and stand safely with both feet on the beam for 3s. |
| | x | 14 | Walk forwards, turn in the middle and walk back | For your starting position, place one foot on the beam and the other foot next to the beam on the ground. As soon as you're ready, you start walking across the beam. As soon as you crossed the middle line, you turn 180° and walk back the way you came from. At the end of the beam, you stop walking and stand safely with both feet on the beam for 3s. |
| x | x | 15 | Walk backwards, turn in the middle, walk forwards | For your starting position, stand with your back to the beam, placing one foot on the beam and the other foot next to the beam on the ground. As soon as you're ready, you start walking backwards. When you crossed the middle line, turn 180° and continue walking forwards to the other end of the beam. At the end of the beam, you stop walking and stand safely with both feet on the beam for 3s. |
| | x | 16 | Walk backwards, turn 360° in the middle, continue walking backwards | For your starting position, stand with your back to the beam, placing one foot on the beam and the other foot next to the beam on the ground. As soon as you're ready, you start walking backwards. When you crossed the middle line, turn 360° and continue walking backward to the other end of the beam. At the end of the beam, you stop walking and stand safely with both feet on the beam for 3s. |
| x | x | 17 | Cross the beam walking forwards while dribbling a volleyball | You may try dribbling this ball prior to the following task. For your starting position, with the volleyball in your hands, place one foot on the beam and the other foot next to the beam on the ground. As soon as you're ready, you start dribbling the ball. Then you walk across the beam to the other end while dribbling. At the end of the beam, you stop walking and stand safely with both feet on the beam for 3s. |
| | x | 18 | Walking forwards with eyes closed | For your starting position, place one foot on the beam and the other foot next to the beam on the ground. As soon as you're ready, you close your eyes and walk across the beam. You may touch the ground slightly while searching for the beam with your feet. At the end of the beam, you stop walking and stand safely with both feet on the beam for 3s. |

| Coordination | Balance | # | task | Description |
|---|---|---|---|---|
| x | | 19 | Throw and catch a ball | You stand behind this line with the ball in your hands. The aim of this task is to throw the ball with one hand against this target mark and to catch it before it hits the ground. To catch the ball you may step across the line. |
| (x) | | 20 | Throw the ball, turn 360°, catch the ball | You stand with the ball in your hand. As soon as you're ready, you throw the ball into the air, turn 360° and catch the ball before it hits the ground.<br>(We omitted this task for safety reasons.) |

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## Eidesstattliche Erklärung

Ich versichere hiermit an Eides statt, dass ich die vorliegende Arbeit ohne unzulässige Hilfe Dritter und ohne Benutzung anderer als der angegebenen Hilfsmittel angefertigt habe; die aus fremden Quellen direkt oder indirekt übernommenen Gedanken sind als solche kenntlich gemacht.

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Ort, Datum

Janina Burschka