The relationship between physical effort and cognitive control

Richard Pham[1];Kevin Tran[2] ;Austin Swisher[1]; Bassam Theodory[1]; Marcus Cappiello[3]; & Weiwei Zhang[3]

[1]University of California Riverside (United States)
[2]University of California Los Angeles
[3]University of California Riverside

rpham009@medsch.ucr.edu

An open access initiative by Psychreg Ltd
ISSN: 2515-138X

The ability to ignore distractions and focus on the tasks at hand, or cognitive control, is a crucial part of our cognitive functioning. Research suggests that some cognitive and physical functioning share resources. Yet, it remains unclear how this shared relationship between cognitive and physical functioning affects cognitive control. We studied this connection by regulating the amount of experienced physical strain, and then comparing how the level of physical strain affects the ability to inhibit distractors. Research has shown that humans have a limited amount of cognitive resources available at any given time. As the expenditure of these resources increases in other cognitive areas, our ability to inhibit distractors diminishes. Our project demonstrated that the relationship between cognitive and physical processes share a similar resource bank and would behave in a similar fashion. This research may lead to the development of treatments for neuropathologies hindering cognitive control, such as ADHD.

Keywords: cognitive effort; distractors; fashion; neuropathologies; physical effort

In an increasingly distracted world, the human ability to exert cognitive control, or the capacity to maintain focus on relevant tasks while suppressing distractors, has become a paramount concern. The implications of this capacity transcend everyday life, influencing a variety of fields ranging from education and career productivity to sports performance and psychological health. Moreover, the necessity of cognitive control is underscored by situations where focus and inhibition of external distractions are critical, such as a sports competition or an exam. Simultaneously, an intriguing observation emerges: the concurrent manifestation of physical strain during cognitive control exertion, such as clenching fists or jaw during a demanding task. This interplay of cognitive control and physical strain forms the core of our investigation, where we seek to unravel the intricate relationship between mental effort and physical effort. We explore this relationship in the context of cognitive control's key aspect: the inhibition of distractors. Unpacking this relationship promises a deeper understanding of the mechanisms driving cognitive control and potentially opens avenues for innovative treatments for cognitive control deficits.

It is important for humans to be able to ignore distractions and focus on what they are doing. For instance, during a soccer game, it is important to ignore the fans and focus on the game. When employing this much cognitive control, players may find themselves clenching their fists or jaw in addition to mentally inhibiting sounds coming from the stands. Support for the relationship between mental strain and physical strain has been found in several domains. For example, both mental and physical effort affect our sense of agency (Bagdhdadi et al., 2021; Relojo, 2018), affect our value of reward (Van den Bussche et al., 2020), and affect our pupils (De Fockert et al., 2001) all in the same way. However, little is known about the relationship between cognitive and physical strain in relation to cognitive control. Presently, we investigate this relationship by manipulating physical strain and measuring participants' ability to inhibit distractors. Understanding this relationship will shed light on the mechanism behind cognitive control and may lead to new clinical treatments for cognitive control deficits.

By further evaluating the connection between cognitive control and physical strain, we hope to gain insight into how these factors may influence the prognosis and severity of diseases such as Attention-deficit hyperactivity disorder (ADHD). In addition, we hope that this knowledge can enable medical practitioners to manipulate these variables as a part of the treatment regimen for disorders affecting cognitive control deficits. Because there have been few studies examining the relationship between physical effort and cognitive control, we believe that these studies contain significant potential for the development of future treatment of ADHD.

When inhibiting distractors, it takes a large amount of cognitive resources. Sometimes, these resources may already be allocated to other cognitive functions, such as holding some information in working memory, a short-term storage of information. Past research has shown that as our working memory load gets larger, our ability to inhibit distractors decreases (Botvinick & Braver, 2015). If physical and mental efforts share the same cognitive resource pool as suggested above, then we also expect a decrease in distractor inhibition due to physical effort.

LITERATURE REVIEW

Sense of agency

A sense of agency describes one's ability to understand, perceive, and anticipate one's actions in relation to the world. In recent studies, researchers found that varying levels of cognitive and physical effort tend to affect one's implicit sense of agency (Bagdhdadi et al., 2021; Van den Bussche et al., 2020). Researchers used the concept of "intentional binding" as a measure of the sense of agency. The effect of intentional binding describes one's ability to accurately estimate the time interval between two external events, yet a tendency exists that causes individuals to underestimate the time interval between one's own actions and their subsequent outcomes. In this experiment, researchers measured intentional binding against varying levels of cognitive and physical effort (Bagdhdadi et al., 2021). Physical effort was manipulated by having participants pull at sports resistance bands with high vs. low levels of resistance. Cognitive effort was manipulated by having participants complete working memory tasks with high vs. low set-sizes and difficulty. Results suggested that intentional binding was significantly higher at low levels of effort in comparison to higher levels of effort. Researchers found that appraised levels of effort were inversely related with intentional binding. As appraised levels of exertion increased, the effects of intentional binding were lowered. As intentional binding was a measure of sense of agency, this evidence suggests that increased levels of effort decreases an individual's sense of agency. This research suggests the validity of the cognitive resource bank theory. As stated in the experiment, "the process of intentional binding is compromised when cognitive resources are depleted, either through physical or mental strain (Bagdhdadi et al., 2021)." Thus, this research supports the concept that increased appraised levels of exertion may impair cognitive processes.

Sense of reward

In making decisions, most humans tend to weigh their choices by comparing the costs of specific actions in relation to the potential rewards of those same actions. While it has been long determined that increased appraised levels of costs causes an increased discounting of reward, recent research has also established the graphical model in which cost is related to reward. It was previously believed that cost and reward were inversely related through linear or hyperbolic relationships. However, a recent study suggests that cost and reward were more closely related through a concave parabolic model (Botvinick & Braver, 2015; De Fockert et al., 2001; Nigg 2017). In this study, participants were asked to squeeze numerous hand grips with varying levels of resistance in order to earn monetary rewards. In doing so, physical exertion levels were being manipulated throughout the experiment as measured by muscular exertion and handgrip resistance. Cognitive exertion levels, as well as appraised time costs, were held constant. The data gathered was fit to linear, hyperbolic, and parabolic models. In nearly all circumstances, the parabolic model was significantly more accurate in demonstrating the relationship between cost and reward than the other two models. As suggested in the study, this effect may be caused by the phenomena occurring as muscular exertion nears one's subjective maximum. As muscular exertion approaches this subjective maximum threshold, perceived effort rises by a power function rather than a linear one. Because of this, a concave parabolic model best relates perceived costs to perceived rewards. Thus, this experiment provides further support for the connection between perceived physical and mental strain in relation to cognitive processes.

Effects on pupil size

Cognitive load, often perceived as stress, has been established as having a significant impact on physiological response (Mulder 1979; Taelman et al., 2011; Wilberg et al., 2015). Pupil diameter has long been known to increase proportionally to cognitive strain during mental tasks. However, recent research has also suggested that pupil diameter also increases proportionally to strain during physical tasks (Eriksen, 1995). The overall pupil diameter increase is related to both actual physical strain and perceived physical strain. During this experiment, participants used a handgrip at varying levels of resistance. While doing so, participants were measured for effort exertion, perceived effort exertion, and pupil size changes. Data analysis revealed that an increase in pupil diameter was related to both physical effort exertion and perceived physical effort exertion. Thus, this research suggests that pupil size is indicative of the amount of perceived invested effort, regardless of if this effort is physical or mental. This discovery acts as further evidence for the intricate, yet closely related physical/mental strain and cognitive processes.

Mental load and distraction inhibition

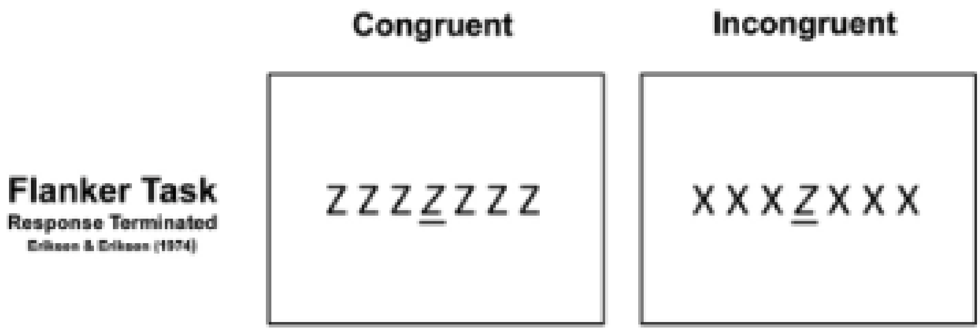
Recent research has demonstrated that working memory is an essential component of distraction inhibition (Hartmann et al., 2013; Engle et al., 1995). This process is believed to function by allowing individuals to prioritise more relevant information while filtering out irrelevant stimuli. During this study, participants were asked to utilise their working memory by recalling a specific sequence of digits. Participants were split into a low memory load and a high memory load. If the memorised sequence was in the same order, the participant was classified as a low memory load. If the memorised sequence was out of order, the participant represented a high memory load. The participants were then required to complete a selective attention task that made participants ignore irrelevant stimuli (in the form of distractor faces) while retaining their memorised sequence of digits. The data demonstrated that participants utilising a higher memory load, known to be related to higher prefrontal cortex activity, caused a "greater interference effects on behavioural performance from the distractor faces, plus increased face-related activity in the visual cortex (Howard et al., 2016)." In essence, those asked to memorise a sequence of digits out of order were less successful at ignoring the irrelevant stimuli. This data suggests that higher working memory loads is related to a lower ability to inhibit distractors. Conversely, lower working memory loads allows individuals to have an increased ability to inhibit distractors.

Eriksen flanker task

We tested how physical effort affects response inhibition using the Eriksen Flanker task (Espinoza & Wheeler, 2022; Mullane et al., 2009). The Eriksen Flanker task tests response inhibition by presenting subjects with a target stimulus that they must act on along with surrounding distractors. For example, participants may be shown numerous letters and asked to identify the centre letter. The target stimuli (centre letter) will be surrounded by distractor stimuli that are the same as the target (congruent stimuli), different than the target (incongruent stimuli), or irrelevant to the target (neutral stimulus) (Figure 1). The time it takes to make a response, or reaction time (RT), tends to be slower for incongruent trials, compared to congruent and neutral trials, giving us a measurement for success of inhibition.

Prior studies have found that individuals with attention deficit disorders (such as ADHD) are impaired in reaction time of response inhibition (Mullane et al., 2009; Wodka et al., 2007) Those affected by such cognitive disorders consistently score lower in Flanker tasks than those who are not affected. By understanding how physical effort relates to cognitive load, we may lead the way to a new treatment for attention deficit disorders.

Figure 1
Example of Eriksen Flanker Task (Roper & Vicera, 2013)



METHODS

Participants

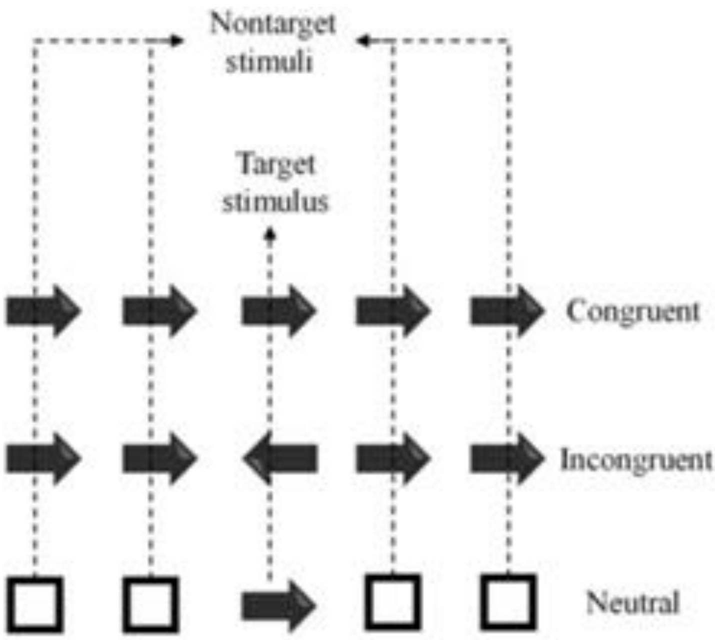
16 Psychology students, between the ages 18-21, at the [masked university] participated in the experiment in exchange for one research credit. Informed consent was obtained at the beginning of the experiment. Approval from the Human Research Review Board was obtained before subject recruitment and data collection. Equipment: We used an isometric hand dynamometer *(Figure 2)* in order to measure physical effort. Higher respective grip strength corresponds to higher physical effort, while lower respective grip strength corresponds to lower physical effort. An Eriksen Flanker task will be given on a 60Hz LCD monitor using MATLAB with Psychtoolbox.

Procedure

Physical effort was categorised as two distinct conditions: high physical load and low physical load. Participants were first tested for their top grip strength by being asked to grip the hand dynamometer as hard as possible. This maximal grip strength measurement corresponds to 100% effort. Low physical load was defined as 10% of the baseline dynamometer measurement, or 10% physical effort. High physical load corresponds to at least 80% dynamometer measurement, or 80% physical effort. Participants performed the Eriksen Flanker task. On each trial, participants first saw a bar on a computer screen whose height was elevated as they grip the dynamometer with increasing force. Based on their individual maximum grip strength, a line was drawn that participants were required to reach by squeezing the dynamometer (either at 10% or 80% maximum grip strength). They maintained this level throughout the trial. If they dropped below the threshold, they were asked to repeat the trial. While maintaining the indicated grip strength, participants were then shown an arrow and asked to push a directional key to indicate which direction the arrow is pointing. The target stimuli was surrounded by distractor arrows that are in the same direction as the target (congruent stimuli), in the opposite direction as the target (incongruent stimuli), or in a neutral direction (neutral stimulus) (Figure 3). We then compared accuracy and reaction time between the low and high physical loads. Differences in these measurements informed us of how physical effort affects distractor inhibition.

Figure 2
Image of the type of isometric hand dynamometer used during the course of this study (Vernier Software Technology, 2012)

Figure 3
While maintaining the indicated grip strength (either 30% or 80% of max), participants were asked to indicate which direction the centre arrow was pointing. The surrounding arrows, both congruent, incongruent, and neutral, acted as distractor stimuli (Zenon et al., 2014).



RESULTS

Higher physical load was correlated with lower ability to inhibit distractors (Figure 4). At 80% effort, participants made more mistakes and had slower reaction times during the Eriksen Flanker task. Lower physical load, conversely, seems to grant an individual a higher ability to inhibit distractors. At 30% effort, individuals made less mistakes and had higher reaction times.

While the data does trend in our predicted direction, a large amount of error is evident. This is most likely due to the low number of participants. In the future, more participants will be tested for this relationship between physical/mental resources and response inhibition. In doing so, we hope to minimize chance error and establish a statistically significant effect throughout the course of our trials. During this study, our 30% physical load group had a .080 standard deviation. Our 80% physical load group had a .098 standard deviation.

Figure 4
The 30% effort group (blue) had lower average differences in accuracy/response times between the congruent and incongruent distractor stimuli compared to the 80% effort group.

DISCUSSION

Error analysis

As mentioned, the most significant error to these studies is the low number of participants. Future studies should increase the participant pool size. Another possible error is that participants may have had trouble understanding aspects of the system in the initial trials. As the number of trials performed increased, reaction times and accuracy improved in both 30% and 80% physical loads. We are unsure if this is a result of better understanding of the Eriksen Flanker task, or whether this improved performance is due to practice. As a result, early confusion about how the Eriksen Flanker task works may cause error. This can be fixed in future trials by integrating numerous practice trials into our experiment before measured trials.

Placement of the hand grip dynamometer itself during trials may have also impacted the measured physical load. While some participants placed the dynamometer on the desk pad during trials, other participants held the device in their lap. While this may seem trivial, placement of the handgrip during trials may affect how easily physical load is distributed into the handgrip, therefore skewing accurate measurements of physical exertion. In order to normalise conditions, future studies should have participants perform the Eriksen Flanker task with uniform device placement. A simple yet likely error could be participant fatigue throughout the measured trials. As the experiment wore on, participants most likely fatigued from the isometric hand dynamometer. The variable 30% versus 80% loads on participants most likely seemed increasingly difficult overtime, therefore affecting performance. As such, physical exertion would increase even further and most likely skew Eriksen Flanker test results. In order to prevent participant fatigue from affecting results in future trials, we will establish break periods for the participants during the trials. The participants will be less affected by fatigue, and the data will better represent the phenomena we are currently studying.

Potential significance

By understanding the connection between physical and cognitive resources, we may be able to gain insight into the mechanism behind response inhibition. In doing so, we will better understand the many factors that affect successful response inhibition. This increased understanding will enable us to further examine how cognitive processes work and may ultimately lead to new treatments for attention deficit disorders. Other research has demonstrated that those who are affected by attention deficit disorders tend to score lower on Eriksen Flanker tests. Those affected by disorders such as ADHD have less accurate responses as well as a slower response time. While this lower score may be a result of a multitude of factors, the shared connection between physical and mental resources is undoubtedly influential on cognitive processes such as response inhibition. Through the continuation of this study, we hope to gain further knowledge about how to best utilise these shared physical/mental resources in order to help increase successful response inhibition, and therefore provide effective treatment for ADHD.

Because the specific relationship between physical effort and cognitive control is relatively unstudied, there is significant potential for further exploring this field. The clinical implications of utilising the relationship between physical load and cognitive control may result in dramatic improvements in the evaluation, treatment, and understanding of disease processes such as ADHD. Because the vast majority of patients with ADHD are typically male adolescents, the potential shift to reliance on non-pharmacological agents could greatly improve long-term management (Souza et al., 2008). By manipulating physical load rather than solely relying on pharmacological agents, patients could potentially have fewer side effects, increased adherence, and decreased drug interactions. This therapeutic effect would prove particularly useful in patients with mild ADHD.

Not only could understanding the mechanism behind the physical effort and cognitive control influence the management of such disease processes, but there is also potential in preventing the development of disorders altering cognitive control. Because physical exercise acts on the same dopaminergic and noradrenergic systems that are altered in ADHD, studies have suggested increasing physical activity may influence the development and long-term prognosis of ADHD (Wigal et al, 2013). In further establishing this relationship, clinical providers can more definitively suggest physical activity as a preventative measure to ADHD. As such, further studies should examine how different types of physical load may influence cognitive control.

Future projects

We believe that this area of research has tremendous amounts of potential in terms of applicability and unexplored concepts. Our current study uses a handgrip dynamometer as a measure of physical strain and exertion. However, future projects studying the relationship between physical/mental strain and response inhibition could determine whether the actual type of physical exertion plays a role. There are four main types of established physical activity that can be studied: aerobic, muscle-strengthening, bone-strengthening, and stretching. Does the type of physical strain affect response inhibition differently? This could be studied through experiments utilising tasks such as running, weight training, jumping, or dynamic stretching.

As we continue with our current experiment, we hope to highlight the effect of physical/mental strain on response inhibition. However, it is likely that this effect influences other cognitive processes as well. Another possible area of study could be studying the concept of limited, shared physical/mental resources in relation to other cognitive processes. Rather than studying only response inhibition, future research could focus on cognitive processes such as decision making, logical reasoning, problem-solving, learning.

CONCLUSION

The present research also sets the stage for expanding this investigation into other cognitive processes. As cognitive control is not limited to response inhibition alone, the exploration of shared physical and mental resources in other cognitive realms, such as decision making, logical reasoning, problem-solving, and learning, could be a fascinating avenue for future studies.

In conclusion, this study adds to our understanding of the symbiotic relationship between cognitive control and physical strain. It paves the way for ground-breaking research that could potentially enhance our comprehension of cognitive processes and inform new clinical interventions for cognitive control deficits. We believe that the implications of this research extend beyond the scientific community and have the potential to bring about tangible changes in how we understand and improve human cognitive abilities in daily life.

Acknowledgements: None
Conflict of interests: The authors declare no competing interests.
Ethical approval: University of California Riverside
Funding: No funding was received.

REFERENCES

Baghdadi, G., Towhidkhah, F., & Rajabi, M. (2021). *Neurocognitive mechanisms of attention: Computational models, physiology, and disease states* (1st ed.). Academic Press.

Botvinick, M., & Braver, T. (2015). Motivation and cognitive control: from behavior to neural mechanism. *Annual review of psychology*, *66*, 83-113.

De Fockert, J. W., Rees, G., & Frith, C. D. Lavie1 3nilli.(2001). *The Role of Working Memory in Visual Selective Attention. Science*, *291*, 1803-1806.

Engle, R. W., Conway, A. R., Tuholski, S. W., & Shisler, R. J. (1995). A resource account of inhibition. *Psychological Science*, *6*(2), 122-125.

Eriksen, C. W. (1995). The flankers task and response competition: A useful tool for investigating a variety of cognitive problems. *Visual Cognition*, 2(2-3), 101-118.

Espinoza, F., & Wheeler, B. (2022). Handgrip as a measure of muscle strength and its physiological dependence on therapeutic variables: A randomized case. *Hand Surgery and Rehabilitation*, *41*(1), 31-36.

Hartmann, M. N., Hager, O. M., Tobler, P. N., & Kaiser, S. (2013). Parabolic discounting of monetary rewards by physical effort. *Behavioural processes*, *100*, 192-196.

Howard, E. E., Edwards, S. G., & Bayliss, A. P. (2016). Physical and mental effort disrupts the implicit sense of agency. *Cognition*, *157*, 114-125.

Mulder, G. (1979). Mental load, mental effort and attention. *Mental workload: Its theory and measurement*, 299-325.

Mullane, J. C., Corkum, P. V., Klein, R. M., & McLaughlin, E. (2009). Interference control in children with and without ADHD: A systematic review of Flanker and Simon task performance. *Child Neuropsychology, 15*(4), 321–342. https://doi.org/10.1080/09297040802348028

Nigg, J. T. (2017). Annual Research Review: On the relations among self-regulation, self-control, executive functioning, effortful control, cognitive control, impulsivity, risk-taking, and inhibition for developmental psychopathology. *Journal of child psychology and psychiatry*, *58*(4), 361-383.

Relojo, D. (2018). Football and mental health: Interview with Manisha Tailor. Psychreg Journal of Psychology, 2(1), 103–105. https://doi.org/kcrr

Roper, Z. J., & Vecera, S. P. 2013. Eriksen Flanker Task. Response terminated displays unload selective attention. Frontiers in psychology, 4, 967.

Souza, I. D., Mattos, P., Pina, C., & Fortes, D. (2008). ADHD: The impact when not diagnosed. *Jornal Brasileiro de Psiquiatria*, 57, 139-141.

Taelman, J., Vandeput, S., Vlemincx, E., Spaepen, A., & Van Huffel, S. (2011). Instantaneous changes in heart rate regulation due to mental load in simulated office work. *European journal of applied physiology*, *111*, 1497-1505.

Van den Bussche, E., Alves, M., Murray, Y. P., & Hughes, G. (2020). The effect of cognitive effort on the sense of agency. *Plos one*, *15*(8), e0236809.

Vernier Software Technology. (2012). Type of isometric hand dynamometer used during the course of this study. www.vernier.com.

Wiberg, H., Nilsson, E., Lindén, P., Svanberg, B., & Poom, L. (2015). Physiological responses related to moderate mental load during car driving in field conditions. *Biological psychology*, *108*, 115-125.

Wigal, S. B., Emmerson, N., Gehricke, J. G., & Galassetti, P. (2013). Exercise: applications to childhood ADHD. *Journal of attention disorders*, *17*(4), 279-290.

Wodka, E. L., Mark Mahone, E., Blankner, J. G., Gidley Larson, J. C., Fotedar, S., Denckla, M. B., & Mostofsky, S. H. (2007). Evidence that response inhibition is a primary deficit in ADHD. *Journal of clinical and experimental neuropsychology*, *29*(4), 345-356.

Zénon, A., Sidibé, M., & Olivier, E. (2014). Pupil size variations correlate with physical effort perception. *Frontiers in Behavioral Neuroscience, 8*, 286. https://doi.org/10.3389/fnbeh.2014.00286