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## Protocol Article

# An Inquisit-web protocol for calculating composite inhibitory control capacity score: An individual differences approach



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## A B S T R A C T

In the present paper, we provide a protocol for experimentally measuring and calculating individual inhibitory control capacity index in adult participants in an online Inquisit-based setting. We believe that this method can serve other researchers in the standardized assessment of individual inhibitory control capacity that can be used in studies on the possible role of inhibitory control in many every-day cognitive phenomena. Thus, the paper focuses mainly on the calculation of a composite inhibitory control capacity score from two inhibitory control tasks. Specifically, it is calculated on the basis of participants' performance in two well-established experimental paradigms: the Stroop Task and the Eriksen Flanker Task. The methods described in this protocol have already been successfully applied in both lab and online settings. In the first part of the article, we provide a short theoretical background and a brief description of the previous usage of this method in our two original studies. In the following parts, we provide step-by-step instructions for measuring and calculating the individual inhibitory control capacity index using web-based methodology. The protocol is supplemented with slides of original experimental tasks and instructions for participants (both translated from Polish).

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## A R T I C L E I N F O

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*Keywords:* Cognitive control, Inhibitory control, Online Stroop task, Online Flanker task

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† Rémi Radel passed away on 14 May 2019. He will be sorely and truly missed.

## Specification table

Subject Area	Psychology
More specific subject area	<i>Cognitive inhibition</i>
Protocol name	An Inquisit-web protocol for calculating composite inhibitory control capacity score: An individual differences approach
Reagents/tools	<i>Inquisit Web software (Millisecond)</i>
Experimental design	Inhibition capacity is calculated on the basis of participants' performance in experimental task: the Stroop Task and the Eriksen Flanker Task (both performed in the web setting).
Trial registration	<i>n.a</i>
Ethics	The Research Ethics Committee approved the Study. Written consent for participation was obtained prior to data collection. Participants were informed that they were free to withdraw from the study at any point
Value of the Protocol	<ul style="list-style-type: none"> <li>• The article provides a protocol for measuring and calculating adult individuals' inhibitory control capacity index.</li> <li>• This method can serve as a standardized way of analyzing synthesized performance in the Stroop Task and the Eriksen Flanker Task in order to assess general inhibition capacity.</li> <li>• This method has been proven in two original studies to successfully differentiate participants with different levels of inhibition efficacy.</li> </ul>

## Introduction

The term “inhibition” refers to a wide class of processes whose primary role is preventing irrelevant information from accessing working memory and stopping off-goal reactions. Inhibition processes play a central role in many cognitive functions, such as long-term memory [1], attention [2] and self-control [3]. There is growing evidence that people with higher inhibitory control are less prone to overeating and being overweight (e.g. [4–6]), increased alcohol intake (e.g. [7]), and unintentional stereotyping (e.g. [8]); moreover, they are more successful at resisting peer pressure encouraging and/or supporting risky behaviors (such as speeding, aggressive driving etc.), thus resulting in safer driving (e.g. [9]). Additionally, impairment of the inhibition processes is considered to be a central mechanism of ADHD [10–12]. Taking this into account, inhibition can be treated as one of the most fundamental psychological functions which is crucial in many domains of everyday life.

There are many experimental methods for measuring the efficacy of inhibition. One of the most representative of these is the Stroop Task [13], the classic version of which consists in presenting the names of various colors to participants (e.g. “red”, “green”, “black” etc.) written in colored fonts. Participants are asked to name the color of the ink while ignoring the meaning of the word. In the congruent condition of the task, the color of the font corresponds to the meaning of the word (e.g., red is written in red); in the incongruent condition, it does not match (e.g., red is written in green). The Stroop effect consists in prolonged reaction times in the incongruent condition. The effect is considered to be a result of increased need for cognitive resources because the incongruent condition requires participants to additionally inhibit the automatic reaction of reading the name of the word [13].

Another well-established paradigm for measuring inhibition is the Eriksen Flanker Task [14]. During this task, participants have to press the arrow keys with either the left or right index finger according to the direction pointed to by the center target arrow. This target arrow is surrounded by other arrows (flankers) that should be ignored. In congruent trials, all targets (including flankers) indicate the same response (they point in the same direction: “→→→ → →→→”). In incongruent trials, they indicate opposite directions, and flankers activate the wrong automatic response that should be ignored and inhibited (e.g. →→→ ← →→→).

## Application of the inhibition capacity index in our original studies

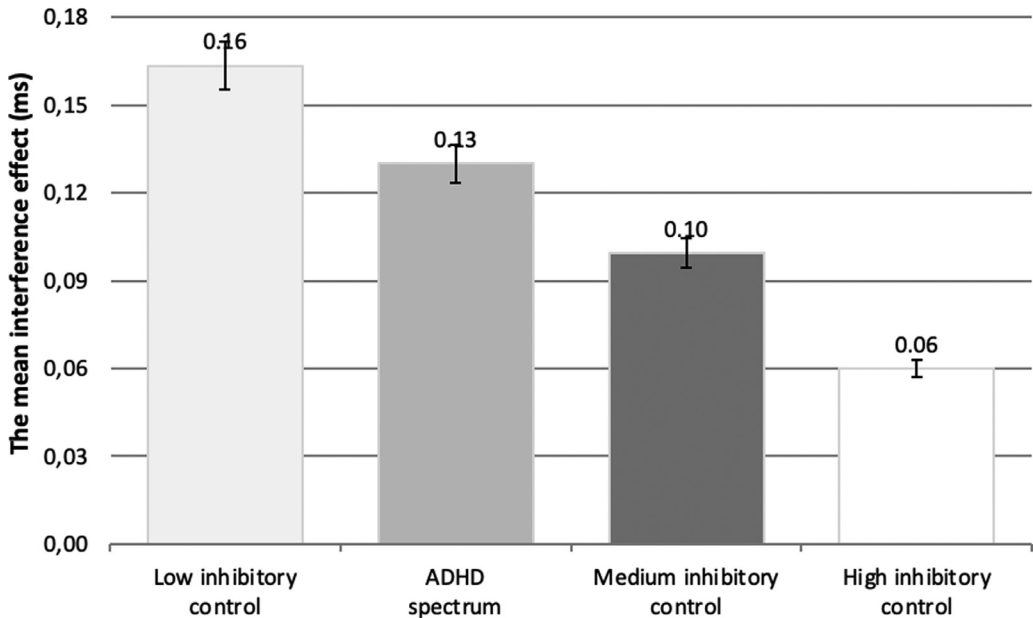
Both of the above tasks were used in our original studies on the role of inhibition capacity in Involuntary Autobiographical Memories (IAM) and Involuntary Future Thoughts (IFT). These terms refer to the mental time-travel phenomenon, during which people spontaneously recall

autobiographical memories (IAM) or start to think about the future (IFT) without a deliberate intention to do so. In our studies, we tested the hypothesis that the cognitive inhibitory control mechanism prevents our consciousness from being flooded by task-unrelated thoughts about the past and the future. In our studies ([15–17]) we aimed to compare people with different individual levels of inhibition capacity (either by using an experimental approach [15] or individual differences approach [16]) in terms of the number of their IAMs and IFTs. We predicted that low inhibition capacity would correspond to an increased number of IFTs and IAMs.

In one study [16] we asked a big pool of participants to complete the Stroop and Flanker tasks in an online setting (the final sample consisted of 433 participants). Participants were recruited to the online pre-selection session via social media, university advertisements and flyers. They were invited to visit the project website, where more detailed information about the study was provided and where they were asked to provide their e-mail addresses. In the following step the links to the site with experimental tasks were sent. More specifically, participants were asked to follow all the instructions and to perform the tasks as well as possible. Additionally, they were asked to start the study only when being certain that their performance will not be disrupted by any noise or other distractions. Participants were also provided with information of how to install the Inquisit Software in order to launch all the experimental tasks.

Based on the results from the online pre-selection stage, we calculated each participant's individual inhibition capacity index. In particular, we examined the standard interference effect, i.e., the difference between the mean response times in incongruent and congruent trials divided by the mean response time in congruent trials, which represents the time needed to inhibit interference and, importantly, is considered a reliable indicator of the efficacy of cognitive control (e.g. [18]): the lower the interference (i.e., the faster the interference is resolved), the stronger one's inhibitory capacity. First, we calculated the interference ratios separately for the Stroop task and the Eriksen flanker task. Second, we standardized these scores (i.e., z-transformed them) to make them comparable with each other. Then, the general inhibitory control capacity index for each participant was calculated as a mean of these two z-transformed interference ratios. These steps allowed us to divide participants into three groups with different levels of inhibition capacity (low, medium, high). A one-way ANOVA on the inhibition capacity index for these two online tasks, with the inhibitory control group (low, medium, high) as a between-subjects variable, resulted in a statistically significant main effect ( $F(2, 117) = 188.35, p < .001, \eta^2 = 0.77$ ), with the strongest and the poorest inhibitory control in the high and low condition, respectively, and with medium inhibitory control in the medium group (all  $ps < 0.001$ ). Additionally, we formed a new pool of people with ADHD, who according to various studies are characterized by an impaired inhibition control mechanism [10–12]. This sample was formed via a separate recruitment phase based exclusively on the Diagnostic Interview for ADHD in adults (DIVA) score [19]. Subsequently, 120 participants without ADHD (40 from each of the 3 groups with different inhibition capacity levels) and 37 participants with ADHD were randomly selected from the final pool and invited to the laboratory to complete the vigilance task, which applied a probe-caught method to measure the frequency of IFTs and IAMs. Additionally, participants were asked to once again complete the Stroop and Flanker tasks for the sake of re-measuring their individual inhibition capacity, but this time in a laboratory under well-controlled experimental conditions. This allowed us to re-group participants based on their inhibitory control ratios obtained in the laboratory rather than based on their initial online session ratios. After this operation we reassigned 21, 25 and 20 participants to the low, middle and high groups, respectively.

Our main prediction that the stronger the participants' inhibitory control capacity, the lower the frequency of their reported IAMs and IFTs, was not confirmed as the number of IFTs and IAMs reported during the vigilance task did not differ significantly between groups. In addition, individuals with ADHD spectrum symptoms did not report more spontaneous thoughts compared to other groups. However, the results revealed that the groups did in fact differ in terms of their re-calculated inhibition capacity indices. A one-way ANOVA on inhibition capacity index with the inhibitory control group (low, medium, high, ADHD spectrum) as a between-subjects variable resulted in a statistically significant main effect,  $F(3, 151) = 30.73, p < .001, \eta^2 = 0.38$ . Post hoc tests indicated that, as expected, participants in the low inhibitory control group were the slowest to exert inhibition (all  $ps < 0.001$ ), while participants in the high inhibitory control group were the fastest (all  $ps < 0.001$ ).



**Fig. 1.** The overall means of aggregated interference effect times in the laboratory-based Stroop-like task and in the Eriksen flanker task in the study by Barzykowski et al. [15]. Error bars indicate 95% confidence intervals for the comparison groups. The higher the Stroop effect, the weaker the individuals' inhibitory control capacity.

As presented in Fig. 1, participants in the medium group were better ( $p = .001$ ) and worse ( $p = .001$ ) compared to participants in the low and high inhibitory control groups, respectively. Finally, ADHD-spectrum participants were better at inhibiting than participants in the low inhibitory control capacity group ( $p = .002$ ) and worse compared to both the medium ( $p = .019$ ) and high inhibitory groups ( $p = .001$ ).

To measure participants' inhibition capacity, we applied the same approach as was used in our other study on the impact of cognitive load on the number of experienced IFTs and IAMs in people with different levels of inhibition efficacy [16]. Group assignment was conducted in the same way as in the study above, namely on the basis of individual capacity index measured online and in a laboratory. Likewise, in our previous study, 3 groups with different levels of cognitive capacity were distinguished (however, no people with ADHD were recruited for this study). Participants were randomly selected from the same big pool as in the study above. A total of 100 participants were randomly recruited. More precisely, from the high and the low inhibitory control capacity groups, we randomly selected and invited 50 participants to participate in the experimental study. Similar to the previous study, the invited participants were once again asked to (among others) complete the Stroop and Eriksen flanker tasks in the laboratory. After calculating their individual inhibition capacity indices, the participants were assigned to low and high inhibitory groups (on the basis of their laboratory performance in both tasks). We reassigned 15 and 19 participants to the low and high groups, respectively.

Finally, our method of measuring individual Inhibition Capacity Indices has once again been proved to be an effective way of dividing participants into groups differing in individual levels of inhibitory control capacity: as expected, participants in the low inhibitory control group were slower at resolving interference ( $M = 0.13$ ,  $SD = 0.05$ ) than the high inhibitory control group ( $M = 0.09$ ,  $SD = 0.04$ ):  $t(96) = 4.65$ ,  $p < .001$ ,  $d = 0.89$  (a large effect size).<sup>1</sup>

<sup>1</sup> Of note: It is worth to highlight that the method of measuring individual Inhibition Capacity Indices as described here is not meant to investigate the differences between participants in this regard as this would be circular, increasing the risk of

Both these studies provide arguments for considering this method of calculating individual inhibition capacity indices to be a very efficient way of measuring this cognitive function. The most important advantage of this method is that it aggregates data from two well-established paradigms, thus its validity is ensured. In the following parts of this paper, we will provide a step-by-step protocol for using this method in an online setting.<sup>2</sup>

## Online inhibition capacity index measurement – method details

### 1. Materials

- **Inquisit Web software:** All instructions and tasks were created and displayed using Inquisit Web software (Millisecond software) in an online setting.
- **The Stroop-like task:** This task consisted of four color words (red, green, blue, and yellow) in Polish, printed in one of these four colors (e.g., the word red could be printed in red, green, blue or yellow). Participants were instructed to identify the color of the ink of the word as quickly as possible by pressing a key corresponding to the color of the ink without paying attention to the meaning of the word. Each word was displayed until the response was given (latencies were measured from the onset of stimuli), with a 400 ms interval between trials and a 400 ms error feedback screen after each error trial. While the meaning of the word and the color of the ink were the same in congruent trials, the meaning differed from the color of the ink in incongruent trials. In total, there were 140 trials, including 70 congruent and 70 incongruent trials presented in a random order. Finally, for the practice trial, we used a short 14-trial version of the Stroop task that consisted of 50% congruent and 50% incongruent trials. The main task lasted up to 10 min. The task started with the following verbal instruction:

*“In the following trials you will see words presented in different colors. Your task is to indicate the COLOR in which each word is printed in while ignoring what the words actually say.*

*Indicate the color of the word by pressing either of the following keys:*

- d for red words
- f for green words
- j for blue words
- k for black words

*Example: if you see the word RED printed in the color GREEN press 'f' for green words regardless of the meaning of the word.*

*Try to respond as quickly and accurately as you can, because you will be timed. If an incorrect response is made, a red X will be flashed onto the screen.”*

- **Eriksen flanker task (Eriksen & Eriksen, 1974):** During this task, participants had to press the arrow keys according to the direction indicated by the target arrow in the center of the screen. This target arrow was surrounded by other arrows (flankers). In congruent trials, all targets, including

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tautology. This is mainly because the groups are prepared based on their inhibitory results thus the differences between them in resolving interference are expected and only prove that the method successfully serves this particular purpose. However, having participants divided into groups with different levels of inhibitory control allows further examination of the possibility that those with high levels of inhibitory control behave/react/function differently in some regard (e.g., may report fewer involuntary past and future thoughts as investigated in one of our study [16]) than participants with low inhibitory control capacity. Therefore, such an approach may open new avenues for research on the possible roles of the cognitive inhibitory control involved in many every-day cognitive phenomena.

<sup>2</sup> Please note that in the present paper we use the term “online” in its main and direct meaning; namely, to indicate the fact that the data were collected by instructing participants to download on their own computer an Inquisit-web software letting them engage themselves in a given experimental tasks without any direct experimenter’s supervision. However, some researchers refer to the online research methods in a more specific way. For example, according to Madge [20] Internet Mediated Research (also called Online Research Methods or Online Research Practices) is simply research that is conducted through the medium of the Internet. On the other hand Reips [21] has introduced the term “Web experiment” as a subtype of Web-based Methods which is characterized by the fact that the experimental task is visible on the Internet and remains there as a documentation of the research method and material.

flankers, indicated the same response (they were pointing in the same direction). In incongruent trials, the flankers indicated the opposite directions, thus activating the wrong automatic responses that had to be ignored and inhibited. The appearance of arrows was preceded by an empty square in the center of the screen – it was a cue indicating that participants would see arrows inside a square in a moment. In total, there were 140 trials (70 congruent and 70 incongruent presented in a random order). Each trial was presented for a maximum of 2700 ms (the target and distractors were presented for a maximum of 1750 ms). Additionally, before starting the main task, participants were provided with additional 10 practice trials. The main task lasted up to 10 min. The task started with the following verbal instruction:

*“Welcome to the attention focusing task.*

*On the computer screen, you’ll see five arrows placed inside a square. Your task is to decide whether the MIDDLE arrow is pointing left or right.*

*\*Sometimes, all five arrows will be pointing in the same direction.*

*\*Sometimes, the MIDDLE arrow will be pointing in a different direction than all the others.*

*Before the five arrows appear, you’ll see an empty square in the middle of the screen. This is a cue which indicates that arrows will appear inside the square in a moment.*

Press <SPACE> in order to start the training session.

The training session started with the following verbal instruction:

*This is the TRAINING session.*

*Remember: your task is to decide whether the MIDDLE arrow is pointing LEFT or RIGHT.*

*\*If the MIDDLE arrow is pointing LEFT, press the “Q” key*

*\*If the MIDDLE arrow is pointing RIGHT, press the “P” key*

*React as quickly as you can. Do not make mistakes. The task will inform you if you’ve made a mistake during the training session.*

*If you’re ready, press <SPACE> in order to start”*

After completing the training session, the instruction above was presented again, and then the main task began.

## 2. Procedure<sup>3</sup>

- 1) Participants were recruited to the online pre-selection session via social media, university advertisements, and flyers. They were invited to visit the project website, where more detailed information about the study was provided. On the website, participants were explicitly informed that on the basis of their results they might be invited to the laboratory session. They were provided with an information sheet explaining that the study examined people’s ability to concentrate on monotonous and boring tasks. Participants were asked to provide their e-mail address via the website so we could send them links to the online experimental tasks.
- 2) Links to all tasks were sent to participants’ email addresses
- 3) When participants followed this link, they were provided with information about the tasks they would complete. They were asked to follow all the instructions and to perform the tasks as well as they could. Importantly, they were asked to start the study only when they were certain that their performance would not be disrupted by noise or other distractions. Participants were also given information about the need to install the Inquisit Software in order to start the tasks. Basic information about the program and a link to the Millisecond website were also provided.

<sup>3</sup> Please note that in the present protocol we only describe the procedure of collecting data relating to the individual inhibitory control capacity using the Inquisit-Web software. Thus, neither the procedure nor the results of studies where this protocol was implemented will be reported here (but for more details see [16,17]).

- 4) Once participants had agreed to continue the experiment, the Stroop Task began (training session).
- 5) After completing the Stroop Task training, participants proceeded to the main Stroop Task.
- 6) After completing the Stroop task, the Eriksen Flanker task began (training session).
- 7) After a brief practice task, participants completed the main Eriksen flanker task.

In total, the online session lasted about 30–40 min

### 3. Calculating the individual Inhibition Capacity Index

In order to calculate the Inhibition Capacity Index for a single participant, we performed the following steps:

#### 1) Calculating the Stroop Task Interference Ratio

In order to calculate the Stroop task Interference Ratio, we subtracted individual participants' mean reaction time in the congruent Stroop condition from the mean reaction time in the incongruent condition. The difference was divided by the mean reaction time in the congruent condition. In general, this ratio represents the time needed to inhibit the interference when taking into account the individual processing speed, and, importantly, is considered as a reliable indicator of the efficacy of cognitive control (e.g., [22]). More precisely, we did not use a simple incongruent and congruent time difference as it does not control for individual differences in general processing speed causing several problems discussed recently in the literature (e.g.[23–26]).

#### 2) Calculating the Interference Ratio for the Eriksen Flanker Task

In order to calculate the interference ratio for the Eriksen Flanker Task, similar to the Stroop task, we subtracted individual participants' mean reaction times in the Eriksen Flanker congruent condition from the mean reaction times in the incongruent condition. The difference was divided by the mean reaction times in the congruent condition.

#### 3) Z-transforming interference ratios from both tasks

We applied a commonly used formula to calculate the z-score separately for each task.

#### 4) Calculating Individual Inhibition Capacity Index

The index for each participant was calculated as the mean of two z-transformed interference ratios.

### Possible limitations

When discussing the presented protocol for assessing inhibitory control capacity using the Stroop Task and the Eriksen Flanker Task, some limitations may be taken into account. For example, while engaging the participants into these tasks we did not counterbalance their order. As a result, participants first performed the Stroop task and then they were instructed to perform the Eriksen Flanker Task. This was mainly because as we measured the inhibitory control, we wanted to be sure that all participants exercised their inhibitory control under highly comparable conditions. For instance, as the Stroop task seems to be more cognitively demanding than the Eriksen Flanker task, we wanted to make sure that all participants perform the more demanding task first to limit the possible effect of cognitive fatigue on their task performance. Ideally, future studies should control for this possible limitation, by manipulating the order to these tasks between participants. It is also worth highlighting that the applicability of this protocol may vary across fields due to the types of stimuli used in these tasks (e.g., Stroop is semantically based etc.). However, the present protocol uses two well-known tasks which, basing on previous studies (e.g., [26–27],28), relate to different aspects of inhibitory control; namely, the inhibition of the prepotent response (i.e., the Stroop task) and the resistance to distractor interference (i.e., the Flanker task). Therefore, we argue that by combining these two types of tasks it is still possible to measure a broadly understood phenomenon of inhibitory control while including its different separate aspects. This way, the protocol may be used in studies investigating the relationship between cognitive inhibitory control and other important and well-known psychological constructs as, for example, intelligence, personality or memory retrieval.

### Concluding remarks

In the present paper we have described a protocol for experimental measurement and calculation of inhibitory control capacity in adult individuals in an online setting. This protocol can be used without experimenter supervision; therefore, individuals can participate in the study without

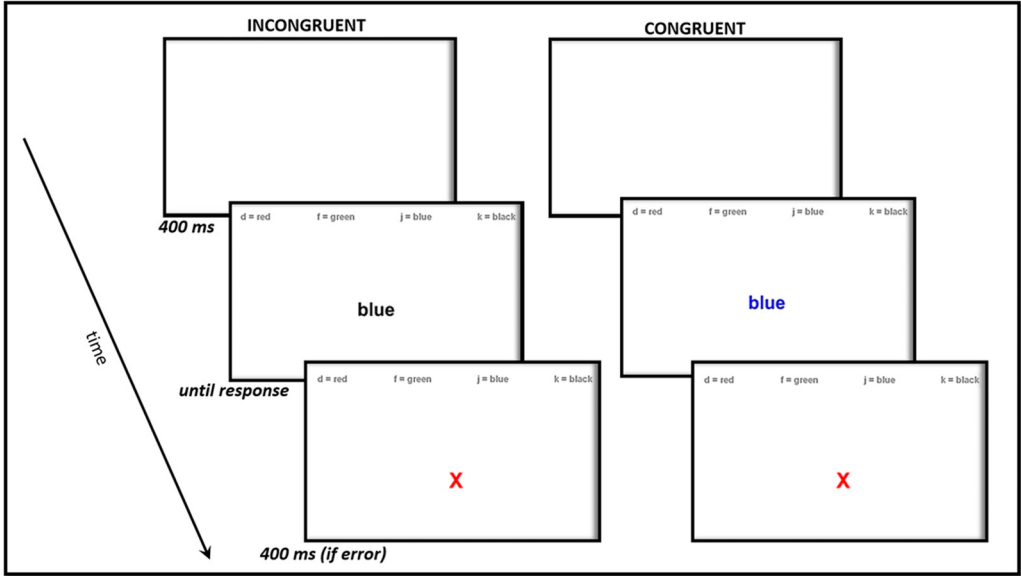


Fig. 2. Trials of the Stroop Task in two conditions. Slides consist of actual screenshots from the task we applied.

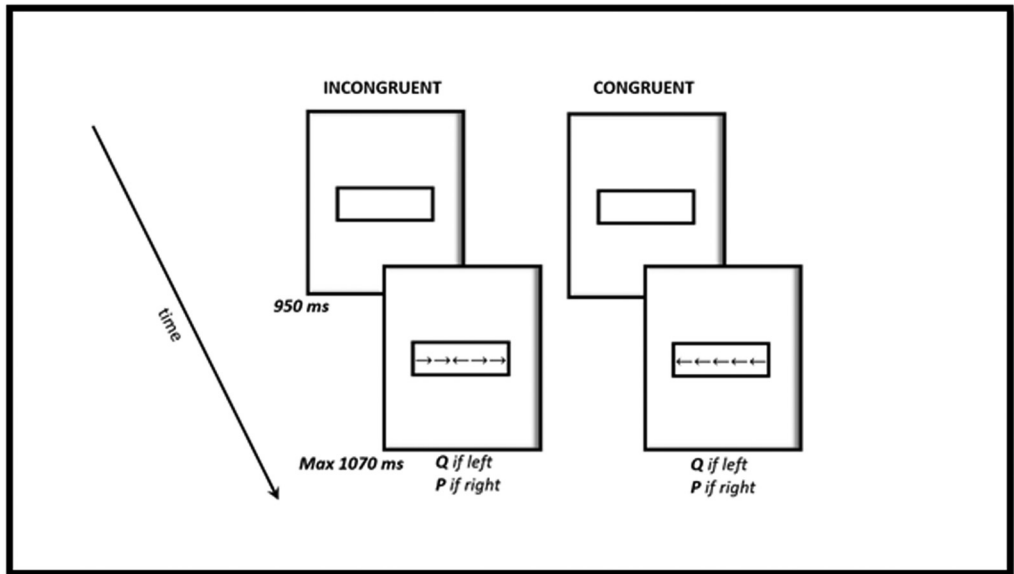


Fig. 3. Eriksen Flanker Task trials in two conditions. Slides consist of actual screenshots from the task we applied.



$$\text{Stroop Task Interference Ratio} = \frac{\text{Individual Mean Correct Response RT (incongruent)} - \text{Individual Mean Correct Response RT (congruent)}}{\text{Individual Mean Correct Response RT (congruent)}}$$

Fig. 4. Stroop Task Interference Ratio formula.

$$\text{Eriksen Flankers Task Interference Ratio} = \frac{\text{Individual Mean Correct Response RT (incongruent)} - \text{Individual Mean Correct Response RT (congruent)}}{\text{Individual Mean Correct Response RT (congruent)}}$$

Fig. 5. Eriksen Flanker Task Interference Ratio formula.

$$\text{z - transformed Individual Interference Ratio} = \frac{\text{Individual Interference Ratio} - \text{Mean Interference Ratio in the sample}}{\text{Standard Deviation of Interference Ratio in the sample}}$$

Fig. 6. Formula for z-transforming the Individual Interference Ratio.

$$\text{Individual Inhibition Capacity Index} = \frac{\text{z - transformed Individual Interference Ratio (Stroop)} + \text{z - transformed Individual Interference Ratio (Flankers)}}{2}$$

Fig. 7. Individual Inhibition Capacity Index formula.

accessing experimental stationary-based laboratories. We hope that this protocol and the resulting methods will help to accelerate studies on inhibitory control and its relation to other psychological constructs (e.g., spontaneous retrieval, personality etc.), especially during the current pandemic and lockdown. To this end, we have presented the online usage of well-established and classical experimental paradigms such as the Stroop Task and the Eriksen Flanker Task. We believe that the presented protocol will also accelerate studies with big sample sizes, thus contributing to our knowledge of inhibitory cognitive control and its underlying mechanisms in general, and its significance for human cognition and behavior (Figs. 2-7).

### Declaration of Competing Interest

The authors declare no conflict of interest.

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