Title
Relationship Between Physical Effort and Cognitive Control

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RELATIONSHIP BETWEEN PHYSICAL EFFORT AND COGNITIVE CONTROL

By

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APPROVED

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Abstract

The ability to ignore distractions and focus on the tasks at hand, or cognitive control, is a crucial part of our cognitive functioning. While this ability was initially believed to be a solely mental mechanism, previous 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. We believed that the relationship between cognitive and physical processes share a similar resource bank, and would behave in a similar fashion. We predicted that the distractor inhibition ability will decrease as physical load increases. This research may lead to the development of treatments for neuropathologies hindering cognitive control, such as ADHD.

Introduction:

For everyday life, 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 (Howard et al., 2016), affect our value of reward (Hartmann et al., 2013), and affect our pupils (Zenon et al., 2014) 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.

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 store of information. Past research has shown that as our working memory load gets larger, our ability to inhibit distractors decreases (de Fockert et al., 2001). 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.

Past Research: Review of Past Research Studies Relevant to Our Experiment

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 a recent 2016 study, researchers found that varying levels of cognitive and physical effort tend to affect one's implicit sense of agency (Howard et al., 2016). In this study, 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. 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 suggest 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 (Howard et al., 2016)." 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 (Hartmann et al., 2013). 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 exertions 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:

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 (Zenon et al., 2014). 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 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:

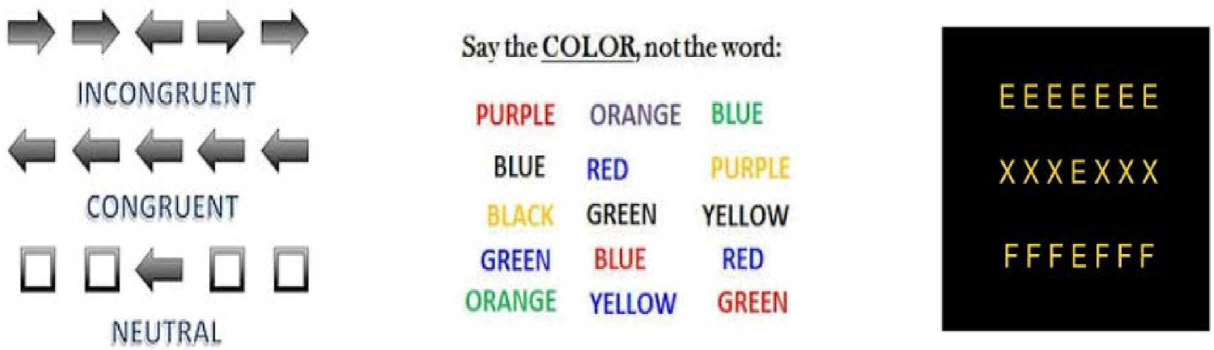
Recent research has demonstrated that working memory is an essential component of distraction inhibition (de Fockert et al., 2001). This process is believed to function by allowing individuals to prioritize more relevant information while filtering out irrelevant stimuli. During this this study, participants were asked to utilize 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 memorized sequence was in the same order, the participant was classified as a low memory load. If the memorized 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 memorized sequence of digits. The data demonstrated that participants utilizing a higher memory load, known to be related to higher prefrontal cortex activity, caused a "greater interference effects on behavioral performance from the distractor faces, plus increased face-related activity in the visual cortex (de Fockert et al., 2001)." In essence, those asked to memorize 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.

Predictions/Reasoning/Significance:

The purpose of this study is to examine how physical effort and mental effort are related in cognitive control. The relationship between mental load and cognitive control is well studied, so here we test the relationship between physical load and cognitive control. Specifically, we will be testing how physical effort affects response inhibition using the Eriksen Flanker task (Eriksen, 1993).

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 an arrow and must push a directional key to indicate which direction the arrow is pointing. The target stimuli will be 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 stimuli). 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. We predict that higher physical effort will decrease the amount of cognitive resources available, which would lead to lower performance in the Flanker tasks, similar to a high working memory load.

Prior studies have found that individuals with attention deficit disorders (such as ADHD) are impaired in reaction time of response inhibition (Mullane, Corkum, & Klein, 2008). 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.



Examples of Eriksen Flanker Task

Experimental Design:

Participants: 16 Psychology students, between the ages 18-21, at the University of California Riverside participated in the experiment in exchange for one research credit. Informed consent was obtained at the beginning of the experiment. Approval from Human Research Review Board was obtained before subject recruitment and data collection.

Equipment: We used an isometric hand dynamometer 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 categorized 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 that 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 whose height was elevated as they grip the dynamometer harder. Based on their individual maximum grip strength, a line was drawn that they are 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. We then compared accuracy and reaction time between the low and high physical load differences. Differences (or lack of) informed us of how physical effort affects distractor inhibition.

Images of the type of isometric hand dynamometer used during the course of this study

Predicted Results:

Because high mental load decreases distractor inhibition (de Fockert et al., 2001) and mental load and physical load have shown similar effects on other cognitive functions (Howard et al., 2016; Hartmann et al., 2013; Zenon et al., 2014), we predict increased physical load will decrease participants' ability to inhibit distractors. We propose that physical and mental efforts share a limited, cognitive resource bank. Simultaneous performance in one area will take away from the available resources for performance in the other area. Due to this shared resource bank, we believe that performance in Flanker tasks will significantly decrease during high physical load when compared to low physical load. Furthermore, Flanker task performance during low physical load will decrease in comparison to no physical load. As physical load gradually increases, we believe less cognitive resources will be available; this will lead to a corresponding gradual decrease in ability to inhibit distractors.

Preliminary Data:

While our sample size is small, therefore more susceptible to error, our data seems to be trending towards our prediction. Higher physical load seems to be more correlated with lower ability to inhibit distractors. 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.

However, there seems to be a high degree of error so far during the experiment. 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. Because there have only been 16 participants so far, our research is neither solidified nor conclusive. In order to have data that represents an established and reliable phenomenon, more participants have to be tested. 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. Thus far, our 30% physical load had a .080 standard deviation. Our 80% physical load has a .098 standard deviation.

*Preliminary data 16 participants. *Note: High errors most likely result from lower number of participants thus far. More participants will be needed in order to establish a significant trend.*

Error Analysis:

As mentioned, the most obvious error to these studies so far are the low number of participants. In the upcoming weeks, we hope to increase the overall number of participants engaging in these trials. In doing so, we hope to establish a more statistically significant trend with lower error values. Furthermore, increasing the number of participants will allow us to increase the generalizability of this trend, examining whether demographic, education, and other background characteristics affects this trend. Thus far, our research is only in its preliminary stages. We predict that more participants will continue to establish a stronger trend agreeable with our preliminary predictions.

Another possible error is that participants may have had trouble understanding aspects of the system in the first trials. Participants may not understand how the Eriksen Flanker tasks work. Because we are only in the preliminary stages of research, we did not provide the participants with a sufficient amount of practice trials. As a result, early confusion about how the Eriksen Flanker task works may cause error, resulting in less significant data. This seemed to be the case in many participants, as accuracy and reaction time tended to increase significantly after the first few trials. This will be easily fixed in future trials by integrating numerous practice trials into our experiment before measured trials.

Another improvement to be made could be hand placement on the isometric hand dynamometer. Because our hand dynamometer had multiple sensor pads, we noticed a few participants were squeezing the handgrip using the wrong sensor pads. As a result, the hand grip device measured a lower load volume. Though we corrected this mistake in future trials, early participants may have been using the wrong sensor pads on the handgrip. Because our preliminary participant number was so low, using the wrong sensor pads in even a few trials may have heavily skewed the data. We will clarify the correct sensor pads to use in future trials. Placement of the hand grip dynamometer itself during trials may have also impacted the measured physical load. While some participants correctly placed the dynamometer on the designated 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 normalize conditions, we will clarify to future participants that the handgrip must remain on the designated desk pad.

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 resource, we may be able to gain insight into the mechanism behind response inhibition. In dong 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 (Mullane, Corkum, & Klein, 2008). 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 utilize these shared physical/mental resources in order to help increase successful response inhibition, and therefore provide effective treatment for ADHD.

Future Projects:

While our current study is still in its early stages, we also 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 studied: aerobic, muscle-strengthening, bone-strengthening, and stretching. Does the type of physical strain affect response inhibition differently? This could be studied through experiments utilizing 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, etc.

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