Hard martial arts for cognitive function across the lifespan: a systematic review

Liye Zou[1BCD], Tao Huang[2ABCD], Tracy Tsang[3BD], Zhujun Pan[4BD], Chaoyi Wang[5BCD], Yang Liu[6ABD], Li Sun[7BD], Huiru Wang[2BDE]

Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Manuscript Preparation
E Funds Collection

[1] Department of Sports Science and Physical Education, the Chinese University of Hong Kong, Hong Kong, China
[2] Department of Physical Education, Shanghai Jiao Tong University, Shanghai, China
[3] Discipline of Child and Adolescent Health, Sydney Medical School, University of Sydney, Sydney, Australia
[4] Department of Kinesiology, Mississippi State University, Starkville, USA
[5] Department of physical education, Jilin University, Changchun, China
[6] Sensorimotor Neurophysiology Laboratory, Indiana University, Bloomington, USA
[7] School of Humanities and Social Science, the Chinese University of Hong Kong, Shenzhen, China

Received: 23 November 2017; **Accepted:** 18 January 2018; **Published online:** 15 February 2018

AoBID: 11861

Abstract

Background and Study Aim: Martial arts are offensive and defensive combat systems, characterised by coordinated and cognitively complex movements. Martial arts are typically classified as "hard" and "soft" styles. Hard styles focus on quick and forceful movements involving striking, kicking, blocking, grabbling, and takedown (e.g., karate, taekwondo, kung fu and judo). The aim of this review is in the existing scientific literature knowledge about pertaining to the effects of martial arts on cognitive function across the lifespan.

Material and Methods: Both electronic and manual searches of the English-language articles published were conducted without limiting year of publication. The rigorous critical appraisal was independently performed, resulting in the inclusion of 18 studies.

Results: Study results from the existing scientific literature indicate that martial arts (karate, taekwondo, kung fu, and judo) can improve some selected aspects of cognitive function and neurotrophic factors (serum BDNF and IGF-1) associated with brain health. Specifically, martial arts could be promising approaches to potentially stimulate the development of cognitive function in children and adolescent, and decelerate cognitive decline in middle-aged and older adults.

Conclusions: Hard martial arts may be beneficial for improving some selected aspects of cognitive function across the lifespan. Because only a few studies used randomised controlled trials, a definitive conclusion regarding the beneficial effects of martial arts on cognitive functions is still difficult to be made at this stage. To better understand the effects of martial arts for cognitive function across the lifespan, future research should involve larger sample sizes, well-controlled designs, standardised assessments and long-term follow-ups, measures of health status, exercise intensity, leisure time activities, and session attendance rates.

Keywords: brain health • cognitive flexibility • inhibitory control • neurotrophic factors • working memory

Conflict of interest: Authors have declared that no competing interest exists

Ethical approval: Not required

Provenance & peer review: Not commissioned; externally peer reviewed

Source of support: This study was supported by Shanghai Pujiang Program (No.16PJC052)

Author's address: Huiru Wang, Department of Physical Education, Shanghai Jiao Tong University, Shanghai, China; email: wanghrsjtu@163.com

Martial arts – plural noun any of various systems of combat and self-defence, e.g. judo or karate, developed especially in Japan and Korea and now usually practised as a sport [70].

Wing Chun or Ving Tsun (VT) – a hard-style Chinese martial art and a whole-body strengthening exercise, is a high-impact combat sport [71].

Tai chi – noun a Chinese form of physical exercise characterised by a series of very slow and deliberate balletic body movements [70].

Cognitive – adjective relating to the process of acquiring knowledge by the use of reasoning, intuition or perception [70].

Inhibitor – noun a molecule that attaches to an enzyme and makes it less active, widely used in drugs [70].

Neurotrophic – adjective relating to the nutrition and maintenance of tissue of the nervous system [70].

Nerve – noun 1. a bundle of fibres that can transmit electrochemical impulses and that forms part of the network that connects the brain and spinal cord to the body's organs 2. the sensitive tissue in the root of a tooth [70].

PE – abbreviation physical education [70].

Working memory – noun the contents of someone's consciousness at the present moment, containing only the information needed to perform the current task [70].

Poomse (kata in karate) – it is traditionally understood as the style of conduct which expresses directly or indirectly mental and physical refinements as well as the principles of offence and defence resulting from cultivation of taekwondo spirit and techniques. Nowadays, poomse is involved in competition in the taekwondo technique modality [72].

INTRODUCTION

Martial arts are offensive and defensive combat systems, characterised by coordinated and cognitively complex movements [1]. Martial arts are typically classified as "hard" and "soft" styles [2]. Hard styles focus on quick and forceful movements involving striking, kicking, blocking, grabbling, and takedown (e.g., karate, taekwondo, kung fu and judo) [2]. Soft styles emphasise the cultivation of internal energy such as tai-chi and health-qigong [3]. Data reported in Info-USA indicated that there were fourteen thousand martial arts schools in the USA [4] and around 18.1 million Americans were involved in learning and practising at least one style of martial arts in the past year [5]. Of the practitioners, there were 9.4 million adults, 5.5 million adolescents and 3.2 million children [5].

Previous studies investigated different types of martial arts in relation to participation motivation [6], injury prevention [7, 8], physiological responses (e.g., energy expenditure, oxygen consumption, blood pressure, and heart rate) [9-11], postural stability [12, 13], and musculoskeletal health [14-16]. The nature of martial arts requires practitioners to memorise multiple sequential movements in a choreographed routine, and avoid attacks from opponents (requiring fast reaction time and sustained attention) and then launch effective counterattacks (cognitive flexibility, movement planning, and problem-solving) in sparring practice [1]. Due to its complexity and multi-component nature, researchers have recently started to examine the effects of martial arts practice on brain health and cognitive functions. Studies showed that martial arts improved cognitive function in children (visual selective attention and executive function) [17-20] and adults (reaction time and divided attention) [21, 22], and may have contributed to mitigations in age-related cognitive decline (cognitive processing incidental memory, work-memory, and learning memory) [23, 24].

With the increasing number of studies in martial arts, three reviews have been published to summarise experimental and observational studies investigating the efficacy of martial arts on health-related indicators [25-27]. These reviews solely focused on evaluating physical and physiological responses resulting from martial arts training. No systematic review has specifically addressed the impact of martial arts on cognitive function and the possible neural mechanisms (e.g. changes in the pattern of cortical activation and/or brain morphology) underlying any cognitive improvements.

The aim of this review is in the existing scientific literature knowledge about pertaining to the effects of martial arts on cognitive function across the lifespan.

MATERIAL AND METHODS

Search strategy

Studies examining the efficacy of martial arts on cognitive function were identified through a comprehensive computerised search of seven electronic English-language databases (Web of Science, Google Scholar, PubMed, SPORTDiscus, Elsevier, PsycINFO, and Archives of Budo) on August 3, 2017. We did not limit the search by publication date. Search terms involved the combination of martial arts (karate, taekwondo, kung fu, wing chun, judo, jiu-jitsu, or wrestling) with cognition-related terms (cognition, executive function, inhibitory control, cognitive flexibility, or working memory). An example of the actual search strategy used can be accessed at (https://www.crd.york.ac.uk/prospero/#recordDetails). Manual searches were also performed through the reference lists of original and review articles. This review protocol (No. CRD42017074449) was registered on the International Prospective Register of Systematic Review (PROSPERO; https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=74449). The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist was used to present detailed information in this systematic review [28].

Eligibility criteria

Studies were included in this review if they met the following criteria: (1) a peer-reviewed English-language publication; (2) retrievable full-text articles (if articles were not easily and readily available online, we had contacted corresponding authors or used library loan to request the full-text articles); (3) any 'hard' style of martial arts (e.g., karate, taekwondo, kung fu, wing chun, judo, jujitsu, and wrestling) as the primary exercise intervention; (4) reported quantitative data for at least one component of cognitive function or cognition-related neurotrophic factors: e.g. brain-derived neurotrophic factor (BDNF); insulin-like growth factor (IGF-1); nerve growth factor (NGF); (5) randomized controlled trials (RCT); non-randomized controlled trials (NRCT); pre-test and post-test study (PPS); cross-sectional study (CSS).

Exclusion criteria were: 1) conference proceeding, magazine articles, cases report, book reviews, and review papers; (2) soft styles of martial arts (e.g., tai chi, qigong)

There was no restriction relating to duration, volume (see Editorial Note), or intensity of martial arts training.

Data selection

Two review authors independently screened all identified article titles and abstracts and classified each as either "relevant", "irrelevant" or "unsure" based on the predefined eligibility criteria. Agreement between the two review authors in their classification of papers as "relevant" was calculated using percent exact agreement [29]. A third reviewer resolved any disagreement between the two review authors about the classification of studies.

Risk of bias in individual studies

The risk of bias of all experimental studies (RCT, NRCT, and PPS) was evaluated using the 9-item quality assessment tool [30]. Specifically, these items pertained to randomisation, use of a control group, isolated martial arts intervention, pre-post test design, retention ≥70%, the similarity of groups at baseline, missing data management, power analysis, and validity and reliability of measures of interest. Each item was scored "1" if present and described. If the information was absent, the item was scored "0". The maximum score possible was nine. The risk of bias of observational studies included was not evaluated, and those studies were narratively described.

Data extraction

Summary tables were developed, which included data entry fields for study authors and year of publication; sample characteristics (sample size, gender, recruitment source, age, health status, and educational level/intelligence quotient; age, health status, educational level/IQ are highly associated with cognitive function [31, 32], which were considered as independent factors in this systematic review); intervention details (session attendance rate, style of martial arts, training duration and volume, training intensity, and qualification of instructor); and dropout rate (lost to follow-up); and cognitive function outcomes (values reported at baseline and post-intervention). Two of the authors independently extracted the abovementioned data. A third author verified the consistency of data extracted by the other two authors. If any inconsistencies in data extracted were found, the original article was referred to and discussed amongst the authors until a consensus was reached.

Statistical analysis

Based on previous literature [33-35], we extracted mean and standard deviation at baseline and posttest or within-group change scores for the variables of interest in these experimental studies. If the change score data were not reported, the leading review author contacted the corresponding author and asked for the original dataset. For experimental studies reporting a statistically significant improvement after martial arts training compared to the control condition, the effect size was computed using the means and standard deviations reported. The interpretation of effect size was as follows: (1) $d \geq 0.2$ is considered small; (2) $d \geq 0.5$ is moderate; (3) $d \geq 0.8$ is considered large [36].

RESULTS

Study selection

The electronic and manual searches resulted in 298 potential relevant records. Sixty-nine articles were included after removing 229 duplicates based on title and abstract. Thirty-six articles were then excluded due to the following reasons: (1) irrelevant topic (n = 18); (2) non-martial art intervention (n = 9); (3) no cognition-related indicator (n = 5); (4) book publication (n = 1); (5) non-peer reviewed studies (n = 2); (6) non-English language study (n = 1). The remaining 33 articles underwent the full-text critical appraisal, and 15 full-text articles were not qualified (1 review studies, 1 case study, and 8 soft martial arts, which resulted in a final number of 18 eligible studies [30, 28, 27, 29, 36, 33-35, 37-46]. The inter-rater agreement for classifying papers as "relevant" was 94.5% (Figure 1).

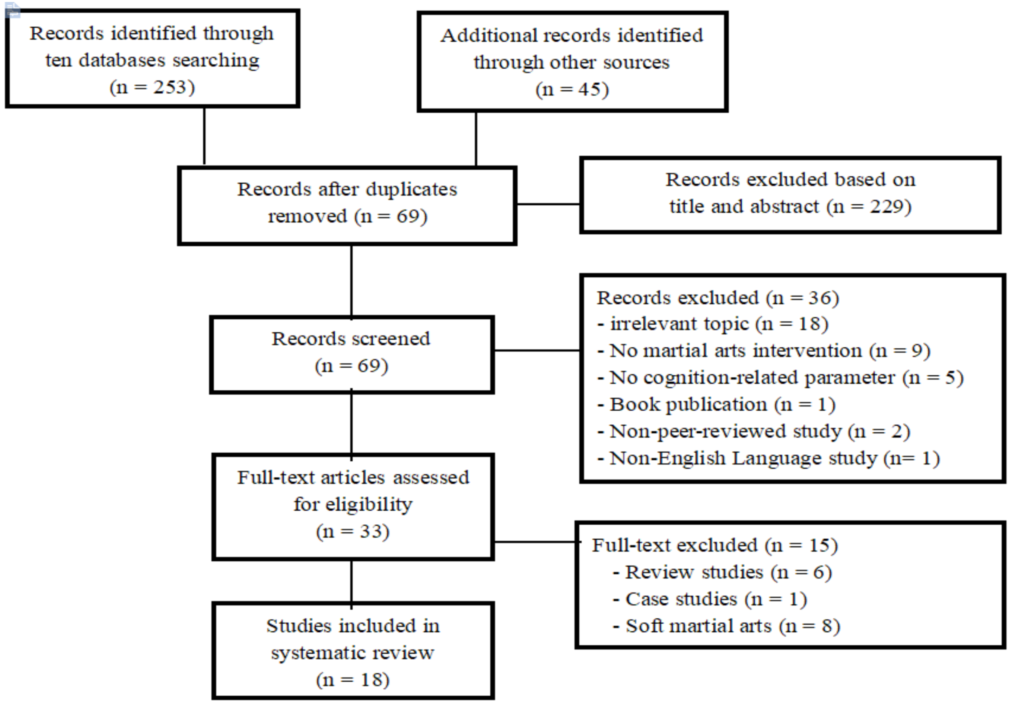

Figure 1. Flowchart showing the retrieval of studies for review.

Study characteristics

Of the 18 studies, six were RCTs [17-20, 23, 24, 47], three were NRCTs [48-50], three were PPS [51-53], and six were CCS [19, 21, 22, 54-56] (Tables 1, 2). Most of the included studies were undertaken in South Korea [20, 47, 48, 50], then USA [17, 18, 53] and Germany [23, 24, 49], with two in Italy [19, 56], and one in Netherlands [52], UK [54], Spain [55], Japan [21], Canada [51], and Hong Kong [22]. Most (n = 13, 72.2%) of these studies were published after 2010 [18-20, 22-24, 47, 49-53, 56] and five were published between 2002 and 2006 [17, 21, 48, 54, 55], indicating that research on the relationship between martial arts and cognitive function is a relatively novel but expanding field. The recruitment source for four studies was not described [20, 23, 24, 54].

A total of 1,026 participants were included in this systematic review, with study sample sizes ranging from 10 to 207 participants. Age of participants ranged from 9.05 to 83.2 years. Of the aforementioned variables (age, health status, education level, and IQ) relating to cognitive function, only one study reported a significant difference in mean age between martial arts and control groups at baseline [49].

Methodological quality within experimental studies

According to the 9-item assessment tool, the methodological quality of the experimental studies ranged from 5 to 8 points. Specifically, 3 studies were awarded 8 points [20, 47, 50], followed by 7 points to 2 studies [17, 18, 23, 24, 48], 6 points to 3 studies [49, 52, 53], and one study obtained only 5 points [51]. Points were deducted because these studies did not met the following criteria, including randomization [48, 51-53], control group [51-53], isolated martial arts intervention [17, 18], similar baseline [49], missing data management [17, 18, 23, 24, 49, 51], and power analysis [20, 23, 24, 47-53] (Table 3).

Child studies

Taekwondo was the only style of martial arts used in all four experimental child studies in which martial arts attendance rate was not reported [17, 18, 20, 47]. Of the experimental studies, taekwondo intervention length ranged from 3 to 9 months, with 3 to 5 sessions weekly (each session ranged from 40 to 70 minutes) [17, 18, 20, 47]. When compared to these RCTs, the control condition involved no intervention [20, 47] and physical education program [17, 18]. Exercise intensity during martial arts training was reported in two experimental studies in which they were a maximum heart rate of 50 to 80% [20] and mean ratings of perceived exertion of 11 to 15 [47]. Of the four experimental child studies, only two RCT clearly reported the qualified taekwondo instructor [17, 18]. None of these experimental studies examined the long-term effects of taekwondo on cognitive function and reported adverse events during taekwondo intervention. For the two observational studies, study participants in the martial arts group involved 3 to 5 years of karate (3 60-to-90 minutes weekly) [19] and a 2.8-years average of taekwondo [22] training experience, without reporting the exercise intensity and qualification of instructor (Table 4).

Adult studies

Of the 8 experimental adult studies, martial arts session attendance rate was only reported in five studies and ranged from 78.4% to 100% [23, 24, 49, 52, 53]. Karate was the most widely studied style of martial arts [23, 24, 51, 53], followed by taekwondo [48, 50, 52], and one experimental study investigated a combination of styles (kung fu, karate, jutsu, and/or taekwondo) [53]. Eight experimental adult studies reported martial arts intervention length ranging from 8 weeks to 15 months, with 1 to 5 sessions weekly (each session ranged from 45 to 90 minutes) [23, 24, 48-53]. The control conditions in five comparative studies received either no training [48, 50], mindfulness-based stress reduction program [24], fitness program [23], and physical exercise and cognitive training [49]. Only one experimental study reported exercise intensity involving mean ratings of perceived exertion of 13-15 [50]. It is worth noting that none of the selected experimental studies reported adverse events. Only two studies examined the long-term effects of martial arts on cognitive function by using 5-month [24], and 6-month follow up assessments [51]. Detailed information relating to the qualification of martial arts instructor was clearly described in 5 experimental studies [23, 24, 48, 49, 51], but not in the other 4 observational studies [21, 54-56]. Four observational studies [21, 54-56] reported martial arts training experience ranging from 1 to 10 years. Details of the training programs are presented in Tables 4, 5.

Retention rate

Three experimental child studies [18, 20, 47] and four experimental adult studies [48, 50, 52, 53] reported a retention rate (retention of initial sample size throughout the martial arts intervention) of 100%. One experimental child study reported 6% attribution rate (94% retention rate) of initial sample size [17] and four experimental adult studies reported the attribution rate ranging from 12.4 % to 28.5% (71.5%-87.6% retention rate) [23, 24, 49, 51] (Table 1).

Cognitive Function Outcomes

Reaction time: The relationship between martial arts and reaction time was studied in four experimental studies [23, 48, 51, 52] and two observational studies [21, 54]. The four experimental studies included adult participants and found positive effects of martial arts on this outcome. Two controlled trials demonstrated improvements after martial arts training on some reaction time variables compared to passive and active control conditions [23, 48]. Specifically, Song et al. [48] reported an improvement in mean motor reaction time (measured using EMG with electrodes of Channel 1 and Channel 2 attached to the biceps femoris and rectus femoris, and ground electrode attached to the tibialis anterior of the right foot when subjects perform right knee kicking) in mentally retarded youth (MA group aged 18.8 ±1.8; control group aged 18.4 ±1.6) after a seven-month (3 x 45min/week) Taekwondo program. Such this martial arts program was designed for the cognitive and physical capabilities of mentally retarded people (mean change: –39.1 msec) compared to no training (mean change: –6.5 msec; $p<0.05$, $d = 0.898$) (Tables 4, 5).

In another study, when compared to the control group (usual sport activities) and fitness group, significant improvements in falling length of the rod in the Rod Test ($p<0.05$, $d = 0.35$) was found in the karate group [23] (Table 6). A pre-test and post-test study by Marie-Ludivine et al. [51] indicated that a 6-month karate program improved reaction time of the non-dominant hand ($p = 0.01$) in 20 adults aged 50 and above. Another PPS indicated that reaction time decreased with 41.2 (posttest minus baseline) ($p = 0.004$) following a 15-month taekwondo training [52]. Research findings from other two cross-sectional studies [21, 54] support the idea that martial arts has the potential to improve reaction time performance in the adult population, but only one study reported significant improvement [21] (Table 7). Only one CCS investigated the relationship between martial arts and reaction time among children, suggesting that martial arts group (0.19 ±0.03 sec) demonstrated significantly shorter reaction time than the control group (0.22 ±0.02 sec).

Executive function in child studies: the relationship between executive function (inhibitory control, working memory, and cognitive flexibility) or its individual component were studied in four experimental studies among children [17, 18, 20, 47] and one observational children study [19]. Two children studies examined the effects of martial arts on the overall executive function as measured by the Heart and Flower Test and [18] and the Tower of London Test [19] (Table 7). Specifically, a RCT by Lakes et al. [18] indicated Taekwondo effectively improved performance on congruent (d = 2.0, p = 0.02), incongruent (d = 1.43), and mixed trials (d = 2.33) among middle schoolers. A cross-sectional study by Alesi et al. [19] indicated that children in the karate group showed significantly better performance on execution quality of planning task ($p<0.05$, d = 0.67) and times of executive function task ($p<0.05$, d = 0.903), as compared to their counterparts. Four experimental children study also examined the relationship between martial arts and inhibitory control as measured by the Stroop Color and Word Test [20, 47], the response to challenge scale [17], the Strengths and Weaknesses of Attention Deficit Hyperactivity Disorder and Normal Behavior [18], respectively. The study findings from the four experimental studies support the idea that martial arts have the potential to generate the significant positive effects on the inhibitory control among children [17, 18, 20, 47]. When researchers examined the relationship between working memory and martial arts in an experimental child study [17] and one cross-sectional study [19], none of the experimental studies reported significant positive effects of martial arts on this outcome (Tables 4, 5).

Executive function in adult studies: three experimental studies examined the relationship between martial arts and inhibitory controlled as measured by the Stroop Color and Word Test [24, 50, 53]. The study findings from only two studies [50, 53] indicated that martial arts could effectively improve the inhibitory control among the adult population. Specifically, an RCT by Kim et al. [50] indicated that taekwondo could effectively improve the performance of the word test (baseline = 60.42 ±9.6 score, posttest = 69.85 ±5.24score, $p<0.05$) as compared to healthy college students receiving no training. Another pre-test and post-test study indicated that significant improvements on the three subtests of the Stroop Color-Word Test were observed following the 60-minute martial arts training, including word test (baseline = 51.2 ±8.5 score, post-test = 58.6 ±9.9 score, <0.05), Color Test (baseline = 48.3 ±7.3 score, posttest = 53.4 ±2.3 score, $p<0.05$), and Color-Word Test (baseline = 54.5 ±9.8 score, posttest = 57.9 ±8.9 score). When three experimental adult studies [24, 49, 52] investigated the relationship between working memory and martial arts none of the experimental studies reported significant positive effects of martial arts on this outcome. Only one randomised controlled trials (RCT) examined the effects of martial arts on cognitive flexibility in older adults, but significant improvement on this outcome was not observed [24].

Cognition-related measures in adult studies: researchers examined the relationship between martial arts and cognitive function [23] or other individual components such as cognitive processing speed [24, 49, 52, 55], selective visual attention and motor speed [23, 52, 56], and semantic memory [52], and reactive stress tolerance [23] (Tables 6, 7). Specifically, dynamic visual acuity as a marker of cognitive processing speed was measured using the Computerized Test (DinVA 3.0 software) in an observational study [55]. Another three experimental studies examined the relationship between martial arts and cognitive processing speed as measured by the Number Symbol Coding Test and the Number Connection Test in the adult population [24, 49, 52]. Only three studies reported positive effects of martial arts on this outcome among this population [24, 52, 55]. Randomized controlled trials by Jansen et al. [24] indicated that martial arts group demonstrated significant cognitive processing speed between baseline (38.91 ±7.9 score) and posttest (46.65 ±9.28 score), whereas no significant improvement was found in the mindfulness-based stress reduction program. A PPS by Pon van Dijk et al. [52] indicated that significant improvement of cognitive processing speed was found between baseline (74.2 ±10.8 score) and posttest (77.8 ±12.6 score) (Table 6). A cross-sectional study by Muinos et al. [55] indicated that both judo and karate groups demonstrated significantly better dynamic visual acuity than those in the control group among both middle-aged (judo = 0.463 ±0.061 score; karate = 0.475 ±0.06 score; control = 0.443 ±0.06) and older adults (judo = 0.418 ±0.083; karate = 0.419 ±0.069 score; control = 0.36 ±0.073) (Table 7).

Researchers examined the relationship between martial arts and selective attention and motor speed as measured by the Trail Making Test [52, 56], and the Computer-based Divided Attention Test [23]. Only one RCT [23] and a CSS [56] reported significant positive effects of martial arts on these outcomes among older individuals (Table 7). For the experimental study, Witte et al. [24] indicated that martial arts (baseline = 900.86 ±113.99 vs. posttest = 859.93 ±100.709) demonstrated significantly better performance in the Divided Attention Test as compared to those in the fitness group (baseline = 874.29 ±109.3 vs. posttest = 865.62 ±97.34) and control group (baseline = 863.31±91.8 vs. 857.5 ±97.71) receiving no training. When compared to the passive group and active group receiving fitness training, reactive stress tolerance test (p = 0.00, d = 0.33) was observed in the karate group [23]. Lastly, a significant improvement on semantic memory was not observed in a PPS [52]. For the child study, only a CCS [19] examined the relationship between martial arts and selective attention and motor speed as measured by the Visual Discrimination Test [19]. This observational study indicated that martial arts group (9.74 ±1.37) demonstrated significantly better selective attention than those in the control group (7.75 ±3.45) [19].

Neurophysiological variables relating to cognition: in addition to the behavioral outcomes, two RCTs examined the potential neurophysiological mechanism underlying the effects of martial arts on cognitive function in children [47] and adult population [50]. When compared to the control group, taekwondo effectively upregulated serum levels of BDNF (p = 0.005, d = 0.444), VEGF (p = 0.04, d = 0.318) and IGF-1 levels (p = 0.046, d = 0.285) in children [47], but not in young adults [50].

DISCUSSION

The results of this review indicate that martial arts can be an effective exercise intervention for stimulating the development of selected aspects of cognitive function in children and adolescents and ameliorating cognitive decline in middle-aged and older adults. Given that multiple issues (e.g., the unclear description of adverse events in all selected studies, the limited number of RCTs and heterogeneity of instruments among different age groups of individuals) exist, a definitive conclusion regarding the effectiveness of MA on CF in a specific population is still difficult to be made at this stage.

The existing evidence has shown that martial arts improved reaction time of upper limbs efficiently across the lifespan, particularly in older populations. Interestingly, martial arts effectively improved reaction time of the non-dominant hand among 20 right-hand dominant individuals [51], which is possibly explained by the features of karate involving powerful and quick bimanual coordination manipulation practice (e.g., hand blocks for avoiding attack, followed by quick counterattack/strikes, which requires fast reaction time). Future studies are investigating the effects of martial arts on reaction time in lower limbs that is also critical. It is commonly recognised that fall in the ageing population is one of the most devastating causes of the death [57, 58]. The ageing population who have faster reaction time in lower limbs are more likely to associate with the decreased number of fall episodes in their daily lives [59, 60]. If martial arts are beneficial for improving reaction time in lower limbs for better physical balance, more exercise options can be offered for this vulnerable populations to attenuate the physical function degeneration for their longer expectancy.

The study findings from this systematic review indicate that martial arts have the potential to improve executive function or its selected aspects across the lifespan, particularly in children and adolescents. With the advance in technology, imaging studies in the emerging literature indicate that prefrontal cortex responsible for the executive function does not fully mature until late adolescence. The immature/developing brain typically experience myelination and synaptic pruning. Such progressive and regressive changes are partially driven by external stimulation (individual experience) in this age group. Martial arts practice may be a rich experience, which possibly helps stimulate the development of immature prefrontal cortex at the sensitive period [44] or effectively facilitate production and efficiency of neurotransmitters, angiogenesis, synaptogenesis, and neurogenesis [61-65], which potentially contributed to improved executive function in children and adolescents. Specifically, martial arts improved inhibitory control as one of the core cognitive skills of the executive function, which may be attributed to that martial arts (e.g., martial arts, kung fu, and taekwondo) emphasise self-regulation/self-discipline and respect. A recently published meta-analysis concluded that martial arts effectively improved inhibitory control/ self-regulation, leading to reduced aggression [66]. Such this kind of cognitive ability is critical for children to succeed in the 21st century.

Because of participating in martial arts, other components of cognitive function improved, including cognitive processing speed, visual selective attention/reactive stress tolerance and motor speed. Such study findings can be explained by martial arts practice involving eye-hand coordination, focused attention and filtering irrelevant information out (best reflects in these tests). However, the study findings from the current systematic seem not to support the beneficial effects of martial arts on improving semantic/working memory and cognitive flexibility in both children and adult populations. Although martial arts improved these outcomes, but the positive effects were not significant. A maximum number of 60-min sessions reported in the four studies examining the effects of martial arts on working memory was 40 for a 15-month intervention period [43]. Additionally, none of the four experimental studies reported exercise intensity [17, 24, 49, 52]. For instance, an inverted U dose-effect relationship between exercise intensity and memory performance was found in a recently published animal study [67]. Thus, it remains unclear whether exercise intensity and martial arts training dosage are inadequate to stimulate prefrontal cortex. Taken together, the findings indicate that martial arts practice may benefit some selected aspects of cognitive function. The potential mechanisms underlying the beneficial effects of martial arts remain unknown. Best [41] proposed three pathways by which physical exercise might improve cognitive function. These potential pathways were followings: (1) the cognitive demands in participation in exercise; (2) the cognitive demands of complex motor movement; (3) and physiological changes resulting from exercise [41. Since martial arts are cognitively-demanding exercise, these pathways may explain at least one part of the underlying mechanisms of martial arts on cognitive function. Interestingly, when two RCTs examined the effects of martial arts on the neurotrophic factors, the study findings indicated that martial arts training effectively upregulated serum BDNF, VEGF, and IGF-1 in children [47], but not in young adults [50]. It could be that young adults are on the peak of some cognitive function (the neurotrophic factors do not significantly improve, which may be due to celling effect) [46]. Since the neurotrophic factors are thought to play key roles in mediating exercise-induced improvements in brain functions [39], the study [50] provided some possible physiological plausibility of the effects of martial arts training on brain health.

LIMITATIONS AND RECOMMENDATIONS

This is the first systematic review examining the effects of martial arts on cognitive function. The current evidence supports the idea that martial arts may be alternative to facilitate the development of some selected aspects of cognitive functions in the immature brain (children and adolescents) and attenuate the process of cognitive function decline in the ageing population. This would add to the literature supporting the benefits of martial arts for physical and physiological domains, including heart rate, cardiopulmonary function, balance performance, bone mineral density [9-13, 14-16]. However, it is worth noting that some study limitations should be acknowledged. Firstly, this review includes only retrievable full-text papers published in the English language regardless of other unpublished (e.g., thesis and dissertation) and non-English work is available on this topic for deepening our understanding. In the included studies, none were able to blind the martial arts instructors or participants. Ideally, study participants and instructors should be blinded in RCTs to minimise the risk of bias. Although the blinding of instructors is often impractical in exercise intervention, the adoption of "sham" exercise control arms could be a better method to blind martial arts participants for reducing the risk of bias [68, 69]. The heterogeneity of samples, assessment tools, experimental designs, the unclear description of exercise intensity during martial arts training and session attendance rate, and poor methodological quality (the lack of randomization, intention-to-treat analysis, prior power analysis and isolated martial arts intervention, and relatively small retention rate in several experimental studies) lessened the power of detecting significant improvement following martial arts training. Multiple styles (e.g., kung fu, karate, judo, and taekwondo) of martial arts in these experimental studies limited the ability to determine which specific style of martial arts are most beneficial for cognitive function. Follow-up assessment was only used in two studies [23, 51], so it remains unclear whether the long-term beneficial effects of martial arts continue following the completion of the intervention period. Moreover, many of the cognitive function tests are intended for use and interpretation by qualified psychologists or trained staff. Therefore, the cognitive function assessor's profession is important to determine the accuracy of the test results. Among the eighteen studies, only one study reported, "All outcome measures were administered by seven blinded student raters who had received training from the first author before the study", and two studies reported, "outcome measure was administrated individually by the experimenter". The rest of studies failed to report assessor qualification. Furthermore, to deeply understand the martial arts-induced cognition mechanism, functional magnetic resonance imaging should be used to identify and quantify the relationship between cognitive function and martial arts.

CONCLUSIONS

This comprehensive systematic review suggests that martial arts program is a promising intervention program that could be incorporated into long-term strategies for enhancing cognitive function and brain health among different age groups of individuals. Prior to more definitive conclusions can be made, future studies should not only involve large-scale, more robust randomized controlled trials with follow-up periods, but also measuring some independent variables (e.g., health status, exercise intensity, and session attendance rate) may be highly associated with cognitive function, which may help researchers gain deeper understanding about the effects of martial arts on cognitive function.

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Table 1. Study and participant characteristic: experimental studies.

Reference & Study design	Country	N (male)	Recruitment source	Age [mean years; ± standard deviation or ÷ range]		Health status		Education level or IQ	
				martial arts	control group	martial arts	control group	martial arts	control group
Children or adolescents									
Lakes et al. [17] RCT	USA	207 (94)	a middle school	not reported	not reported	healthy	healthy	kindergarten to grade 5	kindergarten to grade 5
Lakes et al. [18] RCT	USA	60 (30)	a middle school	12.2	12.3 not reported NS	healthy	healthy	7th and 8th grade	7th and 8th grade
Cho et al. [20] RCT	South Korean	35 (21)	not reported	11.2 ±0.8	11.4 ±0.7 NS	healthy	healthy	not reported	not reported
Cho et al. [47] RCT	South Korean	30 (18)	an elementary school	11.2 ±0.77	11.33 ±0.72 NS	healthy	healthy	4th and 6th grade	4th and 6th grade
Adults									
Witte et al. [23] RCT	Germany	89 (30)	not reported	68.8 ±4.1	fitness group: 69 ±5.3NS CG:68 ±5.1NS	healthy	healthy not reported	college degree	college degree NR
Jansen et al. [24] RCT	Germany	66 (21)	not reported	62.57 ±4.19	MBSR:63.29 ±8.53NS CG:65.24 ±4.66NS	10 somatic illness	9 somatic illness MBSR; 5 CG, NS	not reported	not reported
Song et al. [48] NRCT	South Korea	20	a special high school	18.8 ±1.8	18.4 ±1.6	mentally retarded	mentally retarded	high school students, with IQ range: 50÷75	high school students, with IQ range: 50÷75
Jansen et al. [49] RCT	Germany	52 (15)	a hospital or two nursing homes	73.6 ±3.9	PE 83.2 ±5.4; cognitive training:74.6 ±5.5 CG: 82.7 ±6.6*	healthy	healthy	not reported	not reported
Kim et al. [50] RCT	South Korea	14	university	20.71 ±1.49	20.57 ±0.53	healthy	healthy	college students	college students
Marie-Ludivine et al. [51]	Canada	21	hospitals, schools, government workplaces	51.38÷58.75	not applicable	healthy	not applicable	at least bachelor degree	not applicable
Pon van Dijk et al. [52] PSS	Netherlands	24 (12)	Maastricht University Medical Center	41÷71	not applicable	healthy	healthy	bachelor and master degree	not applicable
Douris et al. [53] PPS	USA	10 (6)	martial arts schools	53.5 ±8.6	not applicable	healthy	not applicable	not reported	not applicable

CG control group; IQ intelligence quotient; MBSR mindfulness-based stress reduction group; NS not significant; NR not reported; NRCT non-randomized controlled trials; PE physical education; PPS pre-test and post-test study; PSS planful problem solving; RCT randomised controlled trials; *…

Table 2. Study and participant characteristic: cross-sectional studies (CSS).

Reference & study design	Country	N (male)	Recruitment source	Age [mean years; ± standard deviation or ÷ range]		Health status		Education level or IQ	
				martial arts	control group	martial arts	control group	martial arts	control group
Children or adolescents									
Alesi et al. [19]	Italy	39 (19)	MA (KT school); CG	9.05 ±1.04	9.15 ±0.99 NS	healthy	healthy	not reported	not reported
Fong et al. [22]	Hong Kong (China)	40 (29)	MA (TKD clubs); CG (a local community)	11.3 ±1.3	11.4 ±1.2 NS	healthy	healthy	not reported	not reported
Adults									
Mori et al. [21]	Japan	13	karate club at the university	21 not reported	28 not reported	healthy	healthy	college student	college student
O'Donovan et al. [54]	UK	25 (17)	not reported	23.7 ±3.1	22.2 ±0.6	healthy	healthy	not reported	not reported
Muinos et al. [55]	Spain	135	judo and karate (martial arts schools in Castellon); CG not reported	young adults: judo: 27.6 ±3.8; KT: 25.3 ±4.8 older adults: judo: 64.1 ±3.6; KT: 63.7 ±3.2	young adults: 23.5 ±3.2 older adults:64.7 ±4.3	healthy	healthy	not reported	not reported
Fabio et al. [56]	Italy	146 (108)	MA (MA schools; CG (academic schools)	15.27 ±6.62	14.5 ±6.07^{NS}	healthy	healthy	IQ:103.2 ±8.6	IQ:102.6 ±7.5^{NS}

CG control group; IQ intelligence quotient; KT karate; MA martial arts; NS not significant; TKD taekwondo.

Table 3. Quality assessment of randomised controlled trials (a higher score indicating better methodological quality).

Study	Item [1 explicitly described; 0 absent, inadequately described, or unclear]									Score
	1	2	3	4	5	6	7	8	9	
Cho et al. [20]	1	1	1	1	1	1	1	0	1	8/9
Cho et al. [47]	1	1	1	1	1	1	1	0	1	
Kim et al. [50]	1	1	1	1	1	1	1	0	1	
Lakes et al. [17]	1	1	0	1	1	1	0	1	1	7/9
Lakes et al.[18]	1	1	0	1	1	1	0	1	1	
Witt et al. [23]	1	1	1	1	1	1	0	0	1	
Jansen et al. [24]	1	1	1	1	1	1	0	0	1	
Song et al. [48]	0	1	1	1	1	1	1	0	1	
Jansen et al. [49]	1	1	1	1	1	0	0	0	1	6/9
Pon van Dijk et al. [52]	0	0	1	1	1	1	1	0	1	
Douris et al. [53]	0	0	1	1	1	1	1	0	1	
Marie-Ludivine et al. [51]	0	0	1	1	1	1	0	0	1	5/9

Item: 1 randomisation; 2 control group; 3 isolated martial arts intervention; 4 pre-posttest design; 5 initial sample size retention ≥70%; 6 groups similar at baseline; 7 missing data management; 8 power analysis; 9 validity and reliability of primary cognitive function measures reported.

Table 4. Intervention program: experimental studies.

Reference & study design	Session attendance rate		Activity		Training characteristic (week or month, session/ week)		Exercise intensity		Qualification of instructor
	MA	CG	hard martial arts	control group	martial arts	control group	MA	CG	
Children									
Lakes et al. [17]	not reported	not reported	TKD (blocks, kicks, punches, forms, board-breaking techniques, stretching, breathing relaxation techniques, character development) + PE	PE classes (stretching, running, playing a variety of physical games, basketball, soccer)	3 x 45min/ week, 3 months (2 TKD +1PE)	3 x45 in/ week, 3 months (3 PE)	not reported	not reported	TKD: a black belt for more than 10 years; PE: trained PE teacher
Lakes et al. [18]	not reported	not reported	TKD (basic stances, poomse (blocking, striking, and punches), kicks, mindful practice) + standardised PE	PE classes (stretching, running, exposure to various sports, games)	5 x 40 to 45 min/week, 9 months (2 TKD + 3 PE)	5 x 40 to 45 min/week, 9 months (5 PE)	not reported	not reported	TKD: fifth-degree black belt; PE: trained PE teacher
Cho et al. [20]	not reported	not applicable	TKD: warm-up stretching, basic physical fitness training, main exercise consisting of basic TKD movements, poomsae, kicks, TKD gymnastics, cool-down stretching	no training	5 x 70 min/ week, 16 weeks	not applicable	HRmax: 50-80%	not applicable	not reported
Cho et al. [47]	not reported	not applicable	TKD: basic physical fitness training, main exercise consisting of basic stances, poomse (blocking, striking, punches), kicks, TKD gymnastics, warm-up and cool-down exercises involving stretching	no training	5 x 60 min/ week, 16 weeks	not applicable	RPE: 11-15 per session	not applicable	not reported
Adults									
Witte et al. [23]	at least 80% of total sessions	fitness group: at least 80% of total sessions	KT (back stances, forward stances, straddle-leg stances, forward, downward punches, lunge punches, reverse punches, upper blocks, kicks, partner practice)	fitness group (balance ability, coordination reaction, rhythm, body awareness, strengthening of muscles while practising with the ball, other devices); CG (no training)	2 x 60min/ week, 6 months	fitness group: 2 x 60 min/ week, 6 months CG: not applicable	not reported	not reported	KT: KT expert, fitness group; fitness trainer
Jansen et al. [24] RCT	83% of total sessions	MBSR: 78.75% of total sessions	KT (form practice, partner practice, kata involving tactical fighting exercises)	MBSR (mindfulness-based stress reduction involving sitting, walking meditation, body scan exercise, mindfulness communication); CG (no training)	2 x 60 min/ week, 8 weeks	MBSR: 2 x 60 min/week, 8 weeks; CG: not applicable	not reported	not reported	KT: more than 20 years of training experience; mindfulness-based stress reduction not reported

Reference & study design	Session attendance rate		Activity		Training characteristic (week or month, session/ week)		Exercise intensity		Qualification of instructor
	MA	CG	hard martial arts	control group	martial arts	control group	MA	CG	
Children									
Song et al. [48]	not reported		TKD (self-defense, kicking, punching, flexibility exercise, coordination and reaction ability training)	no training	3 x 45min/ week, 7 months	not applicable	5-10 repetitions	not applicable	two officially certified TKD instructors
Jansen et al. [49]	78.4% of the total session	not reported	KT (training was performed according to the guidelines of the German-Karate-Federation: forms involving powerful and sequential movements of the legs or arms)	physical exercise group (strength, mobilisation, stretching, relaxation); cognitive training group (104 inductive thinking tasks 17 deductive thinking, concentration task); CG (no training)	20, 60 min training sessions for 3-6 months	physical exercise, cognitive training group: 20-60 min training sessions for 6 months	not reported	not reported	KT: professor KT, teacher physical exercise, cognitive training group: not reported
Kim et al. [50]	not reported	not applicable	TKD (jogging, front kick, roundhouse kick, turn kick, spinning back kick, side kick, jumping techniques, stretching)	no training	5 x 85min/ week, 8 weeks	not applicable	RPE: 13-15	not applicable	
Marie-Ludivine et al. [51]	not reported	not applicable	KT (adapted progression involving training at a slow cadence, a push-attack approach, KT form)	not applicable	4 x 90min / week, 6 months	not applicable	not reported	not applicable	KT expert with third dan
Pon van Dijk et al. [52]	100% (expected sessions)	not applicable	TKD (poomsae involving a fight against one or more imaginary opponents; stances, blocking, kicks, and punches with pads or facing an opponent; self-defence techniques)	not applicable	1 x 60 min/ week, 15 months	not applicable	not reported	not applicable	not reported
Douris et al. [53]	100%	not applicable	typical MA (flexibility exercise, blocking, punching drills, kicking, form practice, self-defence techniques, sparing); atypical MA (practice the MA movements in the opposite side or reverse way); self-selected moderate pace walking	not applicable	60 min exercise conditions, the 1-week break between each 2 exercise for reducing practice effect	not applicable	not reported	not applicable	not reported

CG control group; KT karate; MA martial arts; MBSR mindfulness-based stress reduction; PE physical education; RPE rating of perceived exertion; TKD taekwondo.

Table 5. Intervention program: cross-sectional studies(CSS).

Reference & study design	Session attendance rate		Activity		Training characteristic (week or month, session/week)		Exercise intensity		Qualification of instructor
	MA	CG	hart martial arts	control group	martial arts	control group	MA	CG	
Children or adolescents									
Alesi et al. [19]	not applicable	not applicable	karate, but specific components not reported	sedentary lifestyle	3 x 60 to 80 min/ week, 3 to 5 years of training experience	sedentary lifestyle	not reported	not applicable	not reported
Fong et al. [22] CSS	not applicable	not applicable	TKD, but specific components not reported	age-matched adolescents	at least one 90 min/week, more than three consecutive months 2.8 ±1.8 years	not reported	not reported	not applicable	not reported
Adults									
Mori et al. [21]	not applicable	not applicable	karate	no karate training experience	black belt-holders in karate with training duration ranging from 4 to 6 years	not applicable	not reported	not applicable	not applicable
O'Donovan et al. [54]	not applicable	not applicable	taekwondo and kung fu	no MA training experience	11 of MA practitioners had black belts, 2 were senior brown belts for their black belt	not applicable	not reported	not reported	not reported
Muinos et al. [55]	not applicable	not applicable	judo, karate	no MA training experience	more than 10 years of MA training experience	no regular physical exercise or not played any sport for at least 5 years	not reported	not reported	not reported
Fabio et al. [56]	not applicable	not applicable	three different types of MA (kung fu, karate, jutsu)	no training experience in MA, but were participating in basketball, volleyball, gymnastics).	the year range of training in MA: beginner: less than 2 years; intermediate: at least 3 and 6 years; expert: more than 7 years	not reported	not reported	not reported	not reported

CG control group; CSS cross-sectional study; MA martial arts; TKD taekwondo; ± standard deviation.

Table 6. Outcome measured at baseline and post-test: Experimental studies.

Reference	AR (%)	Outcome measure (qualification of assessor) baseline	Martial Arts (mean ±)		Control group (mean ±)		BGC
			baseline	post-test	baseline	post-test	p-value (ES)
				Children			
Lakes et al. [17]	6%	IC (RCS), working memory, (AT, DST of WISC-III), all outcome measures were administered by seven blinded student raters who had received training from the first author before the study.	not reported for all	physical control: 0.13 ±0.99 NR score, focused attention: 0.22 ±0.86 NR score, emotional control: 0.19 ±0.95 NR score, AT: 0.08 ±0.52 NR score, DST: 0.04 ±0.73 NR score	not reported for all	physical control: 0.15 ±1 NR score; focused attention: 0.26 ±1.09 NR score; emotional control: 0.22 ±1.01 NR score, AT: 0.09 ±0.49 NR score, DST: 0.04 ±0.59 NR score	<0.01(0.28) <0.01(0.49) <0.01(0.42) <0.01(0.34) >0.05(−0.12)
Lakes et al. [18]	0%	IC (SWAN administered by the parents), executive Function (the Hearts and Flowers Test administered by a researcher)	not reported for all	behavioral control: 0.53 ±0.46 NR score, attentional control: 0.39 ±0.54 NR score, congruent trial: 0.99 ±0.01 NR; incongruent trial: 0.97 ±0.03 NR; mixed trial: 0.92 ±0.03 NR	not reported for all	behavioral control: 0.03 ±0.95 NR score, attentional control: 0.00 ±0.61 NR score, congruent trial: 0.98 ±0.01 NR ⁱncongruent trial: 0.94 ±0.02, mixed trial: 0.85 ±0.03 NR	<0.001(0.62) >0.05 (0.95) < 0.05 (2.0) > 0.05 (1.43) > 0.05 (2.33)
Cho et al. [20]	0%	IC (SCWT), assessor qualification was NR	SCWT: 35.4 ±4.9 score	SCWT: 36.8 ±4.3*score	SCWT: 35.2 ±4.5 score	SCWT: 35.6 ±5.0 score	not reported (0.264)
Cho et al. [47]	0%	IC (SCWT); BDNF, VEGF, and IGF-1 (enzyme-linked immunosorbent assay), assessors qualification was NR	SCWT: 50.33 ±6.63 score; BDNF: 24.03 ±6.16 ng/ml; VEGF: 177.54 ±34.63 pg/mL; IGF-1: 373.96 ±48.1 ng/ml	SCWT: 52.4 ± 6.23* score BDNF: 27.62 ± 7.58* ng/ml VEGF: 193.08 ±26.19* pg/mL IGF-1: 402.67 ±48.48* ng/ml	SCWT: 49.07 ±7.84 score; BDNF: 24 ±7.24 g/L; VEGF: 179.4 ± 38.63 pg/mL; IGF-1: 377.27 ± 60.77 ng/ml	SCWT: : 48.87 ±8.07 score; BDNF: 24.45 ±7.18 ng/ml VEGF: 179.4 ±38.63 pg/mL IGF-1:387.6 ±60.28 ng/ml	NR (0.507) NR (0.444) NR (0.318) NR (0.285)
				Adults			
Fong et al. [22]	NA	simple reaction time (ruler-drop reaction time), assessor qualification was NR	0.19 ±0.03 sec	not applicable	0.22 ±0.02 sec	not applicable	<0.05
Witte et al. [23]	12.4%	common cognitive function (DemTect test), reaction time (in RT), reactive stress tolerance (in VDT), and selective attention (Computer-based Divided Attention Test), based on "the blinded test leaders were authorised to carry out the cognitive tests" assessor qualification cannot be identified	falling length of the rod in RT: 17.6 ±6.84 cm, TMED: 0.96 ±0.13 VIS: 900.86 ±113.99	falling length of rod in RT: 15.2 ±7.09*cm, TMED: 0.92 ±0.12**, VIS: 859.93 ±100.709*	fitness group: falling length of the rod in RT: 20.62 ±12.02 TMED: 0.94 ±0.1 VIS:874.29 ±109.3 CG: falling length of the rod in RT:16.62 ±8.17 MED:0.92 ±0.09 VIS: 863.31 ±91.8	fitness group: falling length of rod in RT:18.93 ±10.19 NS, TMED:0.91 ±0.12* VIS: 865.62 ±97.34 NS, CG: falling length of rod in RT: 0.88 ± 0.1 NS, TMED: 0.88 ±0.1**, VIS: 857.5 ±97.71NS	NR for all
Jansen et al. [24]	16.7%	cognitive flexibility (MRT), cognitive processing speed (NCT), IC (SCWT), working memory (DST), assessor qualification was NR.	MRT: 4.26 ±3 score; SCWT: 60.67 ±5.43 score; NCT: 38.91 ±7.9 score DST: 16.39 ±3.39 score	MRT: 6 ±3.67 NS score; SCWT: 63.61 ±63.61 NS score; NCT: 46.65 ±9.28* score, DST: 15.09 ±3.23 NS score	MBSR: MRT: 4.6 ±3.09 score; SCWT: 58.11 ±7.71 score; NCT: 36.53 ±11.62 score DST: 15.67 ±2.94 score CG: MRT: 7.12 ±8.88 score SCWT: 62.79 ±65.24 score NCT: 48.29 ±9.61 score, DST: 20.06 ±3.42 score	MBSR: MRT: 5.67 ±2.94 NS score; SCWT: 60.04 ±5.12 NS score; NCT: 40.4 ±10.99 NS score; DST: 15.09 ±3.23 NS score CG: MRT: 8.88 ±4.64 NS score; SCWT: 65.24 ±7.4 NS score; NCT: 50 ±9.57 NS score; DST: 18.82 ±3.21NS score	>0.05 >0.05 >0.05 (0.646) >0.05 <0.05 >0.05 >0.05 <0.05

Reference	AR (%)	Outcome measure (qualification of assessor) baseline	Martial Arts (mean ±)		Control group (mean ±)		BGC
			baseline	post-test	baseline	post-test	p-value (ES)
Song et al. [48]	0%	reaction time (TeleScan II-EMG), assessor qualification was not reported	226.9 ±37.3 msec.	187.8 ±14.5* msec.	248.5 ±34.1 msec.	242 ±37.3 NS msec	<0.05 (0.898)
Jansen et al. [49]	13%	cognitive processing speed (NCT and NSCT) and working memory performance (DST and the FT), assessor qualification was not reported	not reported	karate: NCT: 29.31 ±NR, NS; NSCT: 35.82 ±NR, NS	not reported	Physical exercise group: NCT: 29.72 ±NR, NS; NSCT: 30.71 ±NR NS; cognitive training group: NCT: 28.83 ± NR, NS, NSCT: 41.11 ±NR, NS CG: NCT: 45.51± NR, NS; NSCT: 26.34 ±NR NS	>0.05 for all
Kim et al. [50]	0%	serum level of BDNF, NGF and IGF-1 (Quantikine Sandwich Enzyme Immunoassay) and IC (SCWT), assessor qualification was NR	BDNF: 1.23 ±0.56 ng/ml; IGF-1: 166.43 ±97.56 ng/ml; NGF: 23.73 ±14.16 score; WT: 60.42 ±9.6 score; CT: 72.42 ±8.54 score; SCWT: 61 ±11.98 score	BDNF: 1.58 ±0.36 NS ng/ml; IGF-1: 254.52±39.92* ng/ml; NGF: 20.49 ±21.22 NS pg/ml; WT: 69.85±5.24*score; CT: 3.71 ±10.62*score; SCWT: 68.57 ±9.84 NS score	BDNF: 2.64 ±1.02 ng/ml, IGF-1: 108.37 ±57.96 ng/ml, NGF: 26.73 ±17.34 pg/mL, WT: 50.42 ±11.35 score CT: 65.57 ±13.03 score, SCWT: 54.14 ±8.15 score	BDNF: 2.22 ±1.23 NS ng/ml IGF-1: 259.61 ±36.93* ng/ml NGF: 24.55 ± 9.05 NS pg/mL, WT: 48.71 ±7.54 NS score, CT: 69.42 ±3.02 NS score, SCWT: 61.85 ±4.29 NS score	<0.05 > 0.05 > 0.05 < 0.05 > 0.05 > 0.05
Marie-Ludivine al. [51]	28.5%	simple reaction time NR, assessor qualification was NR	right hand: 0.23 ±0.01 sec, left hand: 0.2 ±0.01 sec	right hand: 0.23 ±0.01 NS sec left hand: 0.23 ±0.01* sec	not applicable	not applicable	not applicable
Pon van Dijk et al. [52]	0%	reaction time (NR), semantic memory (LFT); visual attention and motor speed (TMT); cognitive processing speed and visuo-motor coordination (NSCT) and working memory (DST), assessor qualification was NR	reaction time: 502.5 ±95.1 sec; NSCT:74.2 ±10.8 score; LFT: 44.47 ±10.7 words; DST: 15.37 ±3.02 words; TMT: 34.47 ±15 words	reaction time: 461.4 ±76.2* sec; NSCT: 77.8 ±12.6* score; LFT: 47.42 ±10.5 NS words; DST: 16.26 ±2.92 NS words; TMT: 31.0 ±13.5 NS words	not applicable	not applicable	not applicable
Douris et al. [53]	0%	IC (SCWT), assessor qualification was NR	atypical MA: WT: 51.2 ±8.5 score, CT: 48.3 ±7.3 score, SCWT 54.5 ±9.8 score; typical MA, WT: 49.4 ±15.0 score, CT: 47.2 ±10.8 score, SCWT: 53.1 ±10.8 score	atypical MA, WT: 58.6 ±9.9* score CT: 53.4 ±12.3* score SCWT: 57.9 ±8.9* score. typical MA, WT: 57.6 ±15* score, CT: 54.2 ±11.6* score, SCWT: 59.6 ±10.4* score	walking group: WT: 50.0 ±10.9 score, CT: 47.1 ±11.0 score, SCWT: 56.4 ±11.5 score	walking group: WT; 55.0 ±10.4* score. CT: 52.6 ±11.6* score. SCWT: 54.5 ±9.8 NS score	not reported

AR attribution rate; AT arithmetic test; BDNF brain-derived neurotrophic factor; BGC between-group comparison; CG -control group; CT Color Test; DST Digit Span Test; ES effect size; FT Figure Test; IC inhibitory control; IGF-1 insulin-like growth factor-1; LFT Letter Fluency Test; MA martial arts; MBSR mindfulness-based stress reduction; MRT Mental Rotation Test; NCT Number Connection Test; NGF nerve growth factor; NA not applicable; NR not reported; NS not significant; NSCT Number Symbol Coding Test; RCS Response to Challenge Scale; RT Rod Test; SCWT Stroop Color and Word Test;SWAN Strengths and Weaknesses of Attention Deficit Hyperactivity Disorder and Normal Behavior; TMED median value of total reaction time in the VDT Vienna Determination Test; TMT Trail Making Test; VEGF vascular endothelial growth factor; VIS median value of reaction time to visual signals in the Divided Attention Test; WISC-III the Wechsler Intelligence Scale for Children-Third Edition; WT Word Test; ± standard deviation; *…..:; **….

Table 7. Outcome measured at baseline and post-test: cross-sectional studies.

Reference	AR (%)	Outcome measure (qualification of assessor)	Martial Arts (mean ±)		Control group (mean ±)		BGC
			baseline	post-test	baseline	post-test	p-value (ES)
Children or adolescents							
Alesi et al. [19]	NA	visual selective attention (Visual Discrimination Test), working memory (DST), executive functioning (The Tower of London Test involves times of executive function task and execution quality of planning task), assessor qualification was NR	forward digit span: 5.37 ±1.26; backward digit span: 3.58 ±0.77; selective attention: 9.74 ±1.37; execution quality of planning task: 9.84 ±1.71; times of executive function task: 11.92 ±4.42	not applicable	forward digit span: 4.55 ±0.76; backward digit span:2.7 ±0.66; selective attention: 7.75 ±3.45; execution quality of planning task:8.7 ±1.78; times of executive function task:16.65 ±6.15	not applicable	<0.05 for all
Fong et al. [22]	NA	simple reaction time (ruler-drop reaction time), assessor qualification was NR	0.19 ±0.03 sec	not applicable	0.22 ± 0.02 sec	not applicable	< 0.05
Adults							
Mori et al. [21]	NA	choice reaction time (SONY Multiscan GDM-17SE2T), assessor qualification was NR	left hand:241 ± NR ms right hand: 231 ± NR ms	not applicable NR	left hand:252 ± NR ms right hand: 242 ± NR ms	not applicable	<0.05 <0.05
O'Donovan et al. [54]	NA	simple reaction time, choice reaction NR, assessor qualification was NR	simple reaction time: 210.91 ±3.75 ms; choice reaction time: 312.33 ±8.77 ms	not applicable	simple reaction time: 222.18 ± 6.61 ms; choice reaction time: 343.10 ±15.69 ms	not applicable	>0.05 >0.05
Muinos et al. [55]	NA	dynamic visual acuity as a marker of motor processing speed (Computerized Test, DinVA 3.0 software), assessor qualification was NR	young adults: judo: 0.463 ±0.061 score KT: 0.475 ±0.06 score; older adults: judo: 0.418 ±0.083 score; KT: 0.419 ±0.069 score	not applicable	young adults: 0.443 ±0.06 older adults: 0.36 ±0.073	not applicable	judo vs CG: <0.05 for all; KT vs. CG: <0.05; judo vs. KT: >0.05
Fabio et al. [56]	NA	visual attention and motor processing speed (TMT), based on researchers reported: "outcome measure was administrated individually by the experimenter."	people aged 7 to 11 years: 62.12 ±22.23 sec; people aged 12 to 16: 35.08 ±14.59 sec; people aged 17 or above: 1.87 ±14.85 sec	not applicable	people aged between 7 and 11 years:81.58 ±48.4 sec; people aged 12 and 16: 45.44 ±21.71 sec; people aged 17 or above; 45.35 ±34.64 sec	not applicable	p<0.01 for all

AR attribution rate; BGC between-group comparison; CG -control group; DST Digit Span Test; ES effect size; KT karate; NA not applicable; NR not reported; TMT Trail Making Test; ± standard deviation.

Cite this article as: Zou L, Huang T, Tsang T et al. Hard martial arts for cognitive function across the lifespan: a systematic review. Arch Budo 2018; 14: 41-58