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Original article

Comparing the effectiveness of karate and fitness training on cognitive functioning in older adults—A randomized controlled trial

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Abstract

Background: Recent studies demonstrate a slowdown in deterioration of cognitive functioning in old age through aerobic training. There is evidence that the combination of aerobic, balance, and coordination exercises leads to an improvement or maintenance of cognitive functions. Such age-related exercises can especially be found in East Asian martial arts. The purpose of the current study is to verify whether karate training for older adults improves cognitive functioning and, if an improvement can be found, which cognitive fields are influenced.

Methods: Eighty-nine older women and men (mean age: 70 years) participated in this study. The participants were randomized into 2 intervention groups (karate group and fitness group, duration of intervention: 5 months) and a control group. All participants had to accomplish a cognitive test battery before and after the intervention. In a secondary study the karate group had an additional intervention for another 5 months.

Results: The results show that there is a significant improvement in motor reactivity, stress tolerance, and divided attention only after the 5-month karate training period. Additionally, the results of the secondary study indicate further improvements after 10 months.

Conclusion: The 5-month karate training can help to enhance attention, resilience, and motor reaction time, but a training period of 10 months is even more efficient.

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Keywords: Cognition; Divided attention; Karate; Motor reactivity; Older adults; Physical exercise

1. Introduction

It is a fact that some cognitive functions decrease while others remain unaffected during aging.^{1–3} According to Glisky³ cognitive functioning contains basic cognitive functions (attention, working memory included speed of information processing, long-term memory, perception) on one hand and higher-level cognitive functions (speech and language, decision making, executive control) on the other hand.

While “crystallized” intelligence (e.g., factual knowledge and experience) retains, the “fluid” intelligence (e.g., working memory and processing speed) deteriorates, which also has an effect on other cognitive areas (e.g., word fluency and problem-solving ability).⁴ The deterioration in cognition, based on biological degradation processes, especially affects the

velocity and flexibility of information processing and memory retention.³ Schapkin⁴ suggests that neuroplasticity can activate additional areas of the brain which reduce the error rate and increase the reaction time.

Another important aspect is the relation between the decrease of cognitive abilities and the risk of falling.⁵ Liu-Ambrose et al.⁶ propose that improved cognitive function, especially executive functions and associated functional plasticity, may be an important mechanism to reduce falls in older adults. But this proposal has not been accepted yet.

A growing number of studies have analyzed the influence of special sports interventions on cognitive abilities in older age. Meta-analyses were carried out by Colcombe and Kramer,⁷ Smith et al.,⁸ Price et al.,⁹ and Zhao et al.,¹⁰ who summarize that physical activity of older persons can improve cognitive performance¹¹ and decrease the risk of dementia in older people.¹² Findings from cross-sectional, longitudinal, and intervention studies with healthy older adults, frail patients, and persons suffering from mild cognitive impairment and dementia

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lead to the conclusion that physical exercise is a promising non-pharmaceutical intervention to prevent age-related cognitive decline and neurodegenerative diseases.¹³

In particular, aerobic endurance training has a significant effect on processing speed, attention, and executive function, but only a minor one on working memory.^{1,8,14–16} A possible reason is given by Colcombe et al.,¹⁷ who, in an intervention study with persons aged 60–79 years, found out that the brain volume (white and gray matter) increases significantly after an aerobic training in comparison to a stretching training. Based on results of interventional studies Gregory et al.¹² show that endurance exercises increase the volume of special brain areas (particularly hippocampi).

Some studies give indications regarding the effect of other training programs than aerobic ones on cognitive performance. Hötting et al.¹⁴ studied middle-aged adults (40–56 years) and found different effects between an aerobic endurance training (cycling) and a training with stretching and coordination on cognitive functioning, which both lead to advances in memory. The cardiovascular fitness correlated more with episodic memory while stretching/coordination training particularly improved selective attention.

However, it should be considered that the heterogeneity of the subject groups (educational level, socioeconomic status) makes comparisons difficult.¹ This can be seen by the results of the meta-analysis by Price et al.,⁹ based on publications between 2006 and 2008, which show a great heterogeneity between the subject groups with regard to training intensity, educational level, and socioeconomic status.

Further research is needed to understand the impact of other forms of exercises as well as the intensity–response relationship that controls the positive impact of exercise on brain functions.¹³

Up to now, the influence of duration, frequency, or intensity of exercises on cognitive performance could not be explained. It is an open issue whether physical exercises with a higher level of motor complexity, in comparison to relatively simple exercises, influence more cognitive functions, brain physiology, respectively. Studies of complex and simple motor tasks are therefore required.

Boyke et al.¹⁸ studied the implication of motor learning (in this case 3-ball cascade juggling) of older people (mean age: 60 years) on brain structure. On the basis of magnetic resonance imaging, they found that there was an increase of gray-matter changes in the middle temporal area of the visual cortex on the left side of the hippocampus and in the nucleus accumbens bilaterally.

Our study focuses on East Asian sports including whole-body exercises on a high coordinative level and investigates a possible effect on the cognitive performance of older adults. Chang et al.¹⁹ postulate that Tai Chi improves cognitive abilities in older adults. The study by Dechamps et al.²⁰ of frail older adults confirms that a Tai Chi training program (twice a week, 30 min) enhances the physical and mental state through the interaction of cognition and action.

Wagner²¹ studied the effect of a modified karate training of adults aged older than 50 years on physical and cognitive abilities and well-being. His findings show advances in short-term and procedural memory. He therefore concludes that appropri-

ate karate training for older adults reduces fall risk and improves the subjective quality of life.

The study by Jansen and Dahmen-Zimmer²² analyzed explicitly the impact of karate training, including exercises with more stringent requirements in coordination, on the well-being and cognitive abilities of older adults. The results show only trends of improvements in memory performance but significant improvements in well-being. It should be noted that the training group contained only 12 subjects and the interventions had a duration of only 3 months.

Marie-Ludivine et al.²³ examined fifteen 50-year-old men in regard to the impact of karate training on healthy well-being, balance, aerobic capacity, and cognitive abilities. However, a control group without intervention is missing. The results show that a karate training over 12 months has a positive influence on mood and perception of physical health. This was confirmed by a better postural control, improved performance on objective physical testing, and shorter reaction time of the non-dominant hand.

From all these research findings we can conclude that a combination of aerobic, balance, and coordination exercises leads to an improvement or maintenance of cognitive functions. These age-related exercises are used in East Asian martial arts, e.g., Tai Chi, taekwondo, Kung Fu, and karate. From these we selected karate, because techniques can exercise relatively slow, weapons may not be used and therefore the risk of injuries for older adults is low. The benefits of karate sport for older adults compared to other martial arts sports are discussed.²³ In summary, karate sport is characterized by aerobic fitness,²⁴ coordination between arms and legs as well as between the right and left sides of the body at a relatively high level, continuous learning of new movements and orientation.

We expect that age-appropriate karate training helps to prevent cognitive decline in older age. Therefore, the aim of the present intervention study is to analyze the influence of age-appropriate karate training on several fields of cognition (common cognitive performance, motor reactivity, reactive stress tolerance, and divided attention) of older adults. We hypothesize that age-related karate training has a positive impact on common cognitive functioning, motor reactivity, reactive stress tolerance, and divided attention in older adults compared to common fitness training or even without special sports programs.

In the primary study we therefore included a second sports intervention group (common fitness training) and a control group without any specific intervention program. The interventions were carried out over 5 months. Another aim was to analyze if there are further changes in cognitive functioning in the karate group. Therefore an additional 5-month karate training was accomplished for the karate group after the common intervention program in a secondary study.

2. Methods

2.1. Study design and participants

The randomized controlled study was carried out at the Department of Sport Science and at the Department of

Occupational Medicine of the Otto-von-Guericke-University Magdeburg and was approved by the Otto-von-Guericke-University Ethics Committee. A written informed consent was obtained from each participant.

The sample size was calculated to detect large effects (in the sense of Cohen's $d \geq 0.8$) with a power of 80% for 2-sided tests at level $\alpha = 0.05$ when comparing the 2 treatment groups.

Two hundred adults with a mean age of 70 years (age range: 63–83 years) were recruited through advertisements in the local newspapers. Eighty-nine persons provided a medical certificate and had a professional training or a higher education degree (inclusion criteria). Three levels of physical activity were assessed through a questionnaire: no sports activity (Level 0), individual sports activity without any instructions (Level 1), and sports club activity (Level 2). The participants were sorted randomly into 2 intervention groups (Group 1: karate group and Group 2: fitness group) and a control group (Group 3): without any planned sports interventions in relation to gender (about 40% men and 60% women), age (mean age: 69 years), and level of physical activity (Levels 0–2 were evenly distributed).

For the primary study the following timeline was defined: pre-test (pre), intervention over 5 months, and post-test 1 (po1). In the secondary study the intervention only for Group 1 was extended for another 5 months of karate training with another post-test 2 (po2) afterwards. The test leaders were authorized to carry out and analyze cognitive tests and executed these blind in regard to groups.

Fig. 1 shows the study timeline and consort participant flow diagram. Only participants who undertook 80% of all training units of the interventions groups (Groups 1 and 2) were involved in the analysis.

2.2. Interventions

In addition to the group classification, Fig. 1 shows at which points in time the interventions were accomplished.

The sports interventions (karate and fitness) of a duration of 60 min were performed twice per week by a karate expert for Group 1 and a fitness trainer for Group 2. A training unit contained a warm-up phase (10–15 min), the specific training (40–45 min), and a cool-down phase (5 min).

The warm-up phase of the karate training for Group 1 contained several balance exercises, exercises for improvement of reactions, as well as games for orientation. The cool-down phase included strengthening exercises for the body and short games. The 5-month specific karate training was divided into modules in conformity with Emmermacher and Witte.²⁴ They included stances such as forward stances (Jap. zenkutsu-dachi), back stances (Jap. kokutsu-dachi), and straddle-leg stances (Jap. kiba-dachi) to train leg and trunk musculature as well as balance skills. Also included were several arm techniques in standing positions and during forward and backward walking (downward-block (Jap. gedan-barai), lunge punches (Jap. oi-zuki), reverse punches (Jap. gyaku-zuki), and upper blocks (Jap. age-uke) to improve arm–leg coordination. In order to facilitate cognitive processes (reactivity, learning processes, memory, and attention) the participants executed simple attack and respond exercises (Jap. kumite) as well as the special karate form (Jap. kata) taikyoku-shodan.

The objectives of the fitness training for Group 2 were: improvement of balance ability, coordination reaction, rhythm, body awareness, and strengthening of muscles. Accordingly, the main part of a training unit contained elements of gymnastics, running exercises, practices with balls and other hand devices, age-related games and strengthening exercises.

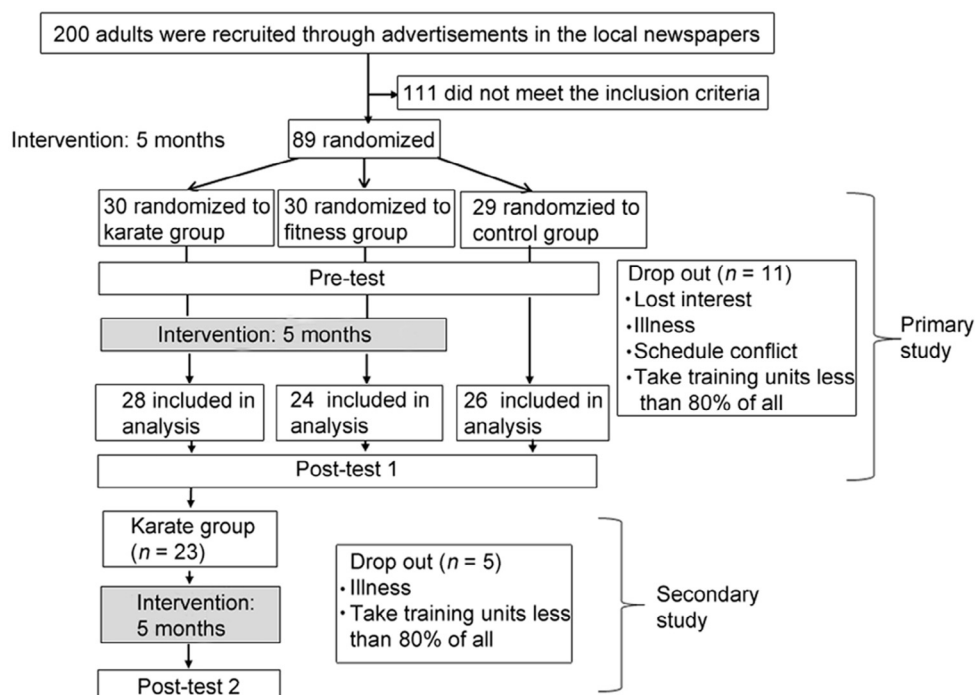


Fig. 1. Study timeline and consort participant flow diagram.

The participants in the control group, Group 3, were only instructed to continue their usual sports activities.

2.3. Outcome parameters

The following tests were conducted to measure common cognitive functioning, motor reactivity, reactive stress tolerance, and divided attention.

2.3.1. Common cognitive functioning

The DemTect test is a screening test for mild cognitive impairment and mild dementia and includes 5 short tasks: memory formation by word list, number transcoding, semantic word fluency task, attention by digit span reverse, and delayed recall of word list.²⁵ Higher scores P_{total} (maximal total score is 18) indicate better cognitive functioning.

2.3.2. Motor reactivity

The rod test is a simple motor test to determine the ability to react to a failed rod: the test leader drops a rod in a defined distance into a person’s hand, which catches it. The falling length is a parameter for measuring the reaction time.²⁶ A shorter falling length (L) indicates a better reaction time.

2.3.3. Reactive stress tolerance

DT Determination Test Version S11 (Vienna Test System 024674-01; SCHUHFRIED GmbH, Mödling, Austria) is a computer controlled test assessing reactive stress tolerance. DT measures stress tolerance, attention, and reaction speed to rapidly changing visual and acoustic stimuli. The subject is presented with color stimuli and acoustic signals during the test procedure and the task is to react by pressing the appropriate buttons on the response panel. The reliability is given with $r = 0.98$. The validity was examined among others in the field of traffic psychology.²⁷ A lower score ($T_{totalMed}$) indicates a better reactive stress tolerance.

2.3.4. Divided attention

Test of Divided Attention (TAP 2.2, Psytest—Psychological Test Systems; PSYTEST Psychologische Testsysteme, Herzogenrath, Germany) is a computer controlled test which examines the divided attention (dual-task performance) to parallel processed visual and acoustic signals. The subject has to respond as fast as possible when a special visual pattern appears or the same tone occurs twice. Lower reaction times to acoustic (Ac_med) and visual signals (Vis_med) indicate a better performance in divided attention. The reliability was examined by

Zoccolotti et al.²⁸ ($r = 0.33 \dots 0.73, p < 0.01$). Objectivity is given through a complete automatic analysis.

The test leaders were authorized to carry out and analyze cognitive tests and executed these blind to the groups.

2.4. Statistical analysis

The normal distribution of all outcome parameters was confirmed by means of the Kolmogorov–Smirnov test. In the primary study the paired t test was used to evaluate differences between the results of the pre and po1 within the groups. In case of a significant result the effect size (Cohens’s d) was calculated. Furthermore, a two-way repeated measures (Time \times Group) ANOVA, with time as the within-subject factor and group as the between-subject factor, was used to assess all outcome parameters in the primary study. In the secondary study the one-way ANOVA (factor time: pre, po1, and po2) and pairwise Bonferroni corrected *post hoc* comparisons were carried out.

The analyses were performed with a significance level of 0.05. In addition, results with a p value smaller than 0.1 were presented to show possible trends.

The data were collected and organized using EXCEL (Microsoft Excel 2010; Microsoft Corp., Redmond, WA, USA). Statistical analyses were performed by the statistical software package IBM SPSS Statistics (Version 22.0, 64-Bit-Version; IBM Corp., Armonk, NY, USA).

3. Results

Eleven participants of the primary study and 5 participants of the secondary study dropped out because of missing more than 20% of all training units based on several reasons (Fig. 1). No significant differences between the groups concerning age (Group 1: 68.8 ± 4.1 ; Group 2: 69.0 ± 5.3 ; Group 3: 68.0 ± 5.1 ; one-way ANOVA: $F = 1.468$, total degree of freedom (df) = 2, $p = 0.229$), gender composition (Group 1: male = 12, female = 16; Group 2: male = 8, female = 16; Group 3: male = 10, female = 16; 2-dimensional χ^2 test: χ^2 (Pearson) = 0.495, $df = 2$, $p = 0.781$; χ^2 (Likelihood quotient) = 0.497, $df = 2$, $p = 0.780$), or physical activity level (2-dimensional χ^2 test: χ^2 (Pearson) = 0.399, $df = 6$, $p = 0.092$) were found.

The results of the two-way repeated measures ANOVA (Table 1) show no significant differences between the groups for each parameter related to factor Group. Based on this, we conclude an equal baseline for all 3 groups. No adverse effects

Table 1
Results of the general common model (two-way repeated measures ANOVA)—primary study.

	Time						Time \times Group						Group					
	df	Sum of squares	Mean squares	F	p	η^2	df	Sum of squares	Mean squares	F	p	η^2	df	Sum of squares	Mean squares	F	p	η^2
P_{total}	1	0.16	0.16	0.007	0.786	0.001	2	1.73	0.867	0.401	0.671	0.011	2	2375	1188	0.0221	0.801	0.006
L (cm)	1	11.32	11.32	0.310	0.580	0.004	2	182.07	91.036	2.491	0.090	0.062	2	294.261	147.130	1.273	0.286	0.033
$T_{totalMed}$ (s)	1	0.06	0.06	42.933	0.000	0.367	2	0.00	0.001	0.431	0.651	0.012	2	0.038	0.019	0.787	0.459	0.021
Ac_Med (ms)	1	2359.63	2359.63	0.558	0.458	0.007	2	29,670.97	14,835.4	3.506	0.035	0.086	2	273.63	136.815	0.009	0.991	0.000
Vis_Med (ms)	1	13,248.53	13,248.53	2.568	0.113	0.033	2	10,272.50	5136.25	0.996	0.374	0.026	2	10,795.149	5397.575	0.343	0.711	0.009

Abbreviations: Ac_Med = median value of reaction time to acoustic signals in Test of Divided Attention; L = falling length of rod in Rod test; P_{total} = total score of DemTect; $T_{totalMed}$ = median value of total reaction time in DT Determination Test; Vis_Med = median value of reaction time to visual signals in Test of Divided Attention.

Table 2
Group data of the test parameters (analyzed at pre-test (pre) and post-test 1 (po1))—primary study (mean ± SD).

	Group 1			Group 2			Group 3		
	Pre	po1	Pre vs. po1 (p/d)	Pre	po1	Pre vs. po1 (p/d)	Pre	po1	Pre vs. po1 (p/d)
n	28	28		24	24		26	26	
P _{total}	16.28 ± 2.05	16.50 ± 1.84	0.713	16.50 ± 1.89	16.21 ± 2.48	0.582	16.69 ± 1.76	16.58 ± 1.50	0.595
L (cm)	17.60 ± 6.84	15.20 ± 7.09	0.050**/0.35	20.62 ± 12.02	18.93 ± 10.19	0.582	16.62 ± 8.17	0.878 ± 0.097	0.248
T _{total} Med (s)	0.958 ± 0.134	0.916 ± 0.120	0.000***/0.33	0.937 ± 0.109	0.907 ± 0.120	0.024***/0.269	0.921 ± 0.093	0.878 ± 0.097	0.000***/0.452
Ac_Med (ms)	594.32 ± 112.20	549.57 ± 5.82	0.063*	570.92 ± 88.89	573.21 ± 98.26	0.843	559.65 ± 90.92	578.73 ± 93.84	0.236
Vis_Med (ms)	900.86 ± 113.99	859.93 ± 100.709	0.048**/0.39	874.29 ± 109.30	865.62 ± 97.342	0.690	863.31 ± 91.80	857.50 ± 97.709	0.758

Notes: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.001$.

Abbreviations: Ac_Med = median value of reaction time to acoustic signals in Test of Divided Attention; d = Cohen’s d (effect size); L = falling length of rod in Rod test; P_{total} = total score of DemTect; T_{total}Med = median value of total reaction time in DT Determination Test; Vis_Med = median value of reaction time to visual signals in Test of Divided Attention.

of karate training and fitness training during intervention in both studies could be found.

3.1. Results of the primary study

3.1.1. Common cognitive functioning

The results of the two-way repeated measures ANOVA show no significant differences in total score P_{total} (DemTect test) related to the factors Time, Group, and their interaction (Table 1). Results of mean comparisons within the groups confirm these findings (Table 2). Only Group 1 is characterized by a slight but not significant improvement of P_{total}.

3.1.2. Motor reactivity

Considering the simple Rod Test we found a significant effect considering Time × Group (Table 1). Remarkably, there is a significant improvement of the Rod test performance L with a small effect for Group 1 (Table 2).

3.1.3. Reactive stress tolerance

For the total performance in the DT Determination Test (T_{total}Med) two-way repeated measures ANOVA could identify a significant effect only for factor Time (Table 1). Concerning differences between pre and po1, the 3 groups offer a significant improvement of this parameter (Table 2).

3.1.4. Divided attention

Significant results could only be found for (median value of reaction time to acoustic signals) (Ac_Med) through a two-way

repeated measures ANOVA for the factor Time × Group (Table 1). The comparison within the groups shows only for Group 1 a trend based improvement (Table 2). It should be noted that a decrease in reaction time related to acoustic signal only occurs for Group 1 (positive sign).

3.2. Results of secondary study

The secondary study should analyze whether further improvements of detected parameters can be confirmed when the karate training was extended for another 5 months.

3.2.1. Common cognitive functioning

Generally, the DemTect test detects changes in mild cognitive impairment. Kalbe et al.²⁵ proved its applicability for early detection of dementia, while Wagner²¹ used DemTect test for healthy adults at middle age. In our findings one-way repeated measures ANOVA shows only a trend when all 3 test dates are compared (Table 3). This improvement could only be confirmed between po2 and pre. Considering the single subtests we could only find an improvement for item A5 (number of the right mentioned words of the recalled word list to measure recalled memory) comparing pre with po2 (pre: 5.32 ± 2.09, po1: 5.71 ± 2.09, po2: 6.39 ± 2.29; one-way repeated measures ANOVA: sum of squares = 20.957, mean squares = 10.478, $F(2, 22) = 4.202$, $p = 0.021$, $\eta^2 = 0.160$; paired t test pre vs. po2: $t = -2.69$, $p = 0.013$) after 10 months of karate training.

Table 3
Results of the general common model (one-way repeated measures ANOVA)—secondary study (mean ± SD).

Parameter	Pre	po1	po2	ANOVA (adopted sphericity)					Post hoc		
				Sum of squares	Mean squares	F(2, 22)	p	η^2	Pre vs. po1	Pre vs. po2	po1 vs. po2
P _{total}	16.00 ± 2.15	16.43 ± 1.88	17.09 ± 1.62	13.768	6.884	2.944	0.063*	0.118	0.404	0.020 [#]	0.129
L (cm)	17.42 ± 7.13	15.53 ± 7.69	12.20 ± 7.45	321.502	160.752	6.596	0.003**	0.231	0.186	0.001 ^{##}	0.018 [#]
T _{total} Med (s)	0.96 ± 0.13	0.92 ± 0.12	0.89 ± 0.12	0.050	0.025	18.890	0.000**	0.474	0.002 ^{##}	0.000 ^{##}	0.017 [#]
Ac_Med (ms)	621.91 ± 85.16	548.39 ± 104.84	585.86 ± 92.74	62,170.522	31,085.261	7.081	0.002**	0.243	0.002 ^{##}	0.025 [#]	0.070
Vis_Med (ms)	903.96 ± 112.64	861.04 ± 103.91	891.95 ± 167.17	22,548.783	11,274.391	1.225	0.303	0.053	0.039	0.484	0.559

Notes: ANOVA/Friedmann test: * $p < 0.10$, ** $p < 0.003$; [#] $p < 0.05$, ^{##} $p < 0.003$.

Abbreviations: Ac_Med = median value of reaction time to acoustic signals in Test of Divided Attention; d = Cohen’s d (effect size); L = falling length of rod in Rod test; po1 = post-test 1 after 5 months; po2 = post-test 2 after 10 months; Pre = pre-test; P_{total} = total score of DemTect; T_{total} Med = median value of total reaction time in DT Determination Test; Vis_Med = median value of reaction time to visual signals in Test of Divided Attention.

3.2.2. Motor reactivity

For the practice-oriented Rod Test (L) high significant improvements of Group 1 were found comparing pre, po1, and po2, especially considering po2 vs. po1 (Table 3).

3.2.3. Reactive stress tolerance

We investigated whether the parameters which show significant or potential changes in Gr1 (primary study) vary more after the second 5-month karate training period. For $T_{total}Med$ significant differences between pre, po1, and po2 were confirmed. *Post hoc* tests show that parameters of po2 improve highly significantly in relation to pre and po1 (Table 3).

3.2.4. Divided attention

On the basis of one-way repeated measures ANOVA the results of Ac_Med in pre, po1, and po2 vary significantly. *Post hoc* tests show significant differences between po2 and pre and between po1 and pre. The impairment of Ac_Med in po2 in relation to po1 is not significant (Table 3).

4. Discussion

Because only a small number of empirical studies analyzing the impact of karate training to cognitive functioning exist, a comparison of our results with findings in literature is limited.

It can be concluded that the effect of the slight improvement of memory performance (item A5 of DemTect) is small compared with the results of the study's finding of significant improvements in memory performance by aerobic endurance training.¹¹ The slight improvement of recalled memory caused by karate training agrees with results of Boyke et al.,¹⁸ who showed that motor learning enhances the plasticity of the brain in older adults. Our results are in contrast to those of Wagner,²¹ who discovered that 50–65-year-old adults ($n = 59$) generally improve their performance in DemTect through age-appropriate karate training. Wagner²¹ found significant improvements in all sub-items (A1–A5) and total score. The contrast in our results to those of Wagner²¹ can be explained by the age of our participants, who were nearly 20 years older than the participants of Wagner's study. Our findings agree with results by Jansen and Dahmen-Zimmer,²² who applied the digit-span test, figure test and block-tapping test with only 12 participants over 20 training units within 3–6 months without finding any cognitive improvements.

The motion-oriented Rod Test only showed an improvement in performance for the karate group after both 5 months and 10 months of training. Similar results were reported by Marie-Ludivine et al.,²³ who found an improvement in reaction time of the non-dominant hand after (adapted) karate training with duration of both 6 months and 12 months for 50-year-old men. So it can be assumed that karate training over an extended period of time has a positive impact on motor reactivity. We therefore conclude that partner exercises in karate training in particular lead to reduced reaction times in physical exercises.

While karate techniques inherit demanding coordinative movements, especially for people of older age, karate training could be valuable for training of reactive stress tolerance and attention, which was analyzed by Determination Test. Based on

our findings it can be concluded that the slight improvements of reactivity in the Determination Test do not result exclusively from karate training. But a trend improvement of the test's parameter $T_{total}Med$ after 5 and 10 months' intervention for Group 1 could be found.

Regarding divided attention, the reaction time to acoustic signals (Ac_Med) was especially reduced through karate training. We explain this finding based on the fact that participants performing karate training have to react immediately to acoustic instructions of the trainer, for instance rhythmic counting in kata exercises. Compared to the other intervention group (Group 2) and control group (Group 3) we can conclude that karate training in older adults counteracts the deterioration of reactivity under stress and in dual tasks.

We explain the general small effects considering the factors Time and Group with the recruitment through advertisements in the local newspapers. It can be assumed that only older adults with active lifestyles express their willingness to be included in a study with physical intervention.

5. Conclusion

The presented study shows a limitation in regard to the study design. While we compared 3 groups in pre and po1 in the primary study, we analyzed only the karate group in the secondary study (single group design). These results can therefore only be shown as a trend.

In general, we have to note that the recruited participants had a good level of fitness. In contrast, there are studies with frail persons that, from a logical point of view, improved their cognitive functions by physical training significantly (mixture from stretching, endurance, strength, and coordination training).¹⁴ From these findings we suppose that age-appropriate karate training positively influences particular cognitive functions of healthy older and frail people. We consider the main reason for positive effects is based on cognitive functioning, the learning of new movement techniques and kata, which includes physical as well as cognitive components, in karate training. Furthermore, we assume that karate training in older adults could have an additional effect: the reduction of falling risk. This is due to the relation between cognitive abilities and falling risk²⁹ and the training of balance and leg muscles by karate exercises.

Acknowledgment

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Authors' contributions

KW conceived of scientific idea, carried statistical analysis, drafted the manuscript, and carried motor tests; SK carried statistical analysis; SD carried cognitive tests; PE carried karate intervention; and IB analyzed cognitive tests and designed the study. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests

None of the authors declare competing financial interests.

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