Review

Benefits of Judo Training for Brain Functions Related to Physical and Cognitive Performance in Older Adults

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Posted Date: 28 June 2023

doi: 10.20944/preprints202306.1990.v1

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Benefits of Judo Training for Brain Functions Related to Physical and Cognitive Performance in Older Adults

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Abstract: Judo is a well-known Japanese martial art that also feature in Olympic games. Recently, an increasing interest has been observed in the application of judo as a multicomponent exercise, with a growing body of evidence showing that multicomponent exercise improves physical and cognitive performance in older adults. Therefore, this review highlights the benefits of judo training in preventing physical and cognitive decline in older adults. Specifically, first, this review outlines the basic characteristics of judo (philosophy, match, and training). Subsequently, prior research examining the impacts of judo training on the physical and cognitive aspects of elderly individuals is reviewed. Thereafter, the brain mechanisms underlying the effects of judo training in improving physical and cognitive performance are discussed. Throughout this review, judo training demonstrated some positive effects on physical (gait and balance, among others) and cognitive (memory and executive function) function in older adults. These positive effects are attributed to a variety of changes in the brain (e.g., increased neurotrophic factor expression and increased cerebral blood flow, among others), that affect different brain regions and networks both functionally and structurally. From these findings, this review concludes that judo training can be an effective way to maintain and prevent physical and cognitive decline in older adults.

Keywords: judo; martial art; combat sport; open-skill exercise; brain function; physical performance; cognitive performance; old adults

1. Introduction

Judo, an internationally renowned Japanese martial art and Olympic combat sport, emphasizes self-improvement, physical and mental well-being, and mutual welfare [1]. Worldwide, this martial arts sport is practiced by millions of people from ages 4 to 80+ [2]. The International Judo Federation consists of over 200 national federations spanning across five continental unions, namely Africa, Asia, Europe, Oceania, and Pan-America [3]. Thus, judo is enjoyed by competitors and fans across the world.

Judo is a competitive sport consisting of throws, takedowns, ground submissions, and pinning of their opponents, with high physical and psychological demands. To excel in judo, individuals need to possess a high level of coordination, cognitive and emotional control, as well as the ability to execute quick and precise technical skills when engaging with their opponents [4]. Moreover, judo can be practiced at various intensities and pursued with different objectives, such as competition, recreation, or health-focused purposes [2]. It also allows people with specific needs to participate [2]. Judo, therefore, is not only a competitive sport, but an optimal physical activity suitable for people of all skill levels, ages, sexes, and abilities.

The most important medical and socio-demographic problem worldwide is the aging of the global population, as it causes various health problems in the elderly [5]. Cognitive impairment and falls are one of the major health problems [5–8]. Conversely, physical activity and exercise are well recognized as one of the most effective lifestyle modifications to counteract brain and muscle aging

 doi:10.20944/preprints202306.1990.v1

[7–9]. For older adults, the World Health Organization advises a minimum weekly commitment of 150 minutes of moderate-intensity aerobic physical activity or 75 minutes of vigorous-intensity aerobic physical activity. It is also recommended to engage in muscle-strengthening activities for major muscle groups on at least 2 days per week [8–11]. Furthermore, a combination of physical and cognition exercises (i.e., dual tasks) should be incorporated in training programs for older people [11].

As a result, judo is progressively utilized as a valuable exercise for older adults, promoting cognitive and physical well-being, by tailoring its multifaceted nature to the individual needs and characteristics of practitioners while upholding traditional values and beliefs [12]. Indeed, practicing judo promotes maintenance or improvement of anthropometrics and functional fitness, psychological health, gait kinematic stability, acquisition of control during falls, and improvement of cognitive function, leading to an improved quality of life later in life [1,4,12–28]. Thus, judo has been proposed as a relatively inexpensive nonpharmaceutical intervention to prevent physical and cognitive function decline in the elderly.

Thus, this review elucidates the benefits of judo training in preventing physical and cognitive decline in older adults. Particularly, this review first provides an overview of the characteristics of judo (philosophy, characteristics of match, and training). Next, the efficacy of judo training on physical and cognitive aspects of older adults is reviewed. Finally, this review discusses the brain mechanisms underlying the benefits of judo training in relation to physical and cognitive functions. From this review, the author suggests that judo training can be an effective strategy for preventing physical and cognitive decline in the elderly.

2. Characteristics of judo

2.1. The philosophy of judo

In 1882, judo was founded in Japan by Prof. Jigoro Kano (嘉納治五郎) (Figure 1a) by combining jujutsu, a form of close combat, with elements of mental discipline [3,29]. The word judo consists of two Japanese characters, "柔 (ju)," which means "gentle," and "道 (do)," which means "the way." The word "柔道 (judo)," therefore, literally means the "gentle way." Its applications can be divided into various types of actual circumstances: it is a martial art; a vehicle for physical, intellectual, and moral education; and a method of everyday life [30].

Prof. Kano defined two core principles that rule judo; "精力善用 (Seiryoku-Zenyo) (maximum efficient use of energy)" and "自他共栄 (Jita-Kyoei) (mutual welfare and benefit)" [31,32]. The principle of "Seiryoku-Zenyo" applies universally, urging individuals to harness their spiritual and physical energies to achieve their desired objectives [31]. "Jita-Kyoei" signifies that each of us prospers together with others when we trust and help each other [32].

The judo moral code which is followed by judo players worldwide is also defined by Prof. Kano. This code is a set of ethics composed of eight parts. The judo moral code encompasses essential qualities such as courtesy, courage, friendship, honesty, honor, modesty, respect, and self-control. Professor Kano emphasized that these traits are crucial for the development of judo practitioners, not only within the practice itself but also in their personal lives [33].

In essence, according to Prof. Kano, judo is the path of utilizing mental and physical strength effectively. By training in offensive and defensive techniques, individuals cultivate and discipline their body and spirit, ultimately mastering the essence of this martial art. Thus, to strive for personal perfection and to benefit the world are the ultimate goals of judo [34].

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Figure 1. Jigoro Kano's bronze statue (嘉納治五郎) in front of the headquarter of the worldwide judo community (Kodokan, 講道館) (**a**), adapted from photo AC (https://www.photo-ac.com/, accessed on June 16, 2023). A judo athlete wearing a judo uniform (judogi, 柔道着) and black belt (kuro-obi, 黒帯) (**b**). Two judo athletes are grappling (**c**). Scenes of a representative throwing techniques (nage-waza, 投技), namely uchi-mata (内股) (**d**) and seoi-nage (背負投) (**e**). A scene in which a representative ground technique (ne-waza, 寝技) (i.e., kesa-gatame, 袈裟固) is performed (**f**).

2.2. Characteristics of judo as a hard martial art and an open-skill exercise

Martial arts are often classified as "soft (or internal)" and "hard (or external)" [35]. Soft martial arts are distinguished by their relaxed and smooth movements, often executed at a slower pace, with a focus on controlling posture throughout the motions. On the other hand, hard martial arts are characterized by fast, vigorous, and dynamic movements that heavily rely on physical strength, speed, and endurance [35]. To execute throws and maintain grips or locks, judo necessitates precise posture, balance, strength, speed, power, as well as increased levels of muscle strength and power [36–38]. Therefore, judo is included as one of the hard martial arts [35].

Physical exercise can be classified into closed-skill and open-skill exercises [10]. Closed-skill exercises are carried out in a stable and foreseeable environment, where motor movements adhere to predetermined patterns. These exercises are often self-paced with fewer cognitive demands and decision-making necessities [10]. In contrast, open-skill exercises take place in unpredictable environments, requiring active decision-making and continuous adaptability to respond to randomly encountered external stimuli. These exercises primarily rely on perception and are externally paced [10]. Judo requires excellent cognitive functions such as executive function, processing speed, working memory, and learning, in addition to excellent physical ability to adapt to a continually changing environment. Thus, judo is classified as an open-skill exercise [10].

Altogether, judo is a highly complex sport that requires both physical and psychological excellence.

2.3. Characteristics of judo matches

In judo, athletes compete based on their athletic abilities to ensure fairness and equality between opponents (i.e., white belt [白帯, shiro-obi] for novice and black belt [黒帯, kuro-obi] for expert) and

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weight categories according to their age and sex (Men's judo weight categories range from below 60 kg to over 100 kg, while women's categories span from below 48 kg to over 78 kg) [38].

Judo matches are fought between two players wearing the judo uniform (柔道着, judogi) on a square mat (畳, tatami mat) measuring 8–10 meters (26–33 fee) per side in a judo hall (柔道場, judojo) [39] (Figure 1b,c). The two competitors begin and end the match with a bow at two lines in the center. A judo match commences when the athletes face each other in an upright position, following the referee's "始め, hajime" command to start.

Hereon, the athletes perform displacement actions, while keeping a visual tracking of the opponent's body, searching for the optimal points to grab. This action requires a high degree of attention and information processing regarding the opponent's action. This phase is referred to as grip dispute (組み方, kumi-kata or 組み手争い, kumite-arasoi) and can be categorized into two stages: grip attempts and grip engagement. In the initial phase of a judo match, the primary objective is to stabilize the grip on the opponent's judogi (judo uniform). This grip serves as a crucial prerequisite for executing throwing techniques (投技, nage-waza). By establishing a grip, athletes gain valuable somaesthetic and opponent-related information. This information aids them in positioning their attacks effectively and controlling the intensity of their technical and tactical actions throughout the match [40].

Athletes can win by using any of the 68 throwing techniques (nage-waza) and 32 grappling techniques (固技, katame-waza) [41,42]. Throwing techniques (nage-waza) can be divided into two main types: standing (立技, tachi-waza) and sacrifice techniques (捨身技, sutemi-waza). A variety of throwing techniques (nage-waza) exist, their purpose being to unbalance an opponent's posture and throw the opponent to the floor (Figure 1d,e). In contrast, grappling techniques (katame-waza) refer to the ground techniques (寝技, ne-waza) which are applied while the opponent is lying on the floor (Figure 1f). The ground techniques (ne-waza) consist of joint locks (関節技, kansetsu-waza), strangling techniques (締技, shime-waza), and hold-down techniques (抑込技, osae-komi-waza) [41,42].

Scores are awarded in various ways. Judo scores are calculated by performing the techniques (技, waza) described above. Throwing techniques in judo, known as nage-waza, can result in a full point (一本, ippon) if executed with strength, speed, and control, causing the opponent to land on their back. If any of these elements are lacking, it may result in a half point (技あり, waza-ari). Additionally, a full point (ippon) can be awarded if an immobilization lasts for 20 seconds or if the opponent submits due to a strangle (shime-waza) or joint lock (kansetsu-waza) technique. Similarly, a half point (waza-ari) can be earned if an immobilization lasts between 10 and 19 seconds [43].

A competitive judo match will last for 4–5 min; however, this can be cut short if one competitor scores a full point (ippon), or can last longer if the match goes into the extra time (the golden score) in case of a tie [43].

2.4. Dynamics and energy demands of judo matches

In judo, high-intensity actions are required for longer periods (e.g., grip dispute [kumi-kata or kumite-arasoi]), while powerful actions during technique application are needed for short durations (e.g., throwing technique [nage-waza] and ground techniques [ne-waza]). Intermittent activity characterizes a judo match as it involves a mix of high-intensity actions such as throws and low-intensity actions like displacement without contact or pauses due to referee stoppage [44].

In a standard 5-minute judo match, approximately 11 sequences of effort take place, with each effort lasting around 20-30 seconds, interspersed with pauses lasting approximately 10 seconds [45]. Thus, the work-to-rest ratio during judo matches is approximately 2:1 to 3:1 [44–46]. In judo matches, the grip dispute, known as kumi-kata or kumite-arasoi, accounts for approximately 50-60% of the total effort-pause sequence time. Experienced athletes allocate more time to the grip dispute, concentrate their visual attention on central areas like the face and collar, and execute attacks more swiftly compared to novice athletes [40]. Performing a throwing technique (nage-waza) in judo necessitates brief yet forceful actions lasting between 1.0 and 1.4 seconds, engaging both lower- and upper-body muscle groups. In instances where ground techniques (ne-waza) are employed, technical

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actions demand a combination of muscle power and strength endurance [46]. As such, judo athletes experience a substantial energy demand due to the multitude of actions they must execute throughout each match.

Thus, to better understand the energy demands of judo, the basics of the human energy system are first explained. In humans, the energy for muscle activity, adenosine triphosphate (ATP), is produced by three energy systems, phosphagen (ATP-creatine phosphate [CP]), anaerobic (glycolytic), and aerobic (oxidative) systems [47]. The phosphagen (ATP-CP) system, utilizing CP, generates ATP at a rapid rate. It is employed during short-duration, high-intensity activities lasting around 1-30 seconds. The anaerobic (glycolytic) system serves as a link between the immediate phosphagen system and the more enduring aerobic system. This system does not rely on oxygen and converts glucose into lactic acid to produce ATP. It serves as an intermediate system capable of quickly generating ATP for activities requiring bursts of energy over a longer period, ranging from 30 seconds to 3 minutes. The aerobic (oxidative) system relies on oxygen to produce ATP. It functions gradually and is primarily utilized during extended periods of lower-intensity activities following the depletion of the phosphagen and anaerobic systems. The contribution of all three systems is essential to meet the body's energy demands during physical activity. However, the dominance of a particular system depends on the duration and intensity of the activity at any given time [47].

Judo matches have been shown to rely on all three energy systems [45,46]. Therefore, judo matches rely predominantly on the aerobic (oxidative) system (70%), whereas the scoring actions depend heavily on both the phosphagen (ATP-CP) (21%) and anaerobic (glycolytic) (8%) systems [45]. Particularly, the phosphagen (ATP-CP) system is responsible for the short-duration powerful actions during technique (waza) applications (21%). Sustaining high-intensity actions over extended durations, such as the grip dispute (kumi-kata or kumite-arasoi), relies on the anaerobic (glycolytic) system, accounting for 8% of the contribution. Conversely, the aerobic (oxidative) system plays a predominant role (70%) in supporting low-intensity actions and facilitating recovery between high-intensity bouts [44].

2.5. Characteristics of judo-specific training modalities

We must first master fall breaking (受身, ukemi) to prevent injury and minimize pain when a judo practitioner (or competitor) falls down or is thrown by an opponent [21]. Therefore, fall breaking (ukemi) is a fundamental part of all judo techniques and is of the highest importance. Fall breaking (ukemi) includes the forward break fall (前受身, mae-ukemi), back-break fall (後受身, ushiro-ukemi), side-break fall (横受身, yoko-ukemi), and forward roll break fall (前回り受身, mae-mawari-ukemi) [21]. The practice of fall breaking (ukemi) also improves the mobility skills of the elderly in the health promotion classes [21].

Judo-specific training requires two participants. The following three modalities are the most common training modes used by judo practitioners: repetition training (打ち込み, uchi-komi), repetitive throwing (投げ込み, nage-komi), and free practice or sparring (乱取り, randori) [48]. Repetition training, known as uchi-komi, involves repetitive technical practice with a partner without executing the actual throw. This training can be performed at varying intensity levels, ranging from slow movements to rapid repetitions for conditioning purposes. Typically, practitioners focus on breaking the opponent's balance without completing the throw. On the other hand, repetitive throwing, referred to as nage-komi, involves executing the complete throw with a partner. The effort exerted in each repetition depends on the player's skill level, with advanced judo practitioners relying more on timing and leverage rather than pure strength. Free practice or sparring, known as randori, involves combat or fight practice where both participants attempt to execute techniques. This activity involves competition. In repetition training (uchi-komi) and repetitive throwing (nage-komi), partners alternate being thrown. In free practice or sparring (randori), both partners simultaneously execute techniques. The range of techniques can be restricted or unrestricted based on safety and competition rules. The most challenging mode is free practice or sparring (randori) [48].

In terms of judo-specific training energy demands, repetition training (uchi-komi) and repetitive throwing (nage-komi) offer optimal metabolic benefits. These involve continuous steady-state or

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technique repetition every 10-15 seconds, beneficial for aerobic fitness. On the other hand, all-out intermittent protocols are effective for anaerobic development and may also enhance aerobic capacity. Longer free practice or sparring (randori) sessions with lower-intensity combat and shorter rest intervals are suitable for improving aerobic fitness. However, to enhance anaerobic capacity, combat sessions should be shorter in duration, more intense, and interspersed with longer intervals [48].

Additionally, the forms (形, kata) are another way of practicing judo [49]. The forms (kata) are practiced following a formal system of prearranged exercise in contrast to free practice or sparring (randori). Nine forms (kata) exist as follows. Namely, forms of throwing (投の形, nage-no-kata), forms of grappling of holding (固の形, katame-no-kata), forms of decisive techniques (極の形, kime-no-kata), forms of gentleness and flexibility (柔の形, ju-no-kata), forms of Kodokan self-defense (講道館護身術, kodokan goshin-jutsu), forms of five (五の形, itsutsu-no-kata), forms of classics (古式の形, koshiki-no-kata),” forms of maximum-efficiency national physical education (精力善用国民体育, seiryoku-zenyo-kokumin-taiiku), and kata for teaching basics to young children (子どもの形, kodomo-no-kata). Through the practice of forms (kata), trainees learn the principles of judo techniques [49].

Therefore, judo-specific training (fall breaking [ukemi], repetition training [uchi-komi], repetitive throwing [nage-komi], and free practice or sparring [randori], and the forms [kata]) may be effective as a multimodal exercise program.

3. Benefits of judo training for physical and cognitive function in the elderly

Judo offers diverse advantages across different age groups, genders, and skill levels. These benefits include encouraging active physical behavior, improving quality of life, enhancing both physical and mental health, as well as developing safe falling skills [1,12]. A recent systematic review conducted on 1,392 middle-aged and older adults (with an average age of 63 ± 12 years) revealed that regular judo training (with sessions lasting 61 ± 17 minutes, 2 ± 1 sessions per week, for a duration of 7 ± 6 months) has multiple positive impacts. These include improvements in health factors such as bone health, anthropometry, and quality of life, enhanced functional fitness in terms of balance, strength, and walking speed, as well as positive effects on psychosocial aspects like fear of falling, cognition, and self-efficacy [50]. Similarly, in a scoping review comprising 648 middle-aged and older adults (aged, 45-77.8 years), judo-based exercise programs (45–60 min session, 1–3 sessions/week; 5 weeks to 24 months) could improve various health outcomes [51]. In older individuals, the practice of judo has been found to have positive effects on physical performance, muscle strength, and flexibility. Additionally, in middle-aged adults, judo has been shown to benefit bone mineral density [51].

Hereafter, this review will focus exclusively on older adults (aged ≥ 65 years). Most studies have examined the benefits of judo training for physical performance, especially fall prevention [1,13–21]. Conversely, to my knowledge, only one study elucidated on the benefits of judo training on cognitive function [22]. An overview of studies examining the effects of judo training on the physical and cognitive function of older adults [1,13–22] are summarized in Table 1. Regarding studies on physical function, judo-specific training modalities employed in training differed among studies. Specifically, in various forms of practice, fall breaking (ukemi), ground techniques (ne-waza), standing techniques (tachi-waza), and forms (kata) training were included [1,13–21]. Furthermore, fall breaking (ukemi) seems to be included in all studies. This is because fall breaking (ukemi) is the basis of judo and that it can be used as an injury prevention method in case of a fall. Improvement in physical functions as a result of judo training includes upper and lower body flexibility and strength, body movement, gait, balance, activity, and fall prevention techniques. Moreover, positive effects such as improved self-confidence, increased motivation, improved social and mental functions, and reduced fear of falling have been observed.

In a study by Kujach et al. [22], the impact of a 12-week judo training program on cognitive processing and muscle function was investigated in the elderly population. This intervention led to improved executive function (Stroop performance). Additionally, the peripheral concentration of brain-derived neurotrophic factor (BDNF) was significantly increased following the judo training compared with the control group. Additionally, there were notable improvements in balance and

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lower limb strength. Based on these findings, the authors suggest that judo training may have positive effects on cognitive performance, as well as on balance and strength capabilities [22].

Overall, judo training methods for older adults differ between studies, and the indicators used to evaluate its effectiveness also differ; hence, the results pertaining to the effects of judo training on physical function also differ between studies (Table 1). However, undoubtedly, judo training has some positive effects on physical and cognitive function. In the future, examining the effectiveness of judo training on physical and cognitive function through good research designs is warranted.

Table 1. An overview of studies examining the effects of judo training on the physical and cognitive function in the elderly.

References	Overview of studies (1. Study Design; 2. Participants; 3. Characteristics of judo training; 4. Outcome measures; 5. Main findings)
Toronjo-Hornillo et al. [13]	1. Intervention study 2. Healthy, prefragile (n = 12; F:M = 12:0; age: 71.5 ± 8 years) 3. Adapted utilitarian judo program (60-min session, 2 sessions/week, 8 weeks); Drawing from the technical elements of traditional judo, specifically the fundamentals of Kodokan judo; The different types of fall breaking (ukemi): side-break fall (yoko-ukemi) and back-break fall (ushiro-ukemi) 4. Fear of falling (FES-I) 5. Fear of falling ⬇
Ciaccioni et al. [1]	1. Intervention study 2. Judo novice practitioners (n = 16; F:M = 8:8; F, age: 67.6 ± 3.7 years; M, age: 71.0 ± 3.5 years); Control (n = 14; F:M = 5:9; F, age: 70.1 ± 5.0 years; M, age: 70.2 ± 4.0 years) 3. Judo training (1-h session, 2 sessions/week, 4 months); During Phase 1, which lasts for 10 minutes, a judo-specific warm-up is conducted. This involves engaging in light activities and performing gentle routines of judo postures, movements, and techniques at a slow pace. In Phase 2, which spans 30 minutes, the main part of the judo session takes place. This includes practicing ground techniques (ne-waza), standing techniques (tachi-waza), forms (kata), and fall breaking (ukemi) Phase 3: (a 20-min judo cool-down): forms (kata) focused on stretching and relaxation 4. Anthropometric (BMI and waist and hip circumferences), upper and lower body flexibility (back-scratch test and chair sit and reach test), upper and lower body strength (30-s chair-stand test and arm-curl test), subjective and emotional dimensions of body image and body dissatisfaction (BIDA), subjective perception of functional health and well-being (SF-12v2), fear of falling (FES-I) 5. Judo novice practitioners group: waist circumference ⬇, lower and upper body flexibility ⬆, lower and upper body strength ⬆; Control group: lower-body strength ⬇
Arkkukangas et al. [14]	1. Intervention study 2. Healthy (health care center: n = 11; F:M = 11:0; mean age: 74.0 years; judo facility: n = 7; F:M = 7:0; mean age: 71.0 years; workplace: n = 10; F:M = 6:4; mean age: 63.0 years) 3. Judo-inspired exercise (45-60-min session, 1 session/week, 10–16 weeks); Block 1: practicing basic fall breaking (ukemi) techniques Block 2: continuing fall breaking (ukemi) techniques and strength exercises Block 3: training in the ability to develop power (fast power) 4. Physical performance (SPPB), self-confidence in the ability to perform various daily activities without falling (FES-S), fall techniques (falling backward and falling forwards) 5. Physical performance ⬆, fall techniques ⬆

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Campos-Mesa et al. [15]	1. Intervention study 2. Healthy, prefragile (n = 19; F:M = 15:4; F, age: 72.6 ± 5.8 years; M, age: 76.0 ± 7.3 years); control (n = 11; F:M = 11:0; age: 77.8 ± 5.5 years) 3. Adapted utilitarian judo program (60-min session, 2 sessions/week, 6 weeks); specific exercises to assimilate safe and protected ways of fall breaking (ukemi) 4. Fear of falling (FES-I) 5. Healthy, prefragile: Fear of falling ⬇
Ciaccioni et al. [16]	1. Intervention study 2. Novice judoka (n = 16; F:M = 8:8; age: 69.3 ± 3.9 years); Control (n = 14; F:M = 5:9; age: 70.1 ± 4.5 years) 3. Judo training (1-h session, 2 sessions/week, 15 weeks); For a duration of 10 minutes, a judo-specific warm-up session is conducted. This warm-up consists of light routines and dynamic movements that engage the entire body, imitating various judo techniques A 30-min judo central part: standing techniques (tachi-waza), ground techniques (ne-waza), fall breaking (ukemi), repetition training (uchi-komi), and forms (kata) A 20-min judo cool-down: stretching and relaxation using forms (kata) 4. Step length (10-m Optojump photocell system), gait cycle time (10-m Optojump photocell system), gait speed (10-m Optojump photocell system), gait cadence (10-m Optojump photocell system) 5. Novice judoka: step length ⬆, gait cycle time ⬇, gait speed ⬆, gait cadence ⬆
Ciaccioni et al. [17]	1. Intervention study 2. Healthy, novice judoka (n = 16; F:M = 8:8; age: 69.3 ± 3.9 years) 3. Judo training (60-min session, 2 sessions/week, 4 months) During the 10-minute judo-specific warm-up, participants engage in a variety of activities. These include walking at different speeds, performing light routines, and moving different segments of the body while executing judo techniques A 30-min judo central phase: ground techniques (ne-waza), standing techniques (tachi-waza), forms (kata), and fall breaking (ukemi) A 20-min judo cool-down: stretching and relaxation as forms (kata) 4. Fear of falling (VAS), training enjoyment (VAS), motivation (MPAM-R, SRQ-E), fall breaking (ukemi) technique performance (evaluation by judo experts) 5. Motivation ⬆, fall breaking (ukemi) technique performance ⬆
Sakuyama et al. [18]	1. Intervention study 2. High-movement ability group (n = 39; mean age: 70.0 years); Low-movement ability group (n = 14; mean age: 72.0 years) 3. Judo exercise program (1-h session, 1 session/month, 3 years and 9 months); Fall breaking (ukemi), ground techniques (ne-waza), and throwing techniques (nage-waza) 4. Physical and psychological functions (SF36 Ver2) 5. High-movement ability group: mental component scores ⬆; Low-movement ability group: physical functioning ⬆, social functioning ⬆, physical component scores ⬆

 doi:10.20944/preprints202306.1990.v1

Arkkukangas et al. [19]	1. Intervention study 2. Exercise (n = 100; F:M = 76:24; age: 72.0 ± 4.5 years); control (n = 99; F:M = 82:18; age: 73.0 ± 5.2 years) 3. Judo training (50-60-min session, 1 session/week, 12 weeks); Block 1: practicing basic fall breaking (ukemi) techniques Block 2: continuing fall breaking (ukemi) techniques and strength exercises Block 3: training in ability to develop power (fast power) 4. Physical performance (SPPB), falling techniques (Strömqvist Bååthe Falling Technique Test), balance (Mini-BESTest), self-confidence (FES-S), activity level (Frändin/Grimby activity), quality of life (EuroQoL-5D-3L), and self-related health (EQVAS) 5. Physical performance ⬆, falling techniques ⬆, balance ⬆, self-confidence ⬆, activity level ⬆, health condition ⬆
Jadczak et al. [20]	1. Intervention study 2. Healthy (n = 17; nonfrail: n = 10; prefrail: n = 7; F:M = 13:4; age: 74.3 ± 6.2 years) 3. Judo-based exercise (60-min session, 2 session/week, 8 weeks); 1: The warm-up includes a 10-minute session focused on practicing getting up and down from the ground 2: Balance, strengthening, and mobility exercises (10 min) 3: Safe fall-breaking (ukemi) techniques (30 min) 4: Cool-down exercises, including stretching and flexibility (10 min) 4. Mobility (TUG), balance (BBS), physical performance (SPPB), physical and mental health (SF-36), fear of falling (FES-I), physical activity (ActivPal accelerometer) 5. Mobility ⬆, balance ⬆, physical performance ⬆
Odaka et al. [21]	1. Intervention study 2. Healthy (n = 10; F:M = 7:3; age: 75.6 ± 5.3 years) 3. Judo ukemi practice (15-min session, 1 session/week, 3 times); Back-break fall (ushiro-ukemi) (5 min), side-break fall (yoko-ukemi) (5 min), and forward break fall (mae-ukemi) (5 min) 4. Fear of falling (VAS), mobility (10-m walking test, TUG) 5. Mobility ⬆
Kujach et al. [22]	1. Intervention study 2. Healthy (n = 40; F:M = 33:7; age: 67.7 ± 5.2 years; judo training group: n = 20; age: 67.5 ± 5.3 years; control group: n = 20; age: 67.6 ± 5.1 years) 3. Judo training (45-min session, 3 sessions/week, 12 weeks); Based on selected exercises from the Kodokan Judo Institute; warm-up, the main training (learn "step by step" judo technique elements), cool-down 4. Executive function (Stroop test), postural control (AccuGait force platform), muscle strength (Biodex System 4 dynamometer), the BDNF peripheral level (blood samples) 5. Executive function ⬆, balance ⬆, lower-limb strength ⬆, peripheral BDNF ⬆

Abbreviation: BBS, Berg Balance Scale; BIDA, Body Image Dimensional Assessment; BDNF, brain-derived neurotrophic factor; BMI, body mass index; EQVAS, Euro Quality of Life Visual Analog; EuroQoL-5D-3L, European Quality of Life 5 Dimensions 3 Levels; FES-I, Falls Efficacy Scale-International; FES-S, Falls Efficacy Scale-Swedish version; MPAM-R, Motives for Physical Activity Measure-Revised; Mini-BESTest, Mini-Balance Evaluation Systems Test; SF-12v2, Short-Form Healthy Survey Version 2; SF36 Ver2, Short-Form Health Survey 36 Version 2; SPPB, Short Physical Performance Battery; SRQ-E, Exercise Self-Regulation Questionnaire; TUG, Timed Up & Go; VAS, Visual Analog Scales; ⬆, increased; ⬇, decreased.

 doi:10.20944/preprints202306.1990.v1

4. Possible mechanism of the brain effects of judo training in relation to improvement in physical and cognitive performance in the elderly

As mentioned above (Section 3), judo training demonstrated positive effects on physical and cognitive performance in older adults. However, the underlying brain mechanisms of its positive effects requires further exploration. Therefore, in this section, the brain mechanisms underlying judo training to improve physical and cognitive performance in older adults are discussed.

In general, physical activity and exercise interventions, particularly aerobic exercise, offer an effective, cost-efficient, and non-pharmacological approach to counteract the negative impact of aging and disease on cognitive function. Specifically, open-skill exercises demonstrate greater effectiveness in improving certain aspects of cognitive function compared to closed-skill exercises [10]. These effects are believed to be mediated by various brain mechanisms, including improvements in cardiovascular risk factors (such as diabetes, hypertension, hyperlipidemia, and obesity), increased expression of neurotrophic factors (such as BDNF, IGF-1, and VEGF), enhanced amyloid-β turnover, increased cerebral blood flow (CBF), and reduced inflammatory responses (CRP, IL-6, and TNF-α) [10]. As mentioned in the previous section (Section 2.2.), judo is described as an open-skill exercise because judo involves more cognitive load and demands. Therefore, judo induces alterations in the structural and functional states of the brain through these brain mechanisms, thereby positively affecting cognitive and physical performance.

In fact, stringent evidence was demonstrated among adolescent and young judo players on the several neurophysiological and neuroimaging alterations in brain structure and function by practicing judo [52–54]. In a study using event-related potentials and a selective attention task [52], it was found that judo players with black belts (kuro-obi) (experts) exhibited a higher peak amplitude of P300 in the middle frontal gyrus and N200 in the cuneus. However, they also displayed a longer latency of P300 in the precuneus compared to judo players with white belts (shiro-obi) (novices). These findings imply the attention network alterations caused by judo training. In functional magnetic resonance imaging (MRI) study [53], compared with the control group, the combat sports (including judo) group exhibited increased intra-network functional connectivity within the sensorimotor network, visual network, and cerebellar network, suggesting functional enhancement. The sensorimotor network plays a key role on motor preparation and execution. Accurate assessment of target position and motion trajectory relies on the improved functioning of the visual network. The cerebellar network plays a vital role in regulating motor function, ensuring postural balance, and facilitating motor coordination [53]. Besides, combat (judo) training reduced the inter-network functional connectivity between motor and various nonmotor networks. In order to accomplish specific functions, reduced functional connectivity between networks may indicate an intentional disconnection between them. This disconnection helps prevent interference between networks, allowing for independent utilization of each network [53]. Thus, judo training appears to alter the functional connectivity patterns of various brain networks. In a structural MRI study [54], it was observed that judo players had notably increased regional gray matter volume compared to sedentary individuals. Specifically, the areas showing significant differences included the frontal lobe (associated with motor planning and execution), prefrontal cortex (related to working memory and cognitive processes), middle and inferior temporal gyri (related to motor learning and memory), parietal and occipital lobes (related to visual associative processes), and cerebellar cortex (related to motor learning). These findings may reflect plastic modifications induced by various judo-specific demands and may also be a sequelae of the increase in the gray matter volume of cortical brain regions secondary to changes in CBF and increased BDNF induced by judo training [54]. In fact, it has been revealed that BDNF increases after judo training (free practice or sparring [randori]) [55].

Altogether, judo training induces various changes in the brain (increase in CBF, BDNF, etc.), which in turn cause functional and structural changes in various brain regions and brain networks. Consequently, judo training provides superior cognitive and physical performance, including improved memory and executive function and fall prevention (Figure 2).

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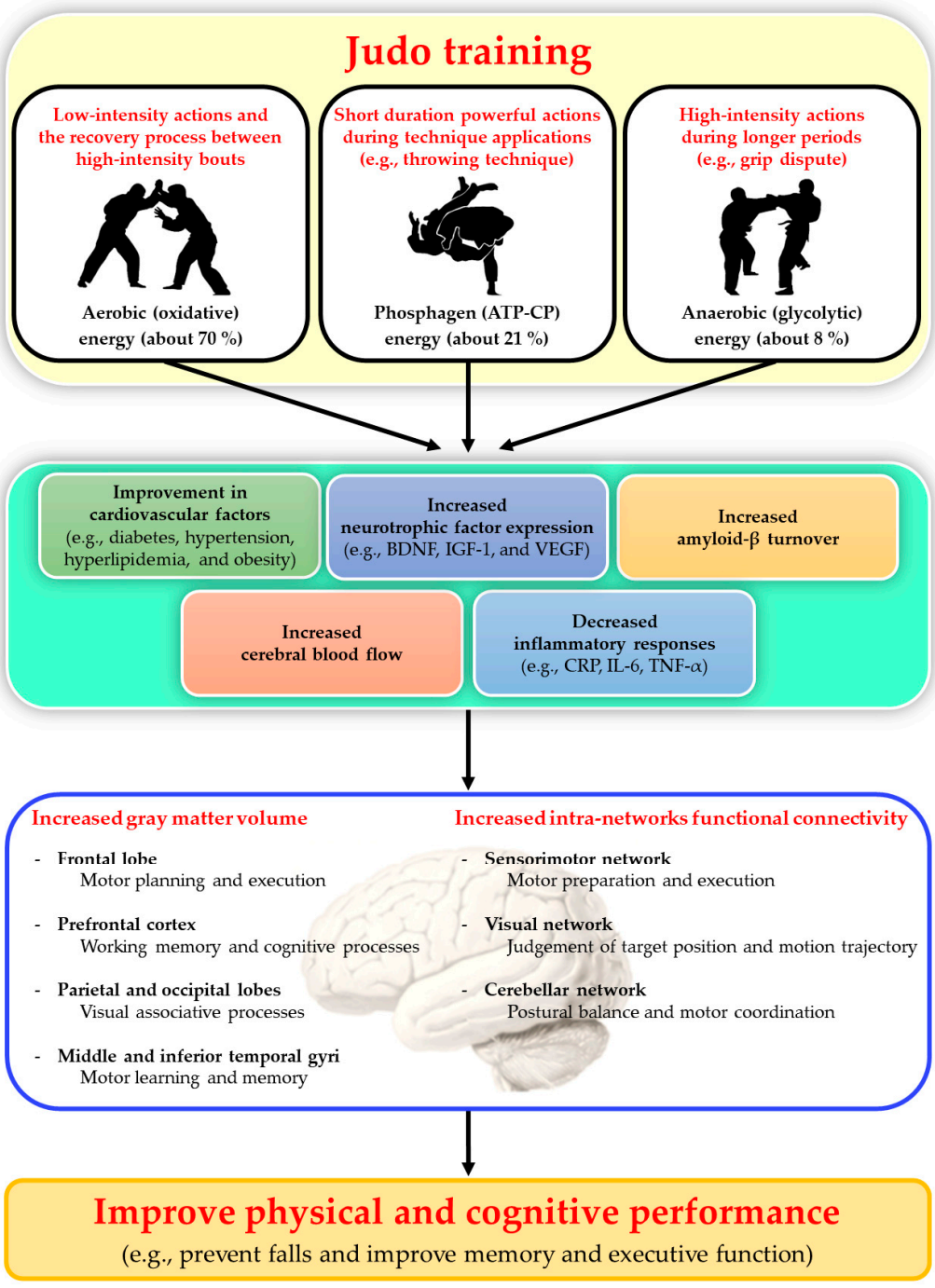

Figure 2. Possible mechanisms of the beneficial effects on physical and cognitive function by judo training. Abbreviation: ATP-CP, adenosine triphosphate-creatine phosphate; BDNF, brain-derived neurotrophic factor; CRP, C-reactive protein; IGF-1, insulin-like growth factor 1; IL-6, interleukin-6; TNF-α, tumor necrosis factor-alpha; VEGF, vascular endothelial growth factor.

5. Conclusions and prospects

Judo is a widely practiced educational martial art originating from Japan and has gained global popularity as an Olympic combat sport. Judo is not only a competitive sport, but a great physical activity suitable for people of all skill levels, ages, sexes, and abilities. In the aging society, numerous studies have shown that multicomponent exercise improves physical and cognitive performance in older adults. Similarly, several studies have reported that judo training, which is characterized by a multicomponent exercise, improved physical and cognitive performance in older adults. Therefore, judo training has some positive effects on physical (gait and balance, among others) and cognitive

(memory and executive) function in the elderly. These positive effects are attributed to various changes in the brain (increase in CBF and BDNF, among others), which in turn cause functional and structural changes in various brain regions and brain networks. Therefore, this review concludes that judo training is a useful strategy for improving cognitive function and preventing falls in older adults.

However, to strengthen the evidence for the benefits of judo training on physical and cognitive performance in the elderly, several outstanding issues must be clarified. Limited research has been conducted on the impact of judo training on physical and cognitive function among adult individuals. Second, the judo-specific modalities used for training are different among the studies. Third, few studies have directly investigated the effects of judo training on brain processes such as neurotrophic factor signaling, CBF, and inflammatory responses in older adults [22,55]. Therefore, further longitudinal intervention studies (behavioral, neurophysiological, neuroimaging, and biochemical studies) with well-randomized arms (large sample size) are needed to confirm the beneficial effects of judo training on physical and cognitive function in older adults. Furthermore, judo training is reported to be a safe exercise intervention [14,18,19,51]. However, comparisons of the frequency and severity of injuries between judo training and other open-skill exercises are also warranted. Finally, judo training requires a judo hall (judojo) and a judo expert as an instructor [51]. Therefore, analysis of its cost-effectiveness in spreading awareness on judo training to the elderly population in the general community is necessary.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: I would like to thank Mr. Keita Nakamoto and Mr. Yutaro Yamasaki (Hiroshima University) for taking judo-related photos.

Conflicts of Interest: The author declares no conflict of interest.

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