Unraveling the Link Between Physical Fitness and Cognitive Function Among Judo Athletes

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ABSTRACT: The present study used a quasi-experimental design (one-group pretest-posttest) to examine the association between physical fitness and cognitive function in judo athletes of university level. A total of 18 athletes (aged 18-26 years) were subjected to a 8weeks long structured judo training program. Reaction time (Ruler Drop Test), agility (T-Test) and grip strength (Isometric Grip Strength Test) were used to assess physical fitness, while the Trail Making Test was used to assess cognitive fitness. Post-intervention, participants showed considerable benefits on all physical fitness parameters as well as cognitive performance, including increased processing speed, attention and mental flexibility. The results showed that judo training has significant effect on the physical and mental development of the university players.

KEYWORDS: Physical Fitness, Cognitive Function and Judoka, Reaction Time, Agility

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Introduction

Physical fitness and cognitive function are closely related domains, and both domains play an important role in human performance. Current research in exercise science, neuroscience and sport psychology suggests that organized exercise is beneficial to brain health and cognitive efficiency throughout the lifespan and beyond physiological capacity. While early studies mostly concentrated on general exercise modalities (aerobic and resistance exercise), more recent research has looked at sport-specific analyses, examining the cognitive load of athletic activities and its impact on mental performance (Campanella et al., 2024). Judo is one of these sports that demands both the physical and mental capacity of its practitioners at the same time and thus serves as a unique model.

Judo is an open-skill, high-intensity combat sport where there is constant interaction with the opponent in an unpredictable environment. Judokas must be strong, have stamina, agility and balance, but also quick decision-making, attentional control, working memory, inhibitory regulation, and perceptual-motor coordination. (Artioli et al., 2010) Athletes need to analyze the visual and tactile information in real time, predict the opponent's next move and execute highly correct technical responses under time constraints. The integration of perception and action that occurs in judo embodies complex mental processing that is tightly coupled with the physical action, making judo a suitable subject for studying the link between fitness and cognition.

Mechanistically, frequent physical activity has been correlated with changes within the brain that facilitate cognitive improvement. Frequent exercise increases cerebral blood flow, enhances delivery of oxygen and nutrients to neural tissue and stimulates release of neurotrophic factors, like brain-derived neurotrophic factor (BDNF), which is associated with enhanced synaptic plasticity and neurogenesis (Ciolac et al., 2023). Skill-based activities with a strong focus on the task also activate prefrontal and motor-related brain networks, which further supports executive functioning. Judoking is aerobic and anaerobic, and involves complex motor learning, and this could result in multidimensional cognitive benefits that go beyond what is seen with single-mode exercise programs (Kujach et al., 2022).

The theory underlying this relationship is in line with the cognitive-motor training theory that states that concurrently presenting mental training to physical activity produces a stronger mental training effect than physical activity alone. Judo training is a strategic, tactical, emotional and quick response selection process with a potential for enhancing brain efficiency, processing speed and executive control (Yamasaki, 2023). In judo, empirical studies have been conducted to assess cognitive adaptations in judo practitioners of various ages, with findings of sport-specific and transferable changes in attention, working memory, reaction time, and inhibitory control (Henschel et al., 2024).

Additionally, the disciplined practice and constant feedback, along with the social interaction, experienced in judo, may also have a positive impact on cognitive health in an indirect way; judo's structured training environment can foster motivation and a sense of engagement.

Furthermore, the sport's focus on being technically efficient, controlling the body and using a grab to execute a combat move demands a high level of sensorimotor integration, which further strengthens the link between the cortical and subcortical brain regions involved in the planning of movement and its cognitive regulation.

Although the positive effects of exercise on cognition are increasingly corroborated by empirical studies, no studies have specifically investigated judo, the sport, and its effect on cognition, and they are methodologically varied. Inconsistent design, differing cognitive measures, and diverse measures of fitness make it difficult to draw a clear picture of causation in many existing studies. Moreover, the unique aspects of judo, which solely rely on cognitive load rather than physical conditioning, have not been sufficiently understood. In addition, the standardization of intervention procedures is lacking, and the relationship between some of the components of fitness (reaction time, agility, muscular strength) and the cognitive outcome in university judo athletes has not been sufficiently explored.

It is crucial to tackle these gaps for both theoretical knowledge and practical use. Elucidating the link between physical fitness and cognitive function in judo athletes may also help guide training methods to maximize mental and physical performance, which could be used in educational, rehabilitation, and healthy-aging contexts where a comprehensive cognitive-motor training approach could improve the well-being of participants (Voss et al., 2010).

This study, therefore, focused on university judo athletes and their association with physical fitness components and cognitive function, specifically reaction time, agility and muscular strength, and their contribution in this population (Fong et al., 2023). The research is designed to help build upon the growing body of literature around sport-specific cognitive adaptation and the holistic development of physical and mental capacity.

Method

Participants

This study used a quasi-experimental, single-group pretest–posttest design to investigate the relationship between physical fitness and cognitive function in university judo athletes after an 8-week structured training. The study took place in the Judo Training Facility of the Sports Complex at the University of Lahore, comprising a well-equipped gymnasium and a specialized judo training hall that is appropriate for judo performance testing and judo intervention delivery.

The overall number of subjects in the study was 18 university judoka. The inclusion criteria were male or female judo athletes aged 18–25 years, with a minimum of one year of judo experience, judged using HEC standards, and with written informed consent. Participants who had any neurological or cognitive disease or disorder or who had had a musculoskeletal injury within the previous three months that might affect performance, who were taking cognitive-enhancing drugs or stimulants, or who did not complete the assessments were excluded. To assure representation of all levels of performance, a stratified sampling approach was used.

Measures

The following standardized instruments were used to measure physical fitness and cognitive performance. The three trials per subject were separated by a rest period between trials, which was designed to minimize fatigue effects and to ensure the reliability of scores; the best score across the three trials was used for analysis.

Reaction Time (Ruler Drop Test)

The Ruler Drop Test was used to measure simple visual reaction time (Baechle & Earle, 2008). The distance through which the ruler fell before it was caught was recorded, and the reaction time was calculated with the help of the standard formula, which deals with the acceleration due to gravity. The reaction time (calculated value) with the smallest number of seconds was kept for the three trials, and the participant's best score was determined by this.

Agility (T-Test)

Agility was assessed using the T-Test, which involves multidirectional movements such as sprinting, shuffling laterally and backward (Sassi et al., 2009). The completion time (in seconds) was noted, and the shorter the time, the better; the minimum completion time of the three trials was used as the best performance score.

Muscular Strength (Isometric Grip Strength Test)

The Isometric Grip Strength Test (IGST) with a handgrip dynamometer was used to measure muscular strength (Franchini et al, 2011). The highest force output over the 3 maximal attempts was used for analysis, with higher values indicating more strength, measured in kg or newtons.

Cognitive Performance (Trail Making Test)

Cognitive function was measured with the Trail Making Test (Reitan, 1955), which is a standardized test of attention processing speed, visual scanning and mental flexibility. Part A focuses on visual scanning and processing speed, while Part B also involves cognitive flexibility and set shifting (Crowe, 1998). The test was administered in the same way for each participant, with the shortest completion time being the best cognitive performance score.

Procedure

The impact of an 8-week judo training program on the physical and cognitive performance of the 18 athletes who participated in this study was explored through a quasi-experimental pretest–posttest design. This training program consisted of progressive and structured exercises focusing on strength, agility, reaction time, and overall conditioning, presented through sport-specific drills. Physical fitness was re-evaluated after the intervention with the T-Test, the handgrip dynamometer test and the Ruler Drop Test, while cognitive function was re-evaluated with the Trail

Making Test. All post-intervention testing sessions were held in a setting where the conditions were standardized to the baseline assessment setting.

Data Analysis

IBM SPSS Statistics was used for analyzing data. Demographic characteristics and performance variables were summarized using descriptive statistics (means and standard deviations), and frequency distributions were used to describe participant characteristics and overall sample trends. Normality of the distribution of each variable was tested before conducting the hypothesis testing using the Shapiro–Wilk test. Pretest and posttest scores of variables having a normal distribution were compared using paired-samples t tests, while for variables that did not meet the assumption of normal distribution, the Wilcoxon signed-rank test was used. All analyses were considered statistically significant at $p < .05$.

Ethical Considerations

All the ethical principles were adhered to during the study. The participants were asked to sign informed consent forms and gave their consent freely, and their data were kept confidential. Participants were also told that they could drop out of the study at any time without any penalty.

Results

Prior to hypothesis testing, the Shapiro–Wilk test was used to evaluate the normality of the distribution for each outcome variable.

Table 1

Shapiro–Wilk Tests of Normality for Study Variables

Test	Statistic	p	Normality
Ruler Drop Test	.906	.072	Normal
T-Test	.940	.292	Normal
Isometric Grip Strength Test (Right)	.798	< .001	Not normal
Isometric Grip Strength Test (Left)	.789	< .001	Not normal
Trail Making Test (A)	.975	.881	Normal
Trail Making Test (B)	.935	.233	Normal

Note: The scores for the Ruler Drop Test, T-Test and both sections of the Trail Making Test were normally distributed ($p > .05$). The scores obtained from the Isometric Grip Strength Test for both hands were not normally distributed ($p < .05$). For normally distributed variables, parametric tests (paired-samples t tests) were used and for the grip strength variables, a non-parametric test (the Wilcoxon signed-rank test) was used.

Table 2

Demographic Characteristics of Participants (N = 18)

Variable	Category	n	%
Age (years)	18–20	8	44.4
	21–23	6	33.3
	24–26	4	22.2
Gender	Male	9	50.0
	Female	9	50.0

Variable	Category	n	%
Locality	Urban	10	55.6
	Rural	8	44.4
Playing level	Intervarsity	9	50.0
	HEC level	6	33.3
	National	2	11.1
	International	1	5.6
Playing experience (years)	< 2	5	27.8
	2–5	11	61.1
	> 5	2	11.1

Note. Percentages are calculated in each demographic group, and may not add to 100 due to rounding.

The sample was predominantly comprised of young adult judo athletes, with 44.4% being in the age range 18-20 years, and a 50% representation of male and female athletes. The majority of athletes lived in urban areas (55.6%) and played mostly at the intervarsity (50.0%) and HEC (33.3%) level. Most of the participants (61.1%) had experience of playing for 2–5 years. The sample overall was diverse in terms of competitive experience, but mainly of moderate competitive experience, competitive judo athletes.

Pretest and posttest performances on the Ruler Drop Test, T-Test, and on the two components of the Trail Making Test were compared using paired-samples t tests. The results are tabulated in Table 3.

Table 3

Pretest and Posttest Comparison of Reaction Time, Agility, and Cognitive Performance

Measure	M pre	SD pre	M post	SD post	t(17)	p	d
Ruler Drop Test	.23	.022	.20	.01	11.05	< .001	0.01
T-Test	11.92	.34	11.48	.42	20.10	< .001	0.17
Trail Making Test (A)	40.0	2.76	35.88	2.67	53.93	< .001	0.32
Trail Making Test (B)	88.70	7.53	80.55	7.23	70.83	< .001	0.48

Note: Participants' scores on all four measures were significantly higher at posttest than at pretest (all p's < .001), showing faster reaction times and more agility, as well as improved performance on both sections of the TMT. Ruler Drop Test, T-Test, and Trail Making Test scores are inversely related, with the lower scores reflecting better performance.

Figure 1

Error Bar Chart of Ruler Drop Test Scores (Pre- and Post-Intervention)

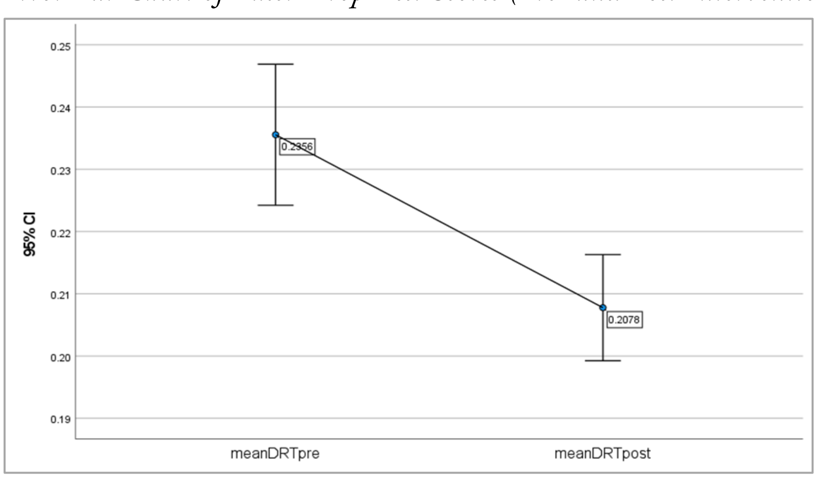
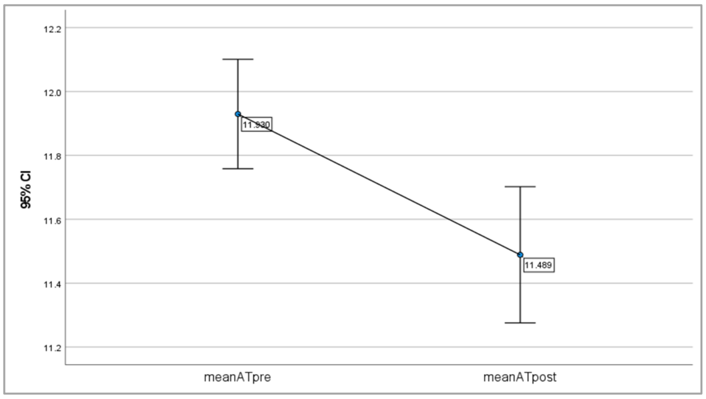


Figure 2

Error Bar Chart of Agility T-Test Scores (Pre- and Post-Intervention)



Note: The Ruler Drop Test demonstrated improvement in reaction time after the intervention, thus indicating improvement in visual–motor reaction. After the intervention, the Agility T-Test demonstrated shorter completion time, which indicates better agility and movement speed.

Figure 3

Error Bar Chart of Trail Making Test—Part A Scores (Pre- and Post-Intervention)

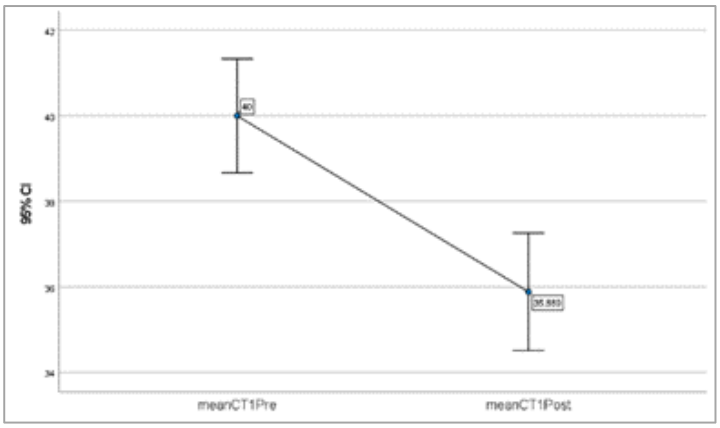
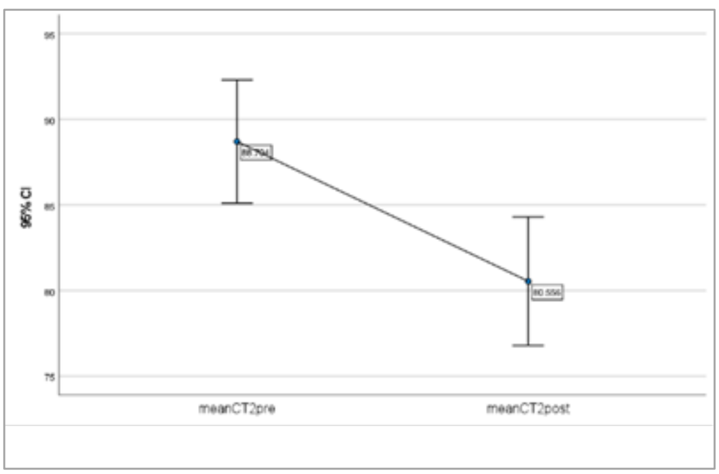


Figure 4

Error Bar Chart of Trail Making Test—Part B Scores (Pre- and Post-Intervention)



Note: The Trail Making Test A results revealed that processing speed and attention were improved, as seen by the decreased completion time following the intervention. The Trail Making Test Part B results showed decreased completion time after the intervention, indicating improved executive functioning, attention, and mental flexibility.

The Isometric Grip Strength Test scores were not normally distributed, and therefore the Wilcoxon signed-rank test was used to compare pretests and posttests for both right and left hands. The results are displayed in the following Table 4.

Table 4

Wilcoxon Signed-Rank Test Results for Isometric Grip Strength (Right and Left Hand)

Measure	M pre (SD)	M post (SD)	Z	p	r
Grip strength (right)	31.76 (9.67)	34.26 (9.17)	–3.83	< .001	–0.70
Grip strength (left)	29.50 (9.36)	32.00 (8.86)	—	—	—

Note: The post-test grip-strength scores were higher for all participants for both hands (18 positive ranks and no negative ranks or ties for either hand), which suggests a general improvement in isometric grip strength after the intervention.

Figure 5

Error Bar Chart of Right-Hand Isometric Grip Strength (Pre- and Post-Intervention)

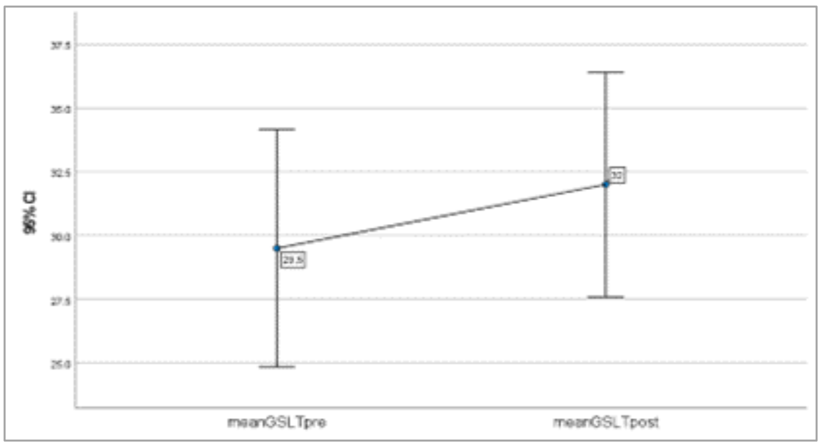
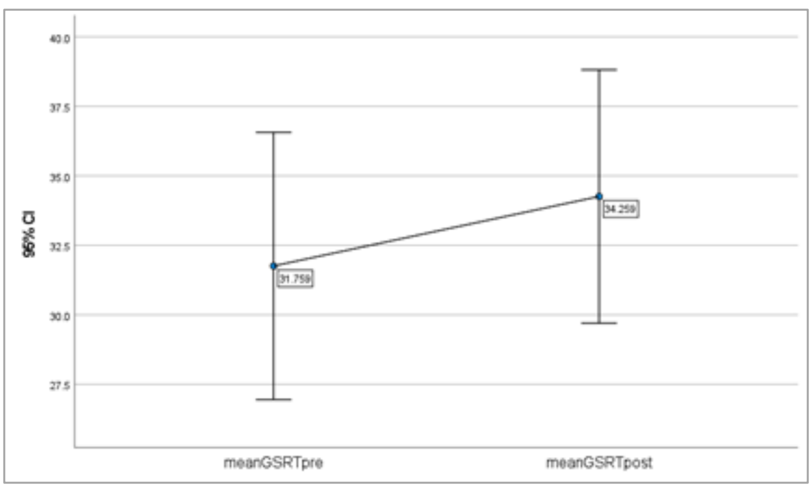


Figure 6

Error Bar Chart of Left-Hand Isometric Grip Strength (Pre- and Post-Intervention)



Note: The results of both the right and left hands demonstrated an improvement in isometric grip strength from pre- to post-tests, supporting the positive impact of the intervention on muscular strength over time.

Discussion

The present study examined the relationship between selected items of physical fitness and cognitive performance in university-level judoka and the effect of an 8-week structured training on physical fitness and cognitive performance. Results showed marked enhancements in reaction time, agility, grip strength and executive cognitive function after the intervention. Together, these findings lend credence to the idea that judo's structured training program not only helps to develop the neuromuscular system, but also improves measurable higher-order cognitive functions.

Judo can be described as a combat sport in which the movements are dynamic, unpredictable, and interactive, and it is an open skill combat sport. Judo is an open skill activity where the motor sequence is not fixed, and the sequence of actions is not predictable like closed-skill activities but demands continuous monitoring of what the opponent is doing, the need to process information quickly, make tactical decisions and adjust the motor sequence immediately (Rossi et al., 2022). The athletes must sense, anticipate, inhibit and execute, all in a timely fashion. Judo is a sport that requires many aspects of performance, making it a perfect sport to examine the interaction between physical and cognitive performance. The surprising decrease in reaction time in the present experiment suggests an increase in sensorimotor efficiency. Reaction time is the time taken to register a stimulus and give a corresponding motor response (in combat sports, milliseconds can make a difference). This is a reduction in the delay between reaction after training, indicative of a quickened processing time of the nervous system and improved communication between the central and peripheral nervous system. This improvement may be attributable to training that involves repeated practice in high-speed decision-making tasks, resulting in stronger neural pathways that are related to stimulus recognition and motor execution. There was also an improvement in agility after the intervention. Agility: Ability to move quickly from one position to another whilst maintaining balance, coordination and control; Judo: Agility is an important part of being able to throw the opponent, to evade attacks and to reposition oneself in combat (Sassi et al., 2009). The improvement in the present study suggests an improvement in neuromuscular coordination, acceleration and deceleration control and movement efficiency.

Steady-state high-intensity training can physiologically enhance motor unit recruitment, inter-muscular coordination and movement economy. These adaptations may also indirectly contribute to cognitive functions, such as attention and anticipatory control, that are important for activities in open, unpredictable environments, and could therefore be important for athletic performance.

The training proved to be effective in improving grip strength of both hands. Isometric grip strength is of particular importance in judo as it directly influences the possibility to take the opponent's gi, which in turn determines the ability to take the opponent and initiate techniques (Osipov et al., 2017).

In addition to its functional relevance in sport, previous strength training studies have correlated neural efficiency and motor cortex activation with strength training; thus, the improvements that were seen here may be due to either peripheral muscular changes or central nervous system changes.

More importantly, there was also a significant improvement in cognitive performance, with a decrease in completion time for both sections of the TMT. Part A is more focused on processing speed, visual scanning and sustained attention, while Part B is designed to test executive functioning (mental flexibility, task switching, cognitive control) (Crowe, 1998). The considerable decrease in the completion time suggests that the structured judo training has a positive effect on cognitive efficiency after the training, which is consistent with the improvement in executive functioning through judo training, especially in the domain of rapid information processing and adaptive thinking.

Some possible neurophysiological mechanisms account for these cognitive enhancements. High-intensity physical activity has been shown to lead to increases in cerebral blood flow, improved oxygen delivery, and higher levels of neurotrophic factors, which are important for neuronal growth and synaptic plasticity. Moreover, judo is an open skill sport demanding constant mental activity like anticipation, inhibition and strategic planning. This constant stimulation of the mind might stimulate brain regions associated with executive control such as the prefrontal cortex and may, over time, develop cognitive efficiency and processing speed.

Meanwhile, there was an interrelated adaptation process with improvements in both physical and cognitive scores. There appear to be two demands of the open skill physical training. The parallel improvements in agility and executive function performance may be due to similar processes, as both require the capacity to update the motor or mental response to changing contexts quickly. Likewise, quicker reaction times can aid in better attentional control, helping athletes to react better to outside stimuli.

The male-to-female ratio was relatively even, and there was no gender difference in the results of the study, meaning the cognitive and physical benefits of judo training could be easily applied to a large number of young athletes. The other benefit of the sample was that they had varying amounts of experience and competitive history, which helped to ensure ecological validity of the results for this study in a university sport context.

There are some important caveats, however, to the promising results. Results may only be generalizable to broader groups of athletes due to the relatively small sample size; while the majority of variables were statistically significant, larger samples would offer increased external validity and enable more fine-grained examination of subgroups. Moreover, the study used a single-group pretest–posttest design without a control group. Although the design allows for an evaluation of within-group change, it does not completely exclude the possibility that improvements could have been due to external factors. Future studies using a randomized controlled design would enhance causal interpretation.

An 8-week intervention was performed. While substantial changes were noted during this period, a longer-term study is required to assess whether further training will yield enduring or further cognitive benefits. Longitudinal studies could also answer the question of whether such benefits last after the training. Sleep, academic load, motivation and stress are other factors that can affect a person's cognitive performance. In an attempt to control for these other variables, the testing conditions were made as standardized as possible; future experiments might be improved by the standardization or monitoring of these other variables to further improve conclusions. Coaches, educators and sport program designers can put these findings into practice. The judo structured training can be integrated into the university athletic programs and can result in enhancement of physical fitness and other cognitive abilities such as attention, processing speed and mental flexibility.

Such cognitive enhancements can go beyond sport performance and could help the young adult to perform academically and make decisions in everyday life. Judo therefore can be a complete development activity of physical fitness and brain activities.

Lastly, the present study revealed that there is a strong link between structuring judo training and marked enhancements in physical fitness factors and executive cognitive function in university athletes (Kujach et al., 2022). As seen with the improvements in reaction time, agility, grip strength and function with the Trail Making Test, there is a significant correlation between the development of the neuromuscular system and the efficiency of cognitive functioning. The data presented here, with the recommendations of additional studies with more subjects and controlled designs, complement the current literature on the cognitive benefits of open skill sports. Last but not least, judo might be a good modality for dealing with the integration of physical and cognitive development in young adults and a combat sport for competition.

Conclusion

The findings demonstrate that there was a positive and significant correlation among changes in the components of physical fitness (reaction time, agility and muscular strength) and the development of cognitive performance (Trail Making Test) in University Judoka. The results support the hypothesis that judo activity, as a physical activity that is structured and cognitively demanding, could have two influences on the development of the individual: the neuromuscular level and the executive level. The results of this study highlight the relevance of open-skill combat sport as an efficient tool for the enhancement of integrated performance and overall human development, and the interconnection between these systems.

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