

Muscle Strength and Executive Function: High Grip Strength Young Males Can Get a Grip on Stroop Task

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Abstract

Handgrip strength (HGS) has been used as a measurement of global muscle strength and its relationship with cognitive function has been evaluated in epidemiological studies. However, whether HGS or global muscle strength is associated with cognitive function remains unclear. Therefore, the association between HGS, back strength (BS), knee extension strength (KES), and executive function related to the prefrontal cortex was examined using a cross-sectional study design. Sixty-seven 18- to 25-yr-old males completed the HGS test, the BS test, the KES test, and the Stroop task in order to assess executive function. Relative muscle strength was calculated by dividing each absolute muscle strength by body mass index. As a result, when the sample is divided based on a median split of each relative muscle strength, the higher HGS group had a significantly shorter Stroop interference time compared to the lower HGS group. However, there were no significant differences in the higher and lower groups of BS and KES. The current findings suggest that a higher HGS, rather than global muscle strength, is associated with better executive function. This confirms and further extends the usefulness of HGS as an indicator of cognitive health.

Keywords: handgrip strength, muscular fitness, cognitive function

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Introduction

Maximal handgrip strength (HGS) measurement is a quick and simple fitness test which has been widely used as a representative marker of global muscular function evaluation. Previous studies have found that HGS can predict various health outcomes including the risk of death (1–3). Moreover, several epidemical studies have reported that HGS can be associated with cognitive health and predict future risk of cognitive decline and dementia (4–7). Thus, there has been an increasing interest in HGS as a potential biomarker of brain health (8, 9). However, the underlying cause behind the relationship between HGS and brain health remains unclear (10). Previous studies found an association between HGS and cognitive function (1, 4, 5, 7), and these concluded that global muscle strength predicted by HGS is associated with cognitive function. However, it is premature to conclude that global muscle strength mediates the relationship between HGS and cognitive function since HGS cannot fully represent global muscle strength (8, 11, 12). HGS reflects the hand's muscular function in a distal part of the human body which has very complex neural control (8). A recent review by Carson (2018) suggests that the connection between HGS and cognitive function can be understood, not only via musculoskeletal factors, but also from the perspective of the mediation between motor and cognitive processes in the central nervous system (CNS) (e.g., the recruitment of motor units and the organization of muscle synergies) (8). Therefore, it is possible that HGS is specifically connected to cognitive function without involvement of global muscle status, but this remains uncertain.

The majority of previous studies have reported a relationship between HGS and cognitive function in middle-aged and older adults (8, 10). However, given the fact that elderly people show overall physical and mental decline due to natural senescence including frailty (13), the distinction of whether HGS or global muscle strength are associated with cognitive function becomes difficult to ascertain. Thus, the present study focused on healthy young adults.

Many epidemiological studies used verbal or written cognitive tests (4, 6, 7). However, if we want to discuss the neural basis of the connection between HGS and cognitive function, a more precise cognitive task, such as the color-word Stroop task (CWST), which has been used to investigate neural bases, is needed (14, 15). The computer-based CWST paradigm has been used in several neuroimaging studies to assess the inhibitory control of a core component of executive function and it has been reported that the prefrontal cortex (PFC) plays a vital role in the inhibition of cognitive conflict (14, 16–18). In this study, the CWST was adopted and Stroop interference was measured to examine the association between each type of muscle strength and prefrontal executive function.

Hence, the present study examined the association between HGS, other typical muscle strengths (back strength [BS] and knee extension strength [KES]), and CWST performance in healthy young adults using a cross-sectional study. To focus on the nervous system factors of each muscle strength type, the relative muscle strength (absolute muscle strength [kg]/body mass index [BMI]) corrected for physique was adopted. BMI-corrected HGS has been used in previous studies which have suggested the association between HGS and health outcomes (19, 20).

Method

Participants

Sixty-seven healthy young males with a mean age of 20.7 ± 1.6 years (range 18-25 years), an average body mass of 65.9 ± 9.1 kg (range 49.8-90.8 kg), and an average height of 171.5 ± 5.9 cm (range 154.7-183.4 cm) participated in this study. All participants were healthy native Japanese speakers, without any major vision disability. No participants had respiratory, circulatory, neurological, or psychiatric disorders, nor any illnesses requiring medical care. Since the menstrual cycle can affect CWST performance, female participants were excluded

(21). The sample size was determined by referring to previous laboratory-based studies examining the cross-sectional association between fitness and cognitive function (17). Written informed consent was obtained from all participants after giving them a complete explanation of the present study.

Experimental procedure

The participants visited the laboratory once. Following the collection of anthropometric measures, all participants were asked to fill in the International Physical Activities Questionnaire – short form (IPAQ) and the Profile of Mood States 2nd Edition (POMS). Afterwards, the CWST was administered to assess inhibitory control as a core component of executive function. Following the CWST assessment, all participants performed the HGS, KES, and BS tests.

Handgrip strength, back strength, knee extension strength tests

Maximal isometric HGS was assessed using a dynamometer (Grip dynamometer; Takei Kiki, Japan). All participants were instructed to adjust the dynamometer width for their individual hands and to relax their arms in a standing and stationary position. Each participant performed 4 attempts using each hand with a brief interval between trials (22). The highest score of all HGS measurements was used as a representative value of maximal HGS. Maximal isometric BS was assessed using a dynamometer (Back & leg dynamometer; Takei Kiki, Japan). The hip joint angle was adjusted to a 30° forward tilt for each individual (23). They performed 2 attempts with a brief interval between trials. The highest of all BS scores was used as a representative value of maximal BS. Finally, all participants performed the maximal isometric KES test on a chair. The grip strength meter (Grip strength dynamometer T.K.K. 5101 GRIP-D; Takei Kiki, Japan) was attached and set up so that the KES could be measured using a pulley. The knee joint angle was adjusted to 90 degrees for each individual participant.

They performed 4 attempts using each leg with a brief interval between trials. The highest of all KES scores was used as a representative value of maximal KES. Relative muscle strengths were calculated for each absolute muscle strength (kg) relative to BMI (height [m]/weight [kg]²).

Executive function test: the color-word Stroop task (CWST)

A computer-based version of the CWST was used following previous studies on the association between fitness and executive function (17). Two rows of letters were presented on the computer screen, and participants responded to whether the color of the letters in the top row corresponded to the color name shown in the bottom row (Fig. 1). Participants pressed "C" on the keyboard with their left forefinger for "YES" responses and "N" on the keyboard with their right forefinger for "NO" responses. Each condition consisted of 60 events including 20 neutral, 24 congruent, and 16 incongruent trials presented randomly. The words were all written in Japanese. Each trial was separated by an inter-stimulus interval of 1,000 ms. The stimulus was presented on the screen for 1,900 ms. For the neutral condition, the top row contained "XXX" printed in blue, green, red, or yellow and the bottom row contained the words あお [BLUE], みどり [GREEN], あか [RED], or きいろ [YELLOW] printed in black. For the congruent condition, the top row contained the words あお [BLUE], みどり [GREEN], あか [RED], or きいろ [YELLOW] printed in a color that coincided with that of the bottom row. For the incongruent condition, the color word in the top row was printed in an incongruent color to produce conflict (i.e., Stroop interference) between the color word and the color name. The mean reaction time (RT) and accuracy were assessed. The difference in reaction time between the incongruent condition and the neutral condition was the Stroop interference, and less Stroop interference was interpreted as higher executive function.

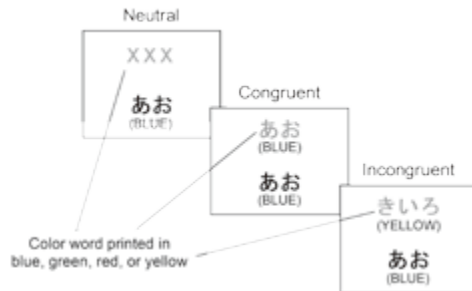


Figure 1 An example of the Japanese version of the color-word Stroop task (CWST) showing single-trial stimuli for neutral, congruent, and incongruent conditions. Translations into English are shown in parentheses.

Statistical analyses

This study included two statistical analyses: group comparison and correlation analysis. For the group analysis, participants were divided into two groups based on a median split of each relative muscle strength. Participants with scores above the median were classified as the higher handgrip (High-HGS), BS (High-BS), and knee extension (High-KES) group, and participants with scores below the median were classified as the lower group (Low-HGS, Low-BS, Low-KES). One subject, whose scores were at the median, was excluded, leaving 33 subjects in each group (High and Low). Participants' characteristics and CWST were compared between the high and low muscle-strength groups using between-subject t-tests. Finally, partial correlation analyses were conducted to test the association between HGS and RT for Stroop interference across all participants controlling for age. Statistical significance was set a priori at $P < .05$.

Results

Participant characteristics

The averaged HGS was 42.7 ± 7.4 kg, BS was 121.4 ± 30.3 kg, and KES was 56.5 ± 12.8 kg. Correlations between each muscle strength presented as follows: HGS-

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BS, $r = 0.77$, $P < .001$; HGS-KES, $r = 0.54$, $P < .001$; BS-KES, $r = 0.49$, $P < .001$.

Analysis of group comparison results for the median split between the high and low of each relative muscle strength group and participant characteristics are provided in Table 1.

No differences were observed for age, mood, or total physical activity (TPA) (all $P > .10$).

Table 1 Participant mean (SD) characteristics data of the group by each muscle strength median split

	HGS		BS		KES	
	High	Low	High	Low	High	Low
Age [year]	20.9 (1.6)	20.4 (1.7) <i>ns</i>	20.8 (1.7)	20.6 (1.6) <i>ns</i>	20.6 (1.6)	20.7 (1.7) <i>ns</i>
IPAQ [METs-hour/wk]						
TPA	48.6 (33.7)	47.0 (40.6) <i>ns</i>	55.1 (32.5)	41.8 (39.8) <i>ns</i>	46.6 (33.7)	48.5 (40.6) <i>ns</i>
POMS [score]						
TMD	19.7 (16.3)	18.3 (21.9) <i>ns</i>	19.3 (18.5)	18.0 (20.2) <i>ns</i>	18.2 (19.3)	18.9 (19.3) <i>ns</i>

Note: HGS = handgrip strength, BS = back strength, KES = knee extension strength, IPAQ = International Physical Activities Questionnaire, TPA = total physical activity, POMS = Profile of Mood States, TMD = Total Mood Disturbance. *ns* = no significant difference in group.

CWST performance

First, group differences in CWST performance of neutral, congruent, and incongruent conditions were evaluated. RT for congruent and incongruent conditions were significantly shorter in the High-HGS group [$T(64) = 2.48$, $P = .016$; $T(64) = 2.49$, $P = .015$, respectively] and in the neutral condition they were marginally significant [$T(64) = 1.87$, $P = .066$] (Fig. 2). In contrast, no differences in RT were observed for the BS and KES groups (all $P > .10$) (Fig. 2). Table 2 provides means (*SD*) for accuracy for neutral, congruent, and incongruent conditions of the CWST for high and low groups. In accuracy, no differences for any CWST conditions were observed in any muscle strength condition (all $P > .10$).

Stroop interference, a reliable marker of the inhibitory control of a core component of executive function, was calculated. Stroop interference was significantly shorter in the High-HGS group compared with the Low-HGS group [$T(64) = 2.30$, $P =$

.024], while no significant differences were observed between the high and low groups for BS and KES [$T(64) = 0.99, P > .32$; $T(64) = 0.07, P > .94$, respectively] (Fig. 3).

Finally, the association of each relative muscle strength with Stroop interference RT was confirmed across all participants. Partial correlation analysis revealed correlations of higher HGS and lower Stroop interference RT after controlling for age ($Pr = -.24, P = .048$). However, no significant association between other groups (i.e., BS and KES) and Stroop interference were observed ($Pr = -.11, P = .37$; $Pr = -.15, P = .22$, respectively).

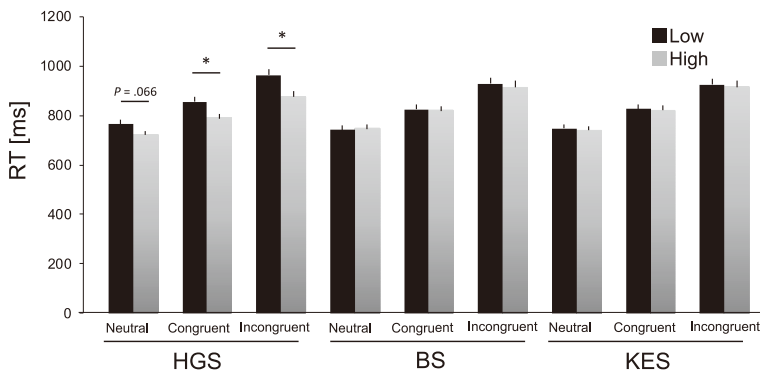


Figure 2 Reaction time (RT) of each type of color-word Stroop task (CWST) in each High-group and Low-group. Values are mean \pm SE, * $P < .05$.

Table 2 Color-word Stroop task (CWST) group accuracy by each muscle strength median split

CWST accuracy [%]	HGS		BS		KES	
	High	Low	High	Low	High	Low
Neutral	99.9 (1.2)	99.8 (0.8) <i>ns</i>	99.9 (0.9)	99.7 (1.2) <i>ns</i>	99.7 (1.2)	99.9 (0.9) <i>ns</i>
Congruent	97.3 (3.4)	98.0 (3.9) <i>ns</i>	97.6 (3.6)	97.7 (3.8) <i>ns</i>	97.5 (4.4)	97.9 (2.7) <i>ns</i>
Incongruent	89.6 (8.2)	91.7 (8.2) <i>ns</i>	90.2 (7.7)	90.3 (9.1) <i>ns</i>	90.7 (7.0)	90.0 (9.8) <i>ns</i>

Note: HGS = hand grip strength, BS = back strength, KES = knee extension strength, CWST = color-word Stroop task, *ns* = no significant difference in group. Values are mean \pm SD.

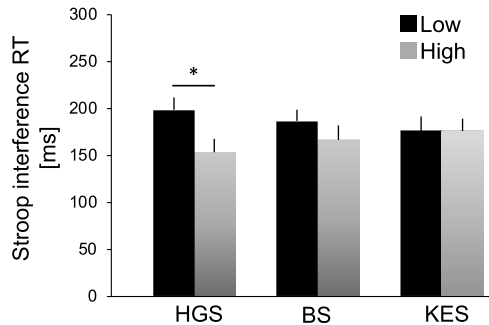


Figure 3 Reaction time (RT) for Stroop interference in each High-group and Low-group. Values are mean \pm SE, * $P < .05$.

Discussion

The aim of the present study was to clarify whether relative HGS and other muscle strengths (i.e., BS and KES) are associated with Stroop interference, an index of prefrontal executive function, in young males. As expected, higher HGS is associated with less Stroop interference (i.e., higher executive function), but there was no significant association for BS and KES. This is the first study to suggest that HGS, rather than global muscle strength, is associated with a PFC-related cognitive function.

First, the current data confirmed the relationship between HGS, BS, and KES, supporting the previous hypothesis that HGS can be a representative predictor of global muscle strength. On the other hand, group comparisons found that the high relative HGS group had lower RTs in each of the task conditions (i.e., neutral, congruent, and incongruent) and less Stroop interference (the difference between incongruent RT and neutral RT); however, this was not the case for the BS and KES groups (Fig. 2 & 3). Moreover, correlation analysis also confirmed the association between higher HGS and less Stroop interference. These results raise concerns about previous conclusions that there is a relationship between global muscle strength and cognitive function. Previous large-scale epidemical

studies reported that higher HGS is associated with present cognitive function and that it also predicts future changes of cognitive function including the risk of dementia (4–7). These past studies used HGS as an indicator of global muscle function; therefore, they concluded that global muscle strength can predict cognitive function. Although several studies have examined the relationship between global muscle strength and cognitive function (11, 24, 25), there are few studies examining whether other muscle strengths are similarly associated with cognition as is HGS. The present results lead to the proposal of a new hypothesis that HGS, rather than global muscle strength, has a positive impact on cognitive function. A recent review partially explains the possibility of the specificity of HGS (8). Maximum handgrip force exertion is strongly dependent not only on muscle mass but also on the CNS (8). The forearm muscles, which are responsible for hand movement, are composed of several small muscle groups. Complex neural circuits, such as the cortex and basal ganglia, are involved during the exertion of hand function including not only dexterity but also maximal strength (8). Although the details of the mechanism behind this are unknown, the forearm muscle groups may be more strongly affected by CNS function than large muscle groups because the human hand might be sensitive to variations in CNS function (26). The present results reveal that relative HGS, weighted by BMI, is linked with executive function in healthy young males. These results may suggest the involvement of nervous system function rather than physique factors including muscle mass. These results might support the hypothesis that HGS is associated with cognitive function mediated by the CNS.

The neural mechanisms linking the relationship between high HGS and high executive function are unknown. The frontal lobe, especially the dorsolateral PFC and anterior cingulate cortex, plays the essential role of efficient processing for Stroop interference (14, 27, 28). A recent study suggested that hand motor performance, including HGS, is dependent not only upon primary motor

structures, but also upon high executive function via executive-function-related neural activation patterns (29). Since the frontal lobe plays a role in the exertion of higher HGS (30), it is likely that these areas are involved in the link between HGS and executive function. Moreover, the involvement of the arousal/motivation system may be a common factor between HGS and executive function. It has been reported that the catecholaminergic systems, projected from the brain stem to the cortex including the PFC and motor cortex and regulating arousal/motivation and cognitive function, are activated for/by higher handgrip force exertion (31). It is unclear whether HGS is specific or not, but it is possible that these responses are greater in smaller muscles such as those in the forearm (32).

Does daily activity that enhances HGS affect executive function? It is well known that physical activity improves not only aerobic fitness but also executive function (33). However, in the present results, there was no significant difference in total physical activity as measured by the IPAQ for differences in HGS; it may be because this questionnaire was designed to target mainly calorie expenditure but not handgrip-related activity. Future work should examine the effects of daily handgrip-related activity on HGS and executive function.

The hand is a highly evolved part of the human body. The possible evolutionary connection between the hand and the brain/cognitive function has been well documented for a long time (34). Stronger HGS, as well as better dexterity, is also an important aspect of the human hand for tool making, hunting, and so on (35, 36). The positive association between HGS and executive function (i.e., PFC-based cognitive function that evolved strongly in the homo genus (37)) may also provide further insight into the missing link between the hand and brain/cognitive function.

There are several limitations regarding the generalization of these findings. The first is that the present study included only healthy young males. Therefore, it is unclear whether the conclusions of this study would be the same for females,

older adults, and people with health issues. Second, in the present study, isometric muscle strength was measured because isometric HGS is commonly used. In addition, only BS and KES were selected as examples of other typical muscle strengths (22, 24). However, the importance of other types of muscle contractions and muscular regions remains unknown. Finally, because the results came from a cross-sectional study, a causal relationship cannot be inferred. To address this issue, intervention studies are needed.

Conclusion

The measurement of HGS seems primitive, but it is propitious for future applications since it is a quick and easy fitness test to predict brain health. In this study, higher maximal HGS weighted by BMI was associated with benefits to inhibitory control as a core component of executive function in healthy young males. In contrast, BS and KES were not related to inhibitory control. The present findings add to the growing literature on the beneficial association of HGS on cognitive function and provides a new possibility that HGS, rather than overall muscle strength in humans, can predict cognitive function. This insight might strengthen the usefulness of HGS for daily clinical practices.

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