

**Task Switching in the Eriksen Flanker Task:
Insights into Response Competition and Cognitive Control Mechanisms**

Department of Psychology, University of Twente

202000384 – BSc Thesis

Maria Aydin (s2645211)

Supervisor: Dr. R.H.J. van der Lubbe

Second Supervisor: Dr. S.M. van den Berg

July 01, 2024

Abstract

The present study investigated the influence of varying task demands and response competition on behaviour using a modified version of the Eriksen flanker task. The task was adapted to include two relevant stimulus features (shape and orientation) and incorporated task switching through a cue-based paradigm. Participants' performances were compared between pure blocks, with consistent task instructions, and mixed blocks, which required task switching. The results confirmed the presence of congruency effects, typical for the Eriksen task, with slower and less accurate responses in stimulus-incongruent trials. Additionally, task switching led to a residual switch cost, evidenced by longer reaction times and lower accuracy in mixed blocks. It furthermore intensified response competition, as shown by higher response compatibility effects in these blocks. The Affordance Competition Hypothesis (ACH) effectively accounts for these findings by suggesting that action selection and specification occur simultaneously, with affordances competing for action execution. Performance was likely influenced by the responses required by the flankers and, in mixed blocks, also the residual effects of the previous trials as well as the irrelevant stimulus feature, competing with the response required by the goal-relevant central target. This interaction either facilitated or impeded response execution depending on the compatibility of responses, i.e., whether the responses of the relevant and irrelevant features in a trial matched. Overall, the study shows that varying task demands differently impact response competition and highlights the importance of unified theoretical frameworks like the ACH, to account for such findings.

Task Switching in the Eriksen Flanker Task: Insights into Response Competition and Cognitive Control Mechanisms

Humans and other animals have evolved to interact with their environments adaptively and efficiently, performing some actions with greater deliberation than others. Picture yourself baking, currently mixing the batter for a cake. You remember that the next step of the recipe is to add milk. But how exactly will you do this? When will you decide to stop mixing? Which hand will you use to grab the glass of milk and pour it into the batter? Will you need to change the spatula from one hand to the other for that? As trivial as this may sound, complex computational mechanisms underlie these seemingly quick and easy decisions which we make every day. In our daily lives, we are surrounded by numerous objects we could engage with in a multitude of ways. This raises the question: how do we navigate our environment in a way that optimises both productivity and efficiency and allows us to reach our goals optimally?

Studying these processes in everyday settings can be quite challenging, as it is difficult to control for all variables and their potential influences. Nonetheless, controlled experimental settings provide a reasonable alternative to delve deeper into the complex processes underlying action selection. Therefore, the present study employs a modified version of the Eriksen flanker task, incorporating elements of task switching and two relevant stimulus features to examine response competition and action selection. The findings will then be interpreted in light of broader theoretical frameworks, specifically the affordance competition hypothesis, to understand how actions are selected and executed amidst competing options.

Attention and Action

Interacting with all objects that are present in our environment simultaneously is neither feasible nor efficient, making attention essential for the selection of appropriate actions. It is important to note, however, that a major limitation in the literature is the lack of a unified conceptualisation of attention, leading to the ambiguous use of the term. As Hommel et al. (2019) bluntly put it, “no one knows what attention is” (p. 2288).

One common notion in the attention literature is that our visual system has a limited capacity to process information (Albright et al., 2000). The idea is that the visual information available in our environment is too extensive for our brain to fully process, necessitating the

selection of a fraction of the input for cognitive processing (Itti & Koch, 2000; Theeuwes et al., 2010). Therefore, attention is often described as a filter that selects certain visual inputs.¹

However, accumulating evidence from an evolutionary perspective criticises the conception of selective attention as a perceptual filter. Levi-Ari et al. (2022) argued that the sensory organs' capacity to provide information should not exceed the brain's processing capacity. Instead, attentional mechanisms evolved to select the most suitable target for behaviour while concurrently suppressing distraction from irrelevant signals. These mechanisms evolved due to the inherent ambiguity and noise in sensory inputs, ensuring behaviour remains goal-oriented by allowing to identify and maintain focus on behaviourally relevant targets. Thus, attention is not about managing limited internal processing resources but about prioritising among various events, objects, and features competing for behavioural focus (Levi-Ari et al., 2022).

This perspective aligns with Gibson's ecological theory of perception, which postulates that we perceive the environment according to perceived or potential actions it offers to an organism, which he coined *affordances* (Gibson, 1979). These affordances provide the necessary information for making intelligent behavioural choices. Accordingly, it seems illogical to engage in an action such as shifting one's attention to only selectively process relevant information afterwards. Instead, all relevant information about affordances in the environment is perceived simultaneously (Gibson, 1979). Attention would then subsequently guide the identification of goal-relevant affordances, facilitating goal-oriented behavioural choices.

Thus, it appears that attention mechanisms are crucial for effectively navigating complex environments. By prioritising relevant targets, suppressing distractors, and capturing the behavioural relevance and potential interactions with objects, attention facilitates efficient and adaptive behaviour.

Affordance Competition Hypothesis

Yet, the question pertains to how we select certain actions over others and specify the means to achieve them. The affordance competition hypothesis (ACH), brought forth by Cisek (2007), builds on the aforementioned premises to provide an answer. It posits that action selection and action specification (i.e., how to perform the action) occur concurrently, even while actively performing movements. Thus, while engaging in one action, one already

¹ This idea dates back to Broadbent's (1958) work, specifically his filter theory of attention, originally formulated for auditory stimuli, which proposed that the brain acts as a limited capacity system that selects sensory input.

prepares for the next, continuously updating potential actions based on incoming sensory information.² Since one usually cannot engage in multiple actions simultaneously, behavioural options offered by the environment (i.e., affordances) compete against one another in frontoparietal circuits. This competition is biased by cortical and subcortical regions, such as the basal ganglia and dorsolateral prefrontal cortex, which modulate activation based on expected rewards, goals, and anticipated costs, thereby assessing the utility of different actions (Cisek, 2007; Cisek & Kalaska, 2010). Despite this influence, the final action decision is made within the sensorimotor circuits themselves (Cisek, 2007; Pastor-Bernier & Cisek, 2011). The action with the highest excitatory activity is executed, and visual feedback from the action, along with the previously competing affordances, may re-enter the competition alongside potential new affordances (Cisek, 2007). This ongoing competition ensures that the most relevant actions are selected and executed at any time, highlighting the intertwined nature of decision-making and action planning for adaptive, context-sensitive behaviour.

The ACH also finds support in neurophysiological studies. Grèzes and Decety (2002) revealed that the perception of objects is associated with neural activation that can be interpreted as partial involvement of motor representations, regardless of the subject's intention to act. Thus, motor representations seem to be automatically activated during object perception, affording actions that can be made toward it (Grèzes & Decety, 2002). Additionally, Caledron et al. (2018) found that brain activity in motor regions increased and coordinated more with frontoparietal areas when choosing between actions, especially when influenced by specific cues. This supports the notion that competition between affordances occurs in the frontoparietal circuits and highlights how predictive information, such as task-relevant factors, biases this competition (Caledron et al., 2018). These findings suggest that the cognitive system is inherently designed to link perception and action, as proposed by the ACH. Importantly, these studies also demonstrate that affordance competition can be effectively studied and manipulated in experimental contexts.

Task Switching

² Note that Cisek's framework posits that attention initially modulates affordances to reduce information transformed into action-related representations (Cisek, 2007). However, in light of Levi-Ari et al. (2022), it might be argued that attention's role should be seen as pervasive and adaptive throughout the entire process of affordance competition. Rather than being just an initial step, attention continuously adjusts focus based on real-time feedback and contextual changes, ensuring the most relevant affordances are prioritised.

A prominent approach to experimentally investigate cognitive control mechanisms, while also offering the opportunity to study response competition, is the use of task-switching paradigms. These paradigms require participants to alternate between two or more tasks with different response rules, creating a controlled competition among multiple possible actions afforded by the tasks. Task-switching experiments typically employ tasks such as categorising digits according to magnitude or parity, classifying letters as vowels or consonants, word reading, colour and object naming, responding to stimulus location, or performing simple arithmetic operations (e.g., Kiesel et al., 2005; Monsell et al., 2003; Rogers & Monsell, 1995; Schmitz & Krämer, 2023; Wylie & Allport, 2000). Although the task rules and relevant stimuli might differ between chosen tasks, responses often overlap, requiring participants to manage competing response tendencies and switch efficiently between tasks. Therefore, this approach is frequently applied to study processes of cognitive control and flexibility (Wylie & Allport, 2000).

As mentioned, task-switching paradigms offer a valuable opportunity to study affordance competition. The stimuli used in experiments (e.g., digits) function as affordances – specifically, acquired affordances as they only gain meaning and relevance through the context of the specific task. Through the task instructions, a certain affordance (i.e., stimulus) is linked to a specific action (i.e., response), forming affordance-action or stimulus-response (S-R) links. Upon perceiving the affordance, all possible or task-relevant actions (e.g., responses for odd and greater than five) are automatically triggered and compete for action execution.

In task switching, trials are categorised as either switch trials (i.e., response rule changes from the previous trial) or repetition trials (i.e., same response rule as the previous trial). A common phenomenon in task switching is the switch cost, characterised by longer response times and higher error rates on switch trials compared to repetition trials (Kiesel et al., 2010; Koch et al., 2018; Monsell, 2003). This effect is often attributed to the fact that participants have to mentally adjust to the new task rule in order to adequately perform the task (Monsell, 2003).³ More specifically, in a switch trial, the previously relevant response must be inhibited while the differing response required by the current task rule must be activated. This creates a competition between the old affordance-action link and the new one.

³ Monsell coined this phenomenon task-set reconfiguration (Monsell, 2003). A mental task set thereby entails relevant attributes of stimuli to attend and their corresponding response values which enable performance in accordance with task requirements (Kiesel et al., 2010; Koch et al., 2018; Schmitz & Krämer, 2023).

The switch cost then reflects the additional cognitive effort required to resolve this competition.

Strikingly, this effect partially persists even when participants are granted time to prepare for the upcoming trial. Task-switching paradigms often incorporate cues which signal the relevant task rule for the upcoming trial (cued trials paradigm; Meiran, 1966). This allows for a random sequence of tasks, including the order of switch and repetition trials (Kiesel et al., 2010). While cues generally reduce switch costs, a residual cost remains despite the preparation time (Monsell, 2003). This is mainly due to the fact that the previously activated affordance and its associated response remain partially active. This residual activity competes and interferes with the selection of the correct response in the subsequent trial, ultimately prolonging response time.⁴ The preparation time and cues are therefore likely not sufficient to completely reset the cognitive system, leading to carryover effects.

Eriksen Flanker Task

In addition to task-switching paradigms, flanker tasks provide a valuable opportunity to investigate response competition. One well-known example is the Eriksen flanker task, developed by Eriksen and Eriksen (1974). In this task, participants are presented with an array of seven letters, of which only the central letter is relevant to their response. The three additional letters on each side, known as flankers or noise letters, can either match or differ from the central target letter.

Trials in which the flankers are similar to the target (e.g., HHHHHHH) are called congruent trials, while those in which the target letter and flankers differ (e.g., SSSHSSS) are called incongruent trials; this classification is hereinafter referred to as *stimulus congruency*. Furthermore, the responses required by the central target and the flankers could be either compatible or incompatible (referred to as *response compatibility*). Note that multiple response sets were included, meaning that several letters required the same response (i.e., H and K required one response, while S and C required another). Thus, even in stimulus-incongruent trials, a flanker could require the same response as the target (i.e., response-compatible). Participants respond by pushing a lever on either the left or right side, with reaction time (RT) and accuracy being the measures of importance (Eriksen & Eriksen, 1974).

⁴ Also referred to as task-set inertia, which suggests that cognitive processes from the previous task persist and influence performance on subsequent tasks (Evans et al., 2015; Monsell, 2003). Specifically in terms of proactive interference due to S-R links (Allport et al., 1994).

A streamlined version of the original flanker task, where each stimulus corresponds directly to a single response, has gained popularity in the literature. Moreover, experiments applying this task frequently substitute the letters with other types of stimuli such as arrows (Davelaar, 2013; Ridderinkhof et al., 1995), digits (Lindgren et al., 1996), or colours (Rafal et al., 1996). The task is often further simplified by reducing the number of stimuli in the array (Servant & Logan, 2019).

Congruency Effect and Response Competition

The main finding in the Eriksen flanker task is that participants respond more slowly and less accurately to incongruent stimulus arrays as opposed to congruent ones. Eriksen & Eriksen (1974) interpreted this as participants needing to actively inhibit responses to the noise letters until the target letter is accurately identified. Importantly, RT and accuracy did not significantly differ between stimulus-congruent or -incongruent arrays in which the responses required by the central target and flanker matched (i.e., response-compatible). Since RTs are more affected by response compatibility than stimulus congruency, these findings suggest that congruency effects are primarily the result of ongoing response competition rather than the mere dissimilarity of letters (Eriksen, 1995; Eriksen & Eriksen, 1974; Servant & Logan, 2019).

In light of the ACH, the congruency effect might be explained as follows. In stimulus- and response-compatible trials, the central target and stimuli are identical. Therefore, the displayed affordance is associated with the same response and no conflict is to be expected, leading to optimal performance. In stimulus-incongruent but response-compatible trials, the stimuli may visually differ but the response they require is the same. In other words, although the affordances differ, they are linked to the same action, resulting in minimal conflict during action selection. Conversely, in stimulus-incongruent and response-incompatible trials, both the stimuli and their required responses differ. Therefore, two affordance-action links compete, creating significant conflict during action selection resulting in longer RT. Hence, similar to switch costs, the congruency effect would be a manifestation of ongoing response competition, which requires increased cognitive effort to resolve.

Neurophysiological Evidence

The notion of response competition within the Eriksen flanker task is also supported by neurophysiological evidence. Studies using electromyographic recordings by Eriksen et al. (1985) and Eriksen (1995) showed partial responses to noise letters alongside activation related to the correct response. Michelet et al. (2010) further explored this measuring motor evoked potentials (MEPs) in a study applying single-puls transcranial magnetic stimulation.

The study revealed that in incongruent trials, MEPs briefly increased corresponding to an initial response to the flankers which was later replaced by MEPs corresponding to the correct response by the central target.

Findings like the aforementioned, have been interpreted as indicative of ongoing response competition (Eriksen 1995; Eriksen et al., 1985; Michelet et al., 2010). Initial activity for the incorrect response in incongruent trials thereby leads to the activity for the correct response to the central target, potentially due to the salience of the flankers dominating the array in incongruent trials (Michelet et al., 2010). Response competition has been observed from early sensory processing (Pastötter & Frings, 2018) to the motor level (Michelet et al., 2010), indicating its presence from the visual cortex to the peripheral motor system. Thus, neurophysiological data supports the role of response competition in the Eriksen flanker task, contributing to the observed congruency effects.

The Present Experiment

The present study aims to investigate how varying task demands and response competition influence participants' behaviour, specifically focusing on RT and accuracy, and to assess whether the ACH as a theoretical framework can effectively account for the findings. Therefore, a modified version of the Eriksen flanker task, incorporating two relevant stimulus features as well as task switching was employed.

Thus far, the Eriksen flanker task has not been studied within the realm of task switching. In the context of response competition, the flanker task is insofar intriguing, as it inherently involves response competition due to the potential stimulus-incongruency between the central target and flankers. By modifying it to include task switching, response competition is further enhanced by the need to switch between additional affordance-action links. Importantly, task switching is not achieved by fundamentally different tasks but by including two relevant stimulus features (i.e., shape and orientation) that participants randomly alternately respond to. Thus, each feature is associated with two affordance-action links.

Assuming that participants can learn responses to specific stimulus features (Verwey, 2023), it is expected that not only the whole array but also the central target itself triggers response competition, as it integrates two features that are potentially mapped onto different responses. Consequently, the central target can either be response-compatible, where the relevant and irrelevant features require the same response, or response-incompatible, where they require different responses. This differs from the typical Eriksen flanker task, as a single stimulus alone is related to multiple actions, extending the typical one-on-one mapping of

stimulus and response in the literature. Thus, response competition is overall enhanced, not solely between flanker and target stimuli, but within the target stimuli themselves. Thereby, enabling the investigation of various potential actions that can be triggered simply by the onset of task-relevant stimuli.

The experiment is divided into two block types: pure blocks, where the task instructions remain constant, and mixed blocks, where participants switch between responding to shape and orientation based on cues. The hypotheses are as follows:

Hypothesis 1: According to the ACH, perceived affordances and their associated actions compete for response execution (Cisek, 2007). Given that flankers in the stimulus array are automatically processed (Eriksen & Eriksen, 1974), the responses associated with both the central target and the flankers are thought to compete. This competition is expected to yield significant response conflict in stimulus-incongruent trials. The response competition is influenced by task demands, allowing for conflict resolution, as there is only one correct response per trial (Caledron et al., 2018). However, the increased cognitive effort required in stimulus-incongruent trials is thought to result in longer RTs and overall lower accuracy. This effect is generally expected to emerge across pure and mixed blocks.

Hypothesis 2: Moreover, in the mixed blocks specifically, switching between tasks is thought to increase response competition due to the concurrent activation of the previously relevant affordance-action link and the activation of the subsequently required affordance-action link. This increased competition is anticipated to manifest as residual switch cost, characterised by longer RTs and lower accuracy in switch trials as opposed to repetition trials (Kiesel et al., 2010; Monsell, 2003). Since pure blocks are not susceptible to this increased response competition, they are expected to have overall lower RTs and higher accuracy compared to mixed blocks.

Hypothesis 3: Finally, the acquired affordance-action links are hypothesised to influence participants' responses. If the processing of stimulus features is not entirely selective, the irrelevant stimulus feature (i.e., the one not responded to in a trial) is expected to interfere with performance. Participants are anticipated to respond slower and less accurately in response-incompatible trials due to the conflicting responses triggered by the relevant and irrelevant stimulus features. Additionally, if the irrelevant stimulus feature is stimulus-incongruent it is thought to further interfere with performance, as it activates more competing affordance-action links, resulting in longer RT and lower accuracy. These effects are expected to be significant in the mixed blocks, where both stimulus features could be relevant at any time. In contrast, the irrelevant stimulus feature is not expected to affect the

pure blocks, as participants focus on a single stimulus feature throughout the block, reducing the likelihood of interference from the irrelevant stimulus feature. Consequently, an interaction between block type and response compatibility is anticipated.

Methods

Participants

The present study comprised an initial sample of 23 students from the University of Twente (UT), who participated in exchange for course credits. Due to a software malfunction during the experiment, data from three participants were excluded, resulting in a final sample of 20 participants (7 male, 13 female; $M_{age} = 21.6$, $SD = 1.93$; all right-handed).

Participants were recruited through the SONA website (utwente.sona-systems.com) accessible to all students of the Behavioural, Management, and Social Sciences (BMS) faculty. Eligibility criteria included normal or corrected-to-normal vision, which was verified using tests for visual acuity and colour blindness. Additionally, participants were required to be well-rested, non-heavy smokers, and to have abstained from alcohol consumption for 24 hours prior to the study. The study was approved by the ethics committee of the BMS faculty at the UT (approval number: 240157).

Task and Stimuli

Each trial commenced with the S-R mapping displayed for 1.5 seconds, featuring a fixation cross, alongside the relevant stimulus features shown at the lower-left (-13, -6 degrees) and lower-right (13, -6 degrees) positions of the screen. Participants sat approximately 60 cm from the screen. If the relevant stimulus feature of a trial (i.e., the feature that must be attended and responded to) was shape, a triangle and circle appeared on the bottom left and right, depending on the counterbalancing condition (see Figure 1A). For orientation trials, a rhombus with lines oriented to the left or right was shown (see Figure 1B). Thus, the cue display signalled the relevant feature that must be responded to in each trial. Additionally, it indicated the correct response instruction for the relevant stimulus feature. If for instance, the cue displays a triangle on the bottom left alongside a circle on the bottom right, participants pressed key “A” if the central stimulus was a triangle and “L” if the central stimulus was a circle.

Subsequently, the stimulus array was displayed comprising five shapes, triangles and/or circles, each incorporating line gratings oriented either to the left and/or right arranged two degrees above the centre. The central stimulus appeared directly above the fixation cross, flanked by two shapes on each side, each spaced four degrees apart. The flankers could either match the central stimulus on the relevant stimulus feature (i.e., congruent trial) or differ (i.e.,

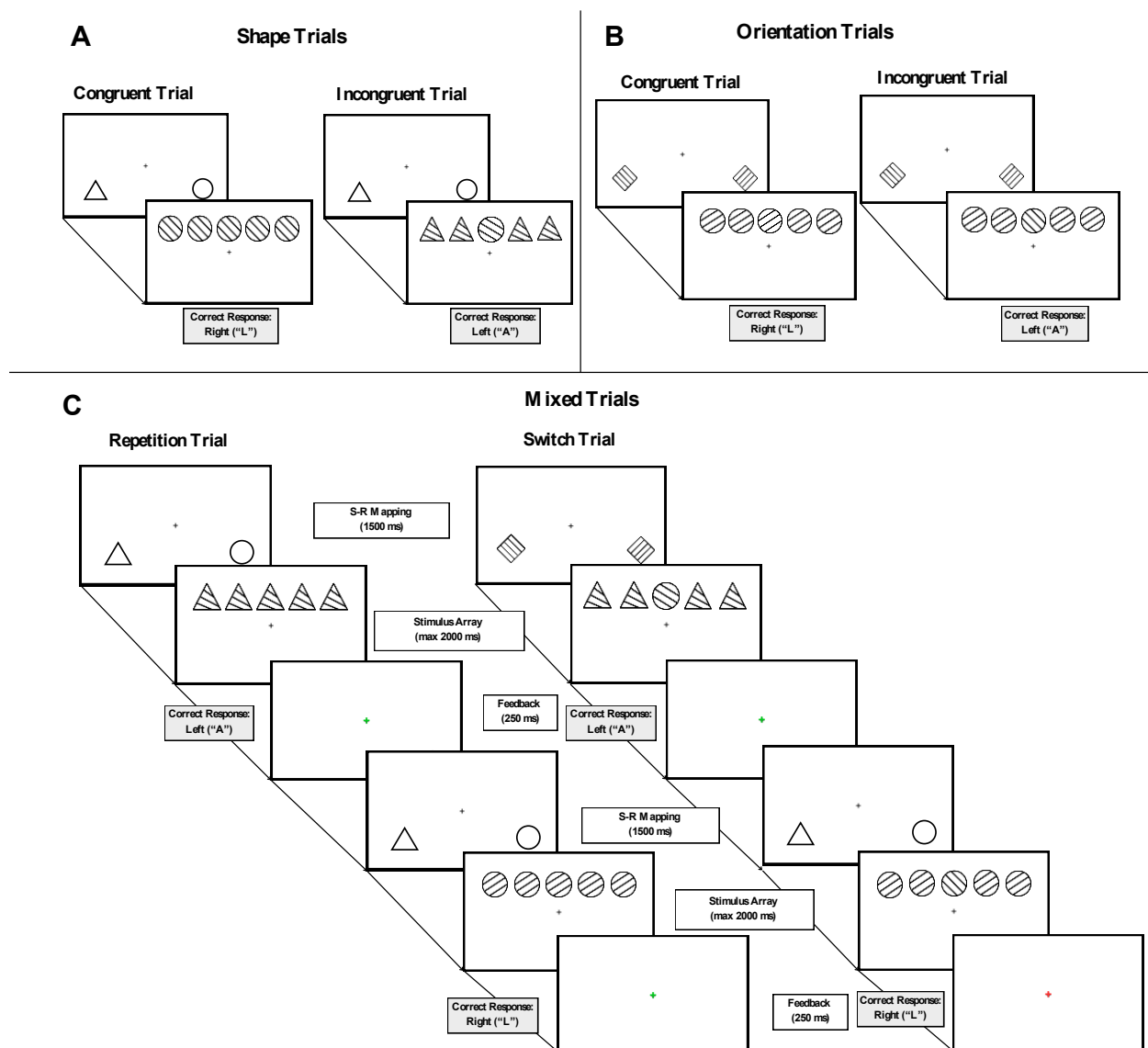
incongruent trial). The stimulus array remained visible for up to two seconds or until the participant's response was recorded.

At the end of the trial, following each response, participants immediately received feedback through the illumination of the fixation cross – turning red for incorrect responses and green for correct responses, lasting for 250 milliseconds.

Throughout the experiment, participants were strictly instructed to focus on and respond to the central target appearing directly above the fixation cross. Furthermore, participants were directed to use their left and right index fingers to execute the two required key presses, ensuring consistency in finger selection throughout the experiment. Participants were additionally asked to respond as quickly and accurately as possible.

Figure 1

Examples of All Trial Types.



Note. Panel A displays examples of congruent and incongruent trials where shape is the relevant stimulus feature. The stimulus-response (S-R) mapping shows the appropriate key press based on the central stimulus. Panel B shows an example of congruent and incongruent trials with line orientation as the relevant feature, with corresponding S-R mappings. Panel C illustrates examples of mixed block trials: a repetition trial (left) where shape trials follow each other consecutively, and a switch trial (right) where the relevant feature alternates from shape to orientation. In switch trials, the relevant feature and S-R mappings change from one trial to another. The correct responses based on the S-R mappings are indicated for each trial.

Design

The experiment comprised eight blocks in total: four pure blocks and four mixed blocks. In the pure blocks, the relevant feature remained the same throughout all trials (see Figure 1A and 1B). Participants responded to shape in two blocks and to orientation in the other two blocks. In the final four mixed blocks, the relevant feature was randomly alternated between trials. This means two consecutive trials could either have the same relevant feature (i.e., repetition trial) or a different one (i.e., switch trial) (see Figure 1C).

Each experimental block comprised 96 randomised trials and lasted about three and a half minutes. There was a total of sixteen combinations per stimulus feature (see Appendix A), with each combination displayed six times per block. Overall, the experiment encompassed 768 trials which lasted about half an hour. To ensure participants' thorough understanding of each task's requirements, they engaged in a short practice block whenever the task switched. Thus, before blocks three and five, participants performed the relevant task for eight trials before the actual test block was started.

The experiment employed a within-subject design, meaning all participants underwent all blocks. The order of the pure blocks and stimulus-key assignments was counterbalanced, resulting in four counterbalanced conditions to which participants were sequentially assigned. Although the order of the pure blocks was counterbalanced, blocks for shape always followed one another, as did blocks for orientation, with the four mixed blocks always conducted at the end.

Procedure

Upon arrival at the laboratory, participants were welcomed and guided to the cubicle in which the experiment took place. Their eligibility to participate in the experiment was then confirmed. Before starting the experiment, participants were verbally guided through the first task and completed a short practice block to confirm their understanding. Next, the first test

block was initiated after which the researcher left the room. Participants had a break of one to two minutes between each block. After every break, the researcher re-entered the room to start the next block. Before the third and fifth blocks, which involved a task switch, participants received additional verbal instructions and completed another short practice block. Written instructions were additionally provided before every block. After completing all eight blocks, the researcher returned to brief the participant on the experiment's objective and provided an opportunity to ask questions. Finally, participants were thanked for their participation and granted their course credit.

Apparatus

The study was conducted in the BMS laboratory at the UT, utilising two distinct experimental setups. To minimise visual distractions, windows were covered to three-fourths of their extent. Regrettably, the rooms differed in susceptibility to background noise and monitor refresh rates, which were accounted for by including the room as an experimental factor in the analysis.

The experiment was executed using the PsychoPy software (version 2023.2.3), developed by Peirce et al. (2019). The first experimental configuration featured an HP Z1 G9 tower desktop computer connected to an EIZO Flexscan EV2436W monitor with a refresh rate of 60Hz. The second setup included a Dell OptiPlex 7050 desktop connected to an AOC G2460PG monitor, that featured a 144Hz refresh rate and incorporated FreeSync technology.

Participants only used the "A" and "L" keys on a standard QWERTY keyboard, with all other keys disabled to prevent accidental inputs. Additionally, a keyboard wrist pad was provided for comfort, which was utilised by most participants.

To ensure participants had normal vision, tests for visual acuity (Vision Source, 2020) and colour blindness (Ishihara, 1972) were administered. Prior to participation, all participants were required to sign informed consent forms.

Data Analysis

RTs were measured using the ioHub backend of PsychoPy to ensure minimal delay and high-accuracy measurement. Recording of the RTs began concurrently with the onset of the stimulus array to the moment the key press was registered (PsychoPy, n.d.). Note that recordings were checked for premature responses, defined as RTs below 100 ms, of which none were present in the data.

Prior to analysis, practice trials as well as outliers, defined as trials with RTs greater than three standard deviations away from their individual conditional mean, were excluded (1.76%) (Abrahamse & Verwey, 2007; Kiesel et al., 2005; Weissman et al., 2016). Moreover,

only trials with correct responses (96.07%) were included in RT analysis (Abrahamse & Verwey, 2008; Kiesel et al., 2005; Koch & Allport, 2006).

The study design included two dependent variables: RT and accuracy. The within-participant factors were: (1) block type (pure, mixed), (2) stimulus congruency (congruent, incongruent), (3) congruency of the irrelevant stimulus feature (congruent, incongruent), (4) response compatibility (compatible, incompatible), (5) as well as task switch (switch trial, repetition trial).

The data was analysed using repeated measures analysis of variance (ANOVA) on the mean RT and accuracy data (Calderon et al., 2018; Pastötter & Frings, 2018; Verwey et al., 2020). Greenhouse-Geisser correction was applied to adjust for violations of sphericity when necessary, and responses were arcsine-transformed to normalise the distribution of accuracy data. Additionally, RTs were scaled to milliseconds. Statistical analyses were conducted in R Studio (version 4.4.0; R Core Team, 2024) using the afex package (Singmann et al., 2024). Probabilities of $p < .05$ were considered statistically significant.

Results

All Blocks

A 2 (block type) x 2 (relevant feature) x 2 (stimulus congruency) x 2 (response compatibility) x 2 (stimulus congruency irrelevant feature) was used to analyse overall effects on RT and accuracy in all experimental blocks.⁵

Block Type, Response Compatibility, Relevant Feature

The ANOVA revealed significant main effects of block type on RT, $F(1, 19) = 9.84, p = .005, \eta_p^2 = .34$, as well as accuracy, $F(1, 19) = 31.34, p < .001, \eta_p^2 = .62$. Participants were overall slower ($M = 556$ ms, $SD = 186$ ms) and less accurate (94.6 %) in mixed blocks compared to pure blocks (RT: $M = 517$ ms, $SD = 142$ ms; accuracy: 97.5 %).

Moreover, there was a significant main effect of the relevant stimulus feature on RT, $F(1, 19) = 30.68, p < .001, \eta_p^2 = .62$. The mean RT was 507 ms ($SD = 168$ ms) in shape trials and 565 ms ($SD = 159$ ms) in orientation trials, indicating faster responses in shape trials. However, no significant effect on accuracy was observed, $F(1, 19) = 0.01, p = .939, \eta_p^2 < .001$ (shape: 95.9%; orientation: 96.9%).

⁵ A model additionally accounting for the room in which participants conducted the experiment, the order of the pure blocks, and the stimulus-key assignment was fitted. No significant differences between conditions were found, indicating that these variables did not introduce any confounding effects. Specifically, there were no significant effects of block order on RT, $F(1, 19) = 1.51, p = .242, \eta_p^2 = .11$, or accuracy, $F(1, 19) = 1.72, p = .215, \eta_p^2 = .13$. Similarly, the room variable did not significantly affect RT, $F(1, 19) = 0.26, p = .619, \eta_p^2 = .02$, or accuracy, $F(1, 19) = 0.16, p = .699, \eta_p^2 = .01$. Finally, the stimulus-key assignment showed no significant impact on RT, $F(1, 19) = 0.26, p = .620, \eta_p^2 = .02$, or accuracy, $F(1, 19) = 0.01, p = .912, \eta_p^2 = .001$.

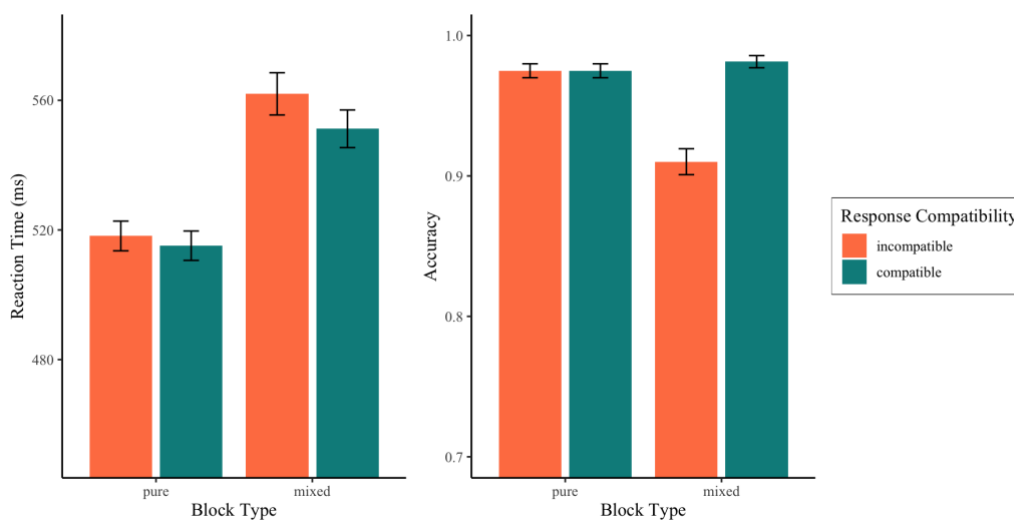
Additionally, the analysis revealed significant main effects of response compatibility on RT, $F(1, 19) = 13.81, p = .001, \eta_p^2 = .65$, and accuracy, $F(1, 19) = 62.06, p < .001, \eta_p^2 = .77$. On average, participants were slower and less accurate in response-incompatible trials (RT: $M = 539$ ms, $SD = 170$ ms; accuracy: 94.3%) compared to response-compatible trials (RT: $M = 533$ ms, $SD = 163$ ms; accuracy: 97.8%).

A significant three-way interaction of the aforementioned variables, block type x relevant feature x response compatibility, on accuracy, $F(1,19) = 39.43, p < .001, \eta_p^2 = .68$, was found. This interaction was not significant on RT, $F(1, 19) = 0.09, p = .764, \eta_p^2 = .01$. The ANOVA also revealed a significant two-way interaction of relevant feature x response compatibility on accuracy, $F(1,19) = 13.02, p = .002, \eta_p^2 = .41$, however not on RT, $F(1, 19) = 2.24, p = .152, \eta_p^2 = .11$. Given the interaction with block type as mentioned previously, this interaction will be further detailed in the sections on the pure and mixed blocks.

In line with hypothesis three, a significant first-order interaction of block type x response compatibility was found on RT, $F(1,19) = 7.83, p = .011, \eta_p^2 = .29$, as well as accuracy, $F(1,19) = 23.39, p < .001, \eta_p^2 = .55$. These findings suggest that response compatibility affects performance differently in the pure and mixed blocks (Figure 2), and will be further elucidated in the following sections.

Figure 2

The Effect of Response Compatibility Across Pure and Mixed Blocks.

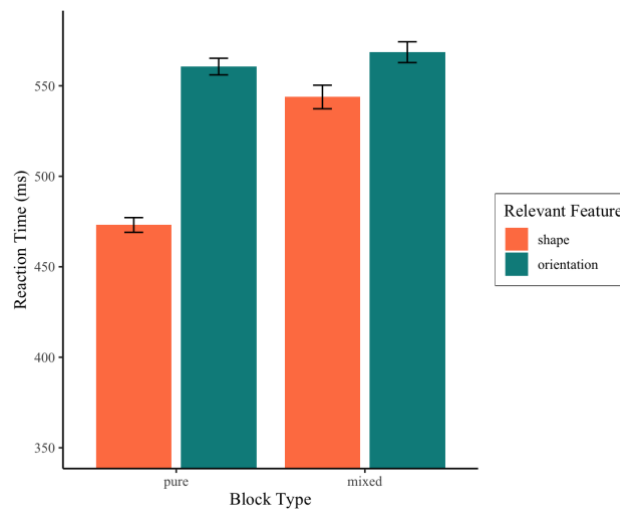


Note. Error bars represent 95% confidence intervals. The left bar plot indicates the differences in response compatibility across block types on reaction time and the right bar plot on accuracy.

Furthermore, the analysis revealed a significant two-way block type x relevant feature interaction on RT, $F(1, 19) = 35.43, p < .001, \eta_p^2 = .65$, but not on accuracy, $F(1, 19) = 2.63, p = .121, \eta_p^2 = .12$. As shown in Figure 3, differences in RT between shape and orientation appear to be larger in the pure blocks as opposed to the mixed blocks. This interaction will be detailed further in the following sections.

Figure 3

Average Reaction Time Across Relevant Stimulus Feature and Block Type.



Note. Error bars represent 95% confidence intervals.

Block Type, Stimulus Congruency, Stimulus Congruency Irrelevant Feature

In line with the first hypothesis, significant main effects of stimulus-congruency on RT, $F(1, 19) = 11.69, p = .003, \eta_p^2 = .38$, and accuracy, $F(1, 19) = 7.02, p = .016, \eta_p^2 = .27$, were found. Participants were on average slower and less accurate in stimulus-incongruent trials (RT: $M = 541$ ms, $SD = 171$ ms; accuracy: 95.8%) as opposed to stimulus-congruent trials (RT: $M = 531$ ms, $SD = 161$ ms; accuracy: 96.3%).

Contrary to hypothesis three, no significant main effect of the stimulus-congruency of the irrelevant stimulus feature was found on RT, $F(1, 19) = 0.98, p = .334, \eta_p^2 = .05$, or accuracy, $F(1, 19) = 1.72, p = .206, \eta_p^2 = .08$.

However, the analysis uncovered a significant three-way interaction of block type x stimulus congruency x stimulus congruency irrelevant feature on RT, $F(1,19) = 4.48, p = .048, \eta_p^2 = .19$. This interaction was not significant on accuracy, $F(1,19) = 0.55, p = .467, \eta_p^2 = .03$. A more detailed analysis will be provided in the following sections.

Pure Blocks

A 2 (relevant feature) x 2 (stimulus congruency) x 2 (stimulus congruency irrelevant feature) x 2 (response compatibility) repeated measures ANOVA was used to analyse the effects on RT and accuracy on a subset of the data including only the pure blocks.

In support of hypothesis three, no significant main effects of response compatibility on RT, $F(1,19) = 1.42, p = .248, \eta_p^2 = .07$, or accuracy, $F(1,19) = 0.07, p = .796, \eta_p^2 = .004$, were observed. Participants were equally fast and accurate in response-compatible (RT: $M = 515$ ms, $SD = 141$ ms; accuracy: 97.5%) and response-incompatible trials (RT: $M = 518$ ms, $SD = 143$ ms; accuracy: 97.5%).

The ANOVA further revealed a significant main effect of the relevant stimulus feature on RT, $F(1,19) = 56.27, p < .001, \eta_p^2 = .75$, and a marginal effect on accuracy, $F(1,19) = 3.61, p = .073, \eta_p^2 = .16$. Participants were faster and slightly more accurate in shape blocks (RT: $M = 473$ ms, $SD = 127$ ms; accuracy: 97.7%) compared to orientation blocks (RT: $M = 561$ ms, $SD = 143$ ms; accuracy: 97.2%).

In line with hypothesis one, a significant main effect of stimulus congruency on RT was found, $F(1,19) = 4.96, p = .038, \eta_p^2 = .21$, but not on accuracy, $F(1,19) = 1.52, p = .233, \eta_p^2 = .07$. On average, participants were faster in stimulus-congruent ($M = 513$ ms, $SD = 140$ ms) as opposed to stimulus-incongruent ($M = 520$ ms, $SD = 143$ ms) trials, as can be seen in Figure 4A. Nonetheless, participants were equally accurate across stimulus-congruent (97.7%) and stimulus-incongruent (97.3%) trials.

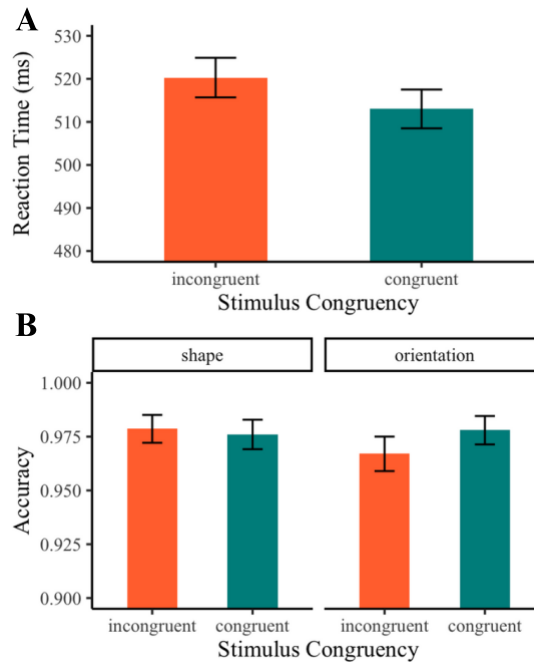
A nearly significant relevant feature x stimulus congruency interaction effect on accuracy was found, $F(1,19) = 4.34, p = .051, \eta_p^2 = .19$, but not on RT, $F(1, 19) = 0.83, p = .374, \eta_p^2 = .04$. Post hoc comparisons using the Tukey HSD adjustment, indicated a significant difference between shape and orientation in stimulus-incongruent trials ($t(19) = 2.94, p = .039$). In these trials, accuracy is significantly higher if the relevant stimulus feature is shape, as opposed to orientation. No significant differences between shape and orientation are observed in stimulus-congruent trials ($t(19) = -0.65, p = .915$).

Further analysis on the impact of the relevant stimulus feature on stimulus congruency was conducted separately for shape and orientation blocks, using a 2 (stimulus congruency) x 2 (stimulus congruency irrelevant feature) x 2 (response compatibility) ANOVA. No significant effect of stimulus congruency on accuracy was found in shape blocks, $F(1,19) = 0.49, p = .492, \eta_p^2 = .03$, indicating that participants were equally accurate across stimulus-congruent (97.6%) and stimulus-incongruent (97.9%) trials (Figure 4B). Conversely, in orientation blocks, a significant effect of stimulus congruency on accuracy was found,

$F(1,19) = 6.35, p = .021, \eta_p^2 = .25$, with higher accuracy in stimulus-congruent (97.8%) compared to stimulus-incongruent (96.7%) trials (Figure 4B). Thus, as the post hoc analysis had already indicated, this analysis confirms a significantly lower accuracy in stimulus-incongruent orientation trials.

Figure 4

Reaction Time and Accuracy Across Stimulus Congruency in the Pure Blocks.



Note. Error bars represent 95% confidence intervals.

Mixed Blocks

A 2 (relevant feature) x 2 (stimulus congruency) x 2 (response compatibility) x 2 (stimulus congruency irrelevant feature) x 2 (task switching) repeated measures ANOVA was used to analyse effects on RT and accuracy in the mixed blocks.

Stimulus Congruency, Response Compatibility, Task Switching

The ANOVA revealed a significant main effect of stimulus congruency on RT, $F(1, 19) = 4.61, p = .045, \eta_p^2 = .195$, and a marginal effect on accuracy, $F(1, 19) = 3.42, p = .080, \eta_p^2 = .15$. Participants were on average slower and slightly less accurate in stimulus-incongruent trials (RT: $M = 563$ ms, $SD = 193$ ms, accuracy: 94.4%) as opposed to stimulus-congruent trials (RT: $M = 550$ ms, $SD = 178$ ms; accuracy: 94.9%), supporting hypothesis one.

In line with hypothesis three, there were significant main effects of response compatibility on RT, $F(1, 19) = 11.73, p = .003, \eta_p^2 = .38$, and accuracy, $F(1, 19) = 40.17, p < .001, \eta_p^2 = .68$. Participants were faster and more accurate in response-compatible (RT: $M = 551$ ms, $SD = 180$ ms; accuracy: 98.1%) as opposed to response-incompatible trials (RT: $M = 562$ ms, $SD = 192$ ms; accuracy: 91 %), as can be seen in Figure 7A.

A significant main effect of task switching on RT, $F(1, 19) = 5.27, p = .033, \eta_p^2 = .22$, and a marginally significant effect on accuracy, $F(1, 19) = 3.09, p = .096, \eta_p^2 = .14$, were found. This indicates that participants responded more slowly and less accurately on switch trials (RT: $M = 562$ ms, $SD = 193$ ms; accuracy: 94.1%) as opposed to repetition trials (RT: $M = 551$ ms, $SD = 179$ ms; accuracy: 95.1%), thereby supporting the second hypothesis.

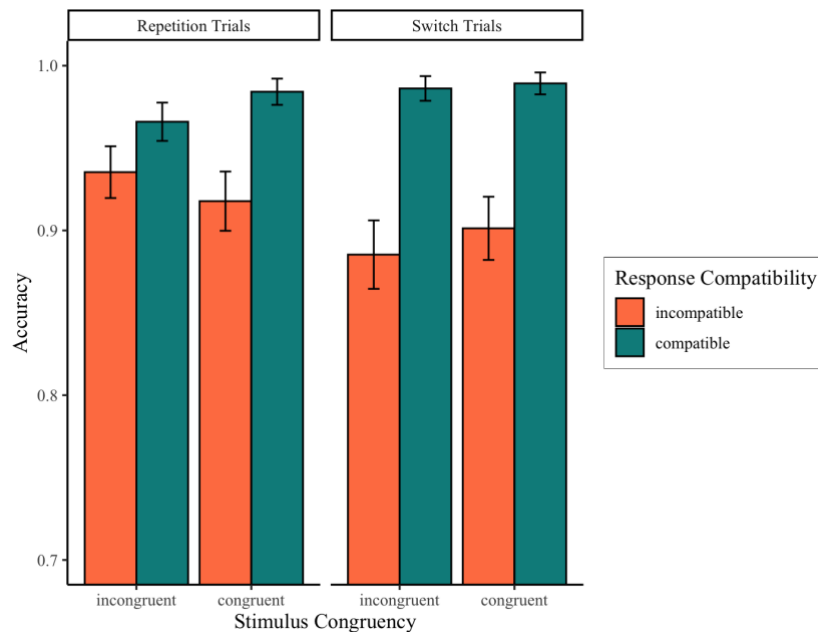
The aforementioned variables interacted significantly with each other (Figure 5). The analysis revealed a three-way interaction of stimulus congruency x response compatibility x task switch on accuracy, $F(1,19) = 5.26, p = .033, \eta_p^2 = .22$, but not on RT, $F(1,19) = 0.00, p = .958, \eta_p^2 < .001$. However, further analysis using a 2 (relevant feature) x 2 (stimulus congruency) x 2 (response compatibility) x 2 (stimulus congruency irrelevant feature) ANOVA conducted separately for switch and repetition trials did not reveal a significant stimulus congruency x response compatibility interaction neither in repetition, $F(1, 19) = 3.84, p = .065, \eta_p^2 = .17$, nor in switch trials, $F(1, 19) = 2.13, p = .161, \eta_p^2 = .10$.

The analysis also revealed a significant first-order interaction of task switch x response compatibility on accuracy, $F(1, 19) = 18.11, p < .001, \eta_p^2 = .49$, but not on RT, $F(1, 19) = 0.01, p = .904, \eta_p^2 < .001$. Post-hoc comparisons using the Tukey HSD adjustment showed significant differences between response-incompatible and -compatible repetition ($t(19) = -4.07, p = .003$) and switch ($t(19) = -6.78, p < .001$) trials. Moreover, response-compatibility effects on accuracy were larger in switch trials (response-compatible: 98.8%, response-incompatible: 89.3%) compared to repetition trials (response-compatible: 97.5%, response-incompatible: 92.7%), as can also be seen in Figure 5.

Taken together, these interactions suggest that response compatibility exerts a stronger effect on accuracy across switch and repetition trials. The influence of stimulus congruency appears not to be a substantial factor in affecting performance within these conditions.

Figure 5

Average Accuracy Across Stimulus Congruency and Response Compatibility in Repetition and Switch Trials.



Note. Error bars represent 95% confidence intervals.

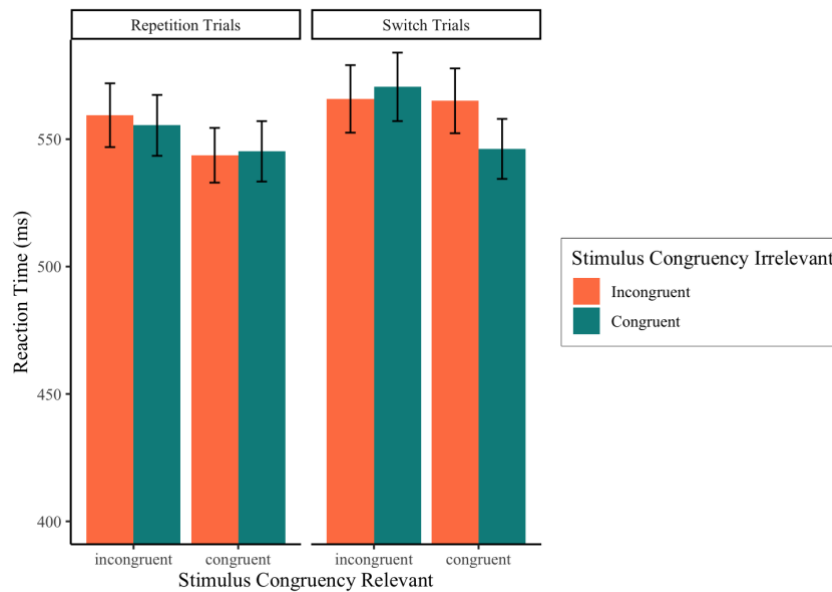
Stimulus Congruency, Stimulus Congruency Irrelevant Feature, Task Switching

Contrary to hypothesis three, no significant main effect of the stimulus congruency of the irrelevant stimulus feature was found on RT, $F(1, 19) = 1.34, p = .261, \eta_p^2 = .07$, or accuracy, $F(1, 19) = 2.95, p = .102, \eta_p^2 = .13$.

However, a significant three-way interaction of stimulus congruency x stimulus congruency irrelevant feature x task switch was found on RT, $F(1,19) = 6.71, p = .018, \eta_p^2 = .26$, but not on accuracy, $F(1,19) = 1.07, p = .314, \eta_p^2 = .05$. Post hoc comparisons using the Tukey HSD adjustment confirmed a significant difference in stimulus-congruent switch trials in regards to the stimulus congruency of the irrelevant feature ($t(19) = 4.12, p = .011$). Specifically, RTs were significantly lower when the irrelevant stimulus feature was also stimulus-congruent compared to when it was stimulus-incongruent. This effect was not observed in stimulus-incongruent switch trials, nor was it present in repetition trials for either condition, as depicted in Figure 6.

Figure 6

Average Reaction Time of the Stimulus Congruency of the Relevant and Irrelevant Stimulus Feature Across Switch and Repetition Trials.



Note. Error bars represent 95% confidence intervals.

Relevant Feature, Response Compatibility

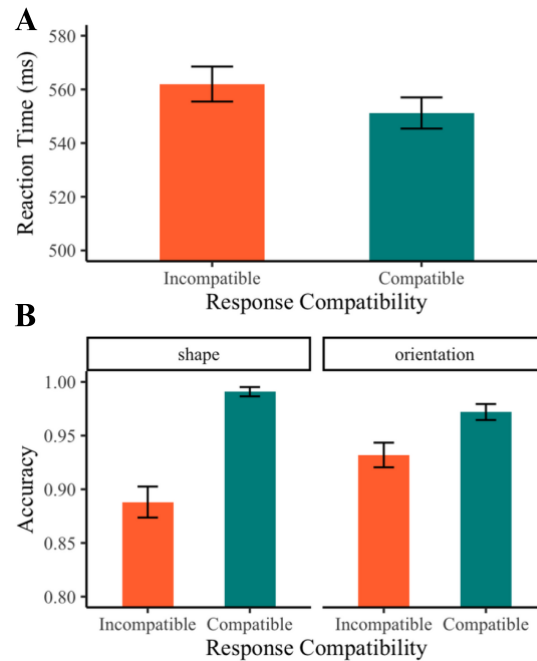
In the mixed blocks, the main effect of the relevant feature was only marginally significant on RT, $F(1, 19) = 3.68$, $p = .070$, $\eta_p^2 = .16$, and insignificant on accuracy, $F(1, 19) = 1.09$, $p = .309$, $\eta_p^2 = .05$. On average, participants were faster in shape trials ($M = 544$ ms, $SD = 196$ ms) compared to orientation trials ($M = 569$ ms, $SD = 175$ ms).

While no significant main effect on accuracy was found, there was a significant first-order interaction of relevant feature x response compatibility on accuracy, $F(1, 19) = 37.71$, $p < .001$, $\eta_p^2 = .67$, but not on RT, $F(1, 19) = 0.83$, $p = .374$, $\eta_p^2 = .04$. Post hoc analysis revealed a significant difference between response-compatible and -incompatible trials for both shape ($t(19) = -7.27$, $p < .001$) and orientation ($t(19) = -3.70$, $p = .008$), with more pronounced effects in shape trials (Figure 7B).

A further 2 (stimulus congruency) x 2 (stimulus congruency irrelevant feature) x 2 (response compatibility) x 2 (task switch) ANOVA was conducted separately for shape and orientation trials. A significant main effect of response compatibility on accuracy was found in shape trials, $F(1, 19) = 52.89$, $p < .001$, $\eta_p^2 = .74$, and orientation trials, $F(1, 19) = 13.7$, $p = .002$, $\eta_p^2 = .42$. Thus, this analysis confirms that participants were significantly more accurate in response-compatible trials.

Figure 7

Average Reaction Time and Accuracy Across Response Compatibility in the Mixed Blocks.



Note. Error bars represent 95% confidence intervals.

Discussion

The present study investigated the influence of varying task demands and response competition on behaviour and assessed whether the ACH can effectively account for the findings. Therefore, a modified version of the Eriksen flanker task was employed, comparing participants' performance on pure blocks, which had a consistent task instruction, with mixed blocks, which incorporated task switching.

Stimulus Congruency

As previously postulated in hypothesis one, the data supported the presence of stimulus congruency effects. Overall, participants were slower and less accurate in stimulus-incongruent as opposed to stimulus-congruent trials. Therefore, this finding aligns with the current body of research on the Eriksen flanker task (Eriksen & Eriksen, 1974; Eriksen, 1995; Eriksen et al., 1985; Michelet et al., 2010). This effect persisted in the pure as well as the mixed blocks, albeit the effect on accuracy in the mixed blocks was solely marginally significant. Thus, aligning with the proposed explanation from the perspective of the ACH – the flankers, the target and their respective responses all compete for response execution. The competition is in this case likely biased by the task instructions allowing the correct response

to be chosen (Caledron et al., 2018). However, in stimulus-incongruent trials, incompatible responses create a conflict which manifests as longer RTs and lower accuracy.

Interestingly, in the pure blocks, stimulus congruency interacted significantly with the relevant feature on accuracy. Further analysis revealed that in stimulus-incongruent trials accuracy is significantly lower for orientation compared to shape. This might be due to differing processing of the stimulus features, as orientation may be more effortful to process indicated by its overall longer RTs and lower accuracy. Given that the flankers and their responses are also being processed (Eriksen & Eriksen 1974; Michelet et al., 2010), it might simply be more effortful and time-consuming to identify the central target orientation amidst differing distractors. However, while participants want to maintain their speed, and no difference in RTs is observed for orientation, it might simply be a strategy of participants to trade accuracy for speed. Accuracy suffers in this case due to the extra time that would be required to identify the correct response.

Task Switching

In line with hypothesis two, task-switching in the mixed blocks was associated with overall longer RTs and lower accuracy. More specifically, participants were faster and marginally more accurate in repetition trials as opposed to switch trials. This finding replicates one of the most well-established phenomena in task-switching literature: the switching cost. Specifically, given the use of a task-cueing paradigm, it demonstrates the residual switch cost, consistently found in experiments applying task switching (Evans et al., 2015; Meiran, 1966; Monsell et al., 2003; Schmitz & Krämer, 2023). Thus, the proposed explanation from the perspective of the ACH remains: the S-R links of the previous trial continue to influence the competition in the subsequent trial, as the cognitive system cannot reset in such a short time, creating a bias. In repetition trials, this bias might be beneficial as the relevant stimulus feature remains the same, effectively priming the current trial. However, in switch trials, it might create a stronger response conflict between S-R links of the relevant and irrelevant feature which needs to be resolved, leading to worse performance.

This explanation is further reinforced by the significant interaction between task switching and response compatibility on accuracy. Specifically, response compatibility effects were larger in switch trials compared to repetition trials. Extending the former argumentation, this may suggest that the enhanced response competition experienced in switch trials benefits from response compatibility. When the task switches but the responses remain the same, lower response competition and easier conflict resolution may occur. Conversely, if the task switches and the responses are incompatible, higher conflict might

arise, and the residual activation of the previously relevant feature must be overcome, resulting in worse performance.

Response Compatibility

As previously hypothesised, response compatibility of the relevant and irrelevant features significantly impacted behaviour. Although response compatibility showed an overall effect, further analysis only revealed a significant effect in the mixed blocks, thus aligning with hypothesis three. Participants were significantly faster in the mixed blocks when the responses of the relevant and irrelevant stimulus features matched. These findings align with the literature on task switching (Kiesel et al., 2005; Meiran, 1966; Meiran & Kessler, 2008; Sudevan & Taylor, 1987). Nonetheless, this phenomenon has received different names in the literature - Kiesel et al. (2005) for example refer to it as response congruency effects while Meiran (1966) refers to it as task compatibility.

More importantly, this finding can also be accounted for by applying the ACH. In the pure blocks, the S-R links of primary importance are that of one task. Thus, participants can stick to the two S-R links for one task and disregard the affordance associated with the irrelevant stimulus feature. Conversely, in the mixed blocks, the S-R links of the relevant and irrelevant stimulus features could be important at any time – there is enhanced response competition. One cannot employ a strategy to entirely disregard one feature, creating a larger interference of the response of the irrelevant stimulus feature which manifests as a response compatibility effect.

Surprisingly, response compatibility had a greater impact on accuracy in shape trials compared to orientation trials. Shape, being the easier stimulus feature as indicated by generally lower RTs and higher accuracy, likely created a stronger expectancy in terms of more robust activation of S-R links. This heightened expectancy could mean that any response conflict, such as from a response-incompatible orientation feature, caused greater disruption, resulting in larger compatibility effects for shape. This might have contributed to longer RTs and lower accuracy in response-incompatible shape trials. In contrast, orientation, being more difficult to process, may not have been as susceptible to interference from shape due to its inherent processing demands, which could have masked the effects of response compatibility.

Stimulus-Congruency of the Irrelevant Stimulus Feature

Contrary to hypothesis three, no significant main effect of the irrelevant stimulus feature was found in the mixed blocks. One plausible explanation is that the increased cognitive load in mixed blocks necessitated a strategy where participants focused more on the

central target to manage the task demands effectively. In light of the ACH, one might argue that this increased focus could bias the competition towards goal-relevant affordances, thereby diminishing the influence of irrelevant features on response competition. Consequently, the incongruency of the irrelevant stimulus feature and its corresponding response did not significantly affect performance.

Furthermore, the inherent difficulty of processing orientation features, particularly in the peripheral visual field, might have compounded this effect. Previous research indicates that diagonal line orientations are more challenging to identify (Li et al., 2003; Rovamo et al., 1982). Combined with the demanding conditions of task switching, this difficulty could further limit the processing of flanker features, thereby restricting their impact on response competition.

However, the congruency of the irrelevant stimulus feature did exert some effect on RT in interaction with the stimulus congruency of the relevant feature and task switching. Specifically, in stimulus-congruent switch trials, participants were significantly faster when the irrelevant feature was also stimulus-congruent compared to stimulus-incongruent. This suggests that while the overall influence of the irrelevant feature is diminished, it is not entirely absent. From the perspective of the ACH, it could be argued that when the irrelevant feature is stimulus-congruent, it aligns with the affordance of the central target, thus reducing the overall response competition. This alignment facilitates faster and more efficient processing, especially in switch trials where the cognitive system is already under strain from task-switching demands. This effect is likely solely pronounced in switch trials because the irrelevant feature in such trials was the relevant feature in the previous trial, carrying over residual activity of the S-R links into the current trial, ultimately biasing the competition.

Affordance Competition Hypothesis and Competing Accounts

The aim of the current study was also to see whether its findings can be interpreted in the light of broader theoretical frameworks, particularly the ACH. As overall shown, the ACH offers a comprehensive approach to explain response competition in the modified version of the Eriksen flanker task. This holds true not only for anticipated and previously hypothesised effects but also for unpredicted results. However, thus far the ACH has not been directly applied to the Eriksen flanker task or task-switching paradigms. Instead, multiple phenomena have been put forth to account for the findings in these research areas, particularly for task switching.

In task switching, the notion of a mental task set surfaces which entails relevant attributes of stimuli to attend to and their corresponding response values, enabling

performance in accordance with task requirements (Kiesel et al., 2010; Koch et al., 2018; Monsell, 2003; Schmitz & Krämer, 2023). Thus, they are essentially characterised by a set of S-R bindings that ensure consistent action across time and provide the cognitive flexibility needed to switch between different tasks as the situational demands require (Schmitz & Krämer, 2023). The switch cost has been attributed by Monsell (2003) to what he coined task-set reconfiguration – a mental adjustment process required to new task requirements before one can proceed. This preparation negatively influences task performance, leading to slower responses and more errors (Monsell, 2003). But what constitutes the residual switch cost then, since participants would technically have time to prepare before a trial in task-cueing paradigms? The explanation provided in the literature is the so-called task-set inertia, which suggests that cognitive processes from the previous task persist and influence performance on the subsequent task (Evans et al., 2015; Monsell, 2003). Specifically, the ongoing activation of the previous task set and the continued inhibition of the current task set impede task switching. This persistence creates proactive interference, where the prior task set's cognitive processes compete with the new task set, particularly in terms of S-R mappings (Allport et al., 1994).

In terms of congruency effects found in the Eriksen flanker task, Kornblum's dimensional overlap model has often been applied. Stimuli and responses in S-R forced choice tasks like the flanker task can have dimensions that are relevant and irrelevant to the task requirements (Kornblum et al., 1990; Kornblum & Lee, 1995). Congruency effects arise whenever dimensions overlap, meaning they share common characteristics such as shape or response attributes. These overlapping dimensions can then either align or conflict, influencing task performance (Kornblum et al., 1990; Kornblum & Lee, 1995). In the Eriksen flanker task, a stimulus-stimulus overlap is present, as the relevant and irrelevant stimulus dimensions are derived from the same letters (Egner, 2007). Incongruent stimulus arrays evoke both a stimulus conflict, due to dissimilar stimulus representations (i.e., differing letters), and a response conflict, due to response competition arising because the two stimulus values are mapped onto different responses. These incompatibilities between relevant and irrelevant dimensions ultimately result in longer RTs as they must be disambiguated before the correct response can be selected (Kornblum et al., 1990; Kornblum & Lee, 1995; Egner, 2007).

Reviewing these theoretical perspectives, it becomes evident that the central issue in both task switching and the Eriksen flanker task can be captured as the competition between S-R links, or in the words of the ACH: affordance-action links. In task switching, the conflict

arises from the persistence of previous task affordances, while in the Eriksen task, it results from overlapping stimulus dimensions and their corresponding affordances. In any case, it highlights how stimuli automatically afford action and concurrently compete for action selection, as indicated by neurophysiological studies (Caledron et al., 2018; Eriksen 1995; Eriksen et al., 1985; Grèzes & Decety, 2002; Michelet et al., 2010). Thus, the ACH provides a comprehensive framework to account for these findings, unifying the explanation of response competition and cognitive control across different tasks.

Notably, the divergence in terminology among researchers clouds the comprehensiveness of the research area. Frameworks related to the ACH, such as the BRAC framework by Frings et al. (2020), also attempt to unify different perspectives by explaining research findings through feature binding and retrieval. However, more effort is needed toward more unified conceptualisations to enhance clarity and cohesion across studies. Yet, the ACH offers a promising direction by accounting for a multitude of findings as a single comprehensive framework.

Attention in the Eriksen Flanker Task

Lastly, to briefly revisit the role of attention, while not directly investigated in this study, it appears to play a crucial role in managing task demands and guiding ongoing response competition. As previously mentioned, attentional mechanisms allow for the selection of the most suitable target for behaviour by concurrently suppressing distractions from irrelevant signals – allowing for goal-directed behaviour towards behaviourally relevant targets (Levi-Ari et al., 2022). In the Eriksen flanker task, this modulation would take the form of allowing a selective focus on the goal-relevant central target while inhibiting the competing responses imposed by the surrounding flankers.

Recent studies using the Eriksen flanker task have further elucidated the neural dynamics underlying this process. For instance, Asanowicz et al. (2023) highlighted the involvement of a fronto-posterior theta network involved in the suppression of conflicting and irrelevant visual information, indicative of attentional modulation. In a similar vein, a study conducted by McDermott et al. (2017) found significant oscillatory events in fronto-parietal regions during the performance of the Eriksen flanker task, demonstrating a strong engagement of cortical regions implicated in attention networks.

These findings underscore the role of attentional modulation in the Eriksen flanker task, highlighting how attentional networks actively suppress irrelevant information to facilitate goal-directed responses.

Limitations and Recommendations for Future Research

Despite the insightful findings, the study design had notable limitations. Primarily, investigating response competition based solely on behavioural data limits the depth of inferences that can be made. While the findings and interpretations aligned with existing neurophysiological research in this field, no direct conclusions on cognitive processes can be drawn from the current findings alone. Future studies could substitute this study design with physiological measures like EEG or MEG to provide a more comprehensive understanding of the underlying mechanisms.

Moreover, the employed stimulus features, shape and orientation, were of differing complexity. This disparity could have introduced a confound, potentially impacting the validity of the results. Despite including the relevant feature in the study design and analysis, the differing complexities might have unevenly influenced participants' responses in various conditions. Future research should use stimuli of comparable complexity to ensure clearer results. For instance, using horizontal and vertical lines instead of diagonal ones for line orientation could already reduce this difference (Li et al., 2003).

Lastly, the current study employed arbitrary S-R links, resulting in acquired affordances. Future research could benefit from using more natural affordances to enhance the ecological validity of the findings. For instance, incorporating arrows, as often employed in the Eriksen task (Davelaar, 2013; Ridderinkhof et al., 1995), or motion patterns (Lange-Malecki & Treue, 2012), could provide stimuli that are more intuitively linked to responses. This approach would more closely mimic natural interactions, potentially simplifying the task. Furthermore, it would allow for a comparison between natural and acquired affordances, exploring how each type influences cognitive processing and action selection. When combined with neurophysiological measures, this method could offer a richer understanding of the neural mechanisms underlying response competition.

Conclusion

In conclusion, the present experiment demonstrates that task switching intensifies the inherent response competition in the Eriksen flanker task. It supports the notion that the perception of stimuli automatically triggers their associated responses, which then compete for response execution. This resulted in larger response compatibility effects in the mixed blocks, due to more competing S-R links, highlighting the dynamic interplay between task demands and response execution. In light of the ACH, these findings underscore a continuous attunement to the environment, where ongoing response competition of behaviourally relevant affordances allows for adaptive and goal-directed behaviour. Finally, the ACH offers a comprehensive approach to understanding response competition, aligning diverse accounts

in the literature of at least two distinct experimental contexts under a unified theoretical model. This highlights the importance of striving for more integrated conceptualisations in the field of action control.

References

- Abrahamse, E. L., & Verwey, W. B. (2007). Context dependent learning in the serial RT task. *Psychological Research*, 72(4), 397–404. <https://doi.org/10.1007/s00426-007-0123-5>
- Albright, T. D., Kandel, E. R., & Posner, M. I. (2000). Cognitive neuroscience. *Current Opinion in Neurobiology*, 10(5), 612–624. [https://doi.org/10.1016/s0959-4388\(00\)00132-x](https://doi.org/10.1016/s0959-4388(00)00132-x)
- Allport, A., Styles, E. A., & Hsieh, H. (1994). Shifting intentional set: exploring the dynamic control of tasks. In C. Umiltà & M. Moscovitch (Eds.), *Attention and Performance XV: Conscious and Nonconscious Information Processing* (Vol. 15, pp. 421–452). MIT Press. <https://doi.org/10.7551/mitpress/1478.003.0025>
- Asanowicz, D., Panek, B., Kotlewska, I., & Van Der Lubbe, R. (2023). On the Relevance of Posterior and Midfrontal Theta Activity for Visuospatial Attention. *Journal of Cognitive Neuroscience*, 35(12), 1972–2001. https://doi.org/10.1162/jocn_a_02060
- Broadbent, D. E. (1958). Perception and communication. In *Pergamon Press eBooks*. <https://doi.org/10.1037/10037-000>
- Calderon, C. B., Van Opstal, F., Peigneux, P., Verguts, T., & Gevers, W. (2018). Task-Relevant information modulates primary motor cortex activity before movement onset. *Frontiers in Human Neuroscience*, 12. <https://doi.org/10.3389/fnhum.2018.00093>
- Cisek, P. (2007). Cortical mechanisms of action selection: the affordance competition hypothesis. *Philosophical Transactions - Royal Society. Biological Sciences*, 362(1485), 1585–1599. <https://doi.org/10.1098/rstb.2007.2054>

- Cisek, P., & Kalaska, J. F. (2010). Neural Mechanisms for Interacting with a World Full of Action Choices. *Annual Review of Neuroscience*, 33(1), 269–298. <https://doi.org/10.1146/annurev.neuro.051508.135409>
- Davelaar, E. J. (2013). When the ignored gets bound: sequential effects in the flanker task. *Frontiers in Psychology*, 3. <https://doi.org/10.3389/fpsyg.2012.00552>
- Egner, T. (2007). Congruency sequence effects and cognitive control. *Cognitive, Affective & Behavioral Neuroscience*, 7(4), 380–390. <https://doi.org/10.3758/cabn.7.4.380>
- Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics*, 16(1), 143–149. <https://doi.org/10.3758/bf03203267>
- 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. <https://doi.org/10.1080/13506289508401726>
- Eriksen, C. W., Coles, M. G. H., Morris, L. R., & O'hara, W. P. (1985). An electromyographic examination of response competition. *Bulletin of the Psychonomic Society*, 23(3), 165–168. <https://doi.org/10.3758/bf03329816>
- Evans, L. H., Herron, J. E., & Wilding, E. L. (2015). Direct Real-Time neural evidence for Task-Set inertia. *Psychological Science*, 26(3), 284–290. <https://doi.org/10.1177/0956797614561799>
- Frings, C., Hommel, B., Koch, I., Rothermund, K., Dignath, D., Giesen, C., Kiesel, A., Kunde, W., Mayr, S., Moeller, B., Möller, M., Pfister, R., & Philipp, A. (2020). Binding and Retrieval in action Control (BRAC). *Trends in Cognitive Sciences*, 24(5), 375–387. <https://doi.org/10.1016/j.tics.2020.02.004>
- Gibson, J. J. (2014). The ecological approach to visual Perception. In *Psychology Press eBooks*. <https://doi.org/10.4324/9781315740218>

- Grèzes, J., & Decety, J. (2002). Does visual perception of object afford action? Evidence from a neuroimaging study. *Neuropsychologia*, *40*(2), 212–222. [https://doi.org/10.1016/s0028-3932\(01\)00089-6](https://doi.org/10.1016/s0028-3932(01)00089-6)
- Hommel, B., Chapman, C. S., Cisek, P., Neyedli, H. F., Song, J., & Welsh, T. N. (2019). No one knows what attention is. *Attention, Perception & Psychophysics*, *81*(7), 2288–2303. <https://doi.org/10.3758/s13414-019-01846-w>
- Ishihara, S., & EJ, N. (1918). Tests for color blindness. *American Journal of Ophthalmology*, *1*(5), 376. [https://doi.org/10.1016/s0002-9394\(18\)90663-x](https://doi.org/10.1016/s0002-9394(18)90663-x)
- Itti, L., & Koch, C. (2000). A saliency-based search mechanism for overt and covert shifts of visual attention. *Vision Research*, *40*(10–12), 1489–1506. [https://doi.org/10.1016/s0042-6989\(99\)00163-7](https://doi.org/10.1016/s0042-6989(99)00163-7)
- Kiesel, A., Steinhauser, M., Wendt, M., Falkenstein, M., Jost, K., Philipp, A. M., & Koch, I. (2010). Control and interference in task switching—A review. *Psychological Bulletin*, *136*(5), 849–874. <https://doi.org/10.1037/a0019842>
- Kiesel, A., Wendt, M., & Peters, A. (2005). Task switching: on the origin of response congruency effects. *Psychological Research*, *71*(2), 117–125. <https://doi.org/10.1007/s00426-005-0004-8>
- Koch, I., & Allport, A. (2006). Cue-based preparation and stimulus-based priming of tasks in task switching. *Memory & Cognition*, *34*(2), 433–444. <https://doi.org/10.3758/bf03193420>
- Koch, I., Poljac, E., Müller, H., & Kiesel, A. (2018). Cognitive structure, flexibility, and plasticity in human multitasking—An integrative review of dual-task and task-switching research. *Psychological Bulletin*, *144*(6), 557–583. <https://doi.org/10.1037/bul0000144>

- Kornblum, S., Hasbroucq, T., & Osman, A. (1990). Dimensional overlap: Cognitive basis for stimulus-response compatibility--A model and taxonomy. *Psychological Review*, 97(2), 253–270. <https://doi.org/10.1037/0033-295x.97.2.253>
- Kornblum, S., & Lee, J. (1995). Stimulus-response compatibility with relevant and irrelevant stimulus dimensions that do and do not overlap with the response. *Journal of Experimental Psychology. Human Perception and Performance*, 21(4), 855–875. <https://doi.org/10.1037/0096-1523.21.4.855>
- Lange-Malecki, B., & Treue, S. (2012). A flanker effect for moving visual stimuli. *Vision Research*, 62, 134–138. <https://doi.org/10.1016/j.visres.2012.03.016>
- Lev-Ari, T., Beerli, H., & Gutfreund, Y. (2022). The ecological view of selective attention. *Frontiers in Integrative Neuroscience*, 16. <https://doi.org/10.3389/fnint.2022.856207>
- Li, B., Peterson, M. R., & Freeman, R. D. (2003). Oblique effect: a neural basis in the visual cortex. *Journal of Neurophysiology*, 90(1), 204–217. <https://doi.org/10.1152/jn.00954.2002>
- Lindgren, M., Stenberg, G., & Rosén, I. (1996). Effects of nicotine in visual attention tasks. *Human Psychopharmacology*, 11(1), 47–51. [https://doi.org/10.1002/\(sici\)1099-1077\(199601\)11:1](https://doi.org/10.1002/(sici)1099-1077(199601)11:1)
- McDermott, T. J., Wiesman, A. I., Proskovec, A. L., Heinrichs-Graham, E., & Wilson, T. W. (2017). Spatiotemporal oscillatory dynamics of visual selective attention during a flanker task. *NeuroImage*, 156, 277–285. <https://doi.org/10.1016/j.neuroimage.2017.05.014>
- Meiran, N. (1996). Reconfiguration of processing mode prior to task performance. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, 22(6), 1423–1442. <https://doi.org/10.1037/0278-7393.22.6.1423>

- Meiran, N., & Kessler, Y. (2008). The task rule congruency effect in task switching reflects activated long-term memory. *Journal of Experimental Psychology: Human Perception and Performance*, 34(1), 137–157. <https://doi.org/10.1037/0096-1523.34.1.137>
- Michelet, T., Duncan, G. H., & Cisek, P. (2010). Response competition in the primary motor cortex: corticospinal excitability reflects response replacement during simple decisions. *Journal of Neurophysiology*, 104(1), 119–127. <https://doi.org/10.1152/jn.00819.2009>
- Monsell, S. (2003). Task switching. *Trends in Cognitive Sciences*, 7(3), 134–140. [https://doi.org/10.1016/s1364-6613\(03\)00028-7](https://doi.org/10.1016/s1364-6613(03)00028-7)
- Monsell, S., Sumner, P., & Waters, H. (2003). Task-set reconfiguration with predictable and unpredictable task switches. *Memory & Cognition*, 31(3), 327–342. <https://doi.org/10.3758/bf03194391>
- Pastor-Bernier, A., & Cisek, P. (2011). Neural correlates of biased competition in premotor cortex. *The Journal of Neuroscience*, 31(19), 7083–7088. <https://doi.org/10.1523/jneurosci.5681-10.2011>
- Pastötter, B., & Frings, C. (2018). It's the other way around! Early modulation of sensory distractor processing induced by late response conflict. *Journal of Cognitive Neuroscience*, 30(7), 985–998. https://doi.org/10.1162/jocn_a_01267
- Peirce, J., Gray, J. R., Simpson, S., MacAskill, M., Höchenberger, R., Sogo, H., Kastman, E., & Lindeløv, J. K. (2019). PsychoPy2: Experiments in behavior made easy. *Behavior Research Methods*, 51(1), 195–203. <https://doi.org/10.3758/s13428-018-01193-y>
- PsychoPy. (n.d.). *Keyboard Component*. Retrieved May 10, 2024, from <https://www.psychopy.org/builder/components/keyboard.html>

- R Core Team. (2024). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria (V4.4.0)
[Software]. <https://www.R-project.org/>
- Rafal, R., Gershberg, F., Egly, R., Ivry, R., Kingstone, A., & Ro, T. (1996). Response channel activation and the lateral prefrontal cortex. *Neuropsychologia*, *34*(12), 1197–1202. [https://doi.org/10.1016/0028-3932\(96\)00045-0](https://doi.org/10.1016/0028-3932(96)00045-0)
- Ridderinkhof, K., Van Der Molen, M. W., & Bashore, T. R. (1995). Limits on the application of additive factors logic: Violations of stage robustness suggest a dual-process architecture to explain flanker effects on target processing. *Acta Psychologica*, *90*(1–3), 29–48. [https://doi.org/10.1016/0001-6918\(95\)00031-o](https://doi.org/10.1016/0001-6918(95)00031-o)
- Rogers, R. D., & Monsell, S. (1995). Costs of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology. General*, *124*(2), 207–231. <https://doi.org/10.1037/0096-3445.124.2.207>
- Rovamo, J., Virsu, V., Laurinen, P., & Hyvärinen, L. (1982). Resolution of gratings oriented along and across meridians in peripheral vision. *PubMed*, *23*(5), 666–670. <https://pubmed.ncbi.nlm.nih.gov/7129811>
- Schmitz, F., & Krämer, R. J. (2023). Task Switching: On the Relation of Cognitive Flexibility with Cognitive Capacity. *Journal of Intelligence*, *11*(4), 68. <https://doi.org/10.3390/jintelligence11040068>
- Servant, M., & Logan, G. D. (2019). Dynamics of attentional focusing in the Eriksen flanker task. *Attention, Perception & Psychophysics*, *81*(8), 2710–2721. <https://doi.org/10.3758/s13414-019-01796-3>
- Singmann, H., Bolker, B., Westfall, J., Aust, F., & Ben-Shachar, M. S. (2024). *afex: Analysis of factorial experiments (Version 1.3-1) [R package]*. <https://CRAN.R-project.org/package=afex>

- Sudevan, P., & Taylor, D. A. (1987). The cuing and priming of cognitive operations. *Journal of Experimental Psychology. Human Perception and Performance*, 13(1), 89–103. <https://doi.org/10.1037/0096-1523.13.1.89>
- Theeuwes, J., Olivers, C. N. L., & Belopolsky, A. (2010). Stimulus-driven capture and contingent capture. *Wiley Interdisciplinary Reviews. Cognitive Science*, 1(6), 872–881. <https://doi.org/10.1002/wcs.83>
- Verwey, W. B. (2023). The basis of S–R learning: associations between individual stimulus features and responses. *Psychological Research*. <https://doi.org/10.1007/s00426-023-01873-1>
- Verwey, W. B., Wright, D. L., & Van Der Lubbe, R. H. (2020). The Simon effect in a discrete sequence production task: Key-specific stimuli cannot be ignored due to attentional capture. *Acta Psychologica*, 205, 103044. <https://doi.org/10.1016/j.actpsy.2020.103044>
- Vision Source. (2020, April 13). *Free Eye Chart - download, print, test*. Retrieved February 29, 2024, from <https://visionsource.com/patients/free-eye-chart-download/>
- Weissman, D. H., Hawks, Z. W., & Egner, T. (2016). Different levels of learning interact to shape the congruency sequence effect. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, 42(4), 566–583. <https://doi.org/10.1037/xlm0000182>
- Wylie, G., & Allport, A. (2000). Task switching and the measurement of “switch costs.” *Psychological Research*, 63(3–4), 212–233. <https://doi.org/10.1007/s004269900003>

Appendix A

Table 1

Possible Stimulus-Congruency Combinations for Shape and Orientation.

Congruency	Stimulus Array				
shape: congruent (circle) orientation: congruent (right)					
shape: congruent (triangle) orientation: congruent (right)					
shape: congruent (circle) orientation: congruent (left)					
shape: congruent (triangle) orientation: congruent (left)					
shape: incongruent (circle) orientation: congruent (right)					
shape: incongruent (triangle) orientation: congruent (right)					
shape: incongruent (circle) orientation: congruent (left)					
shape: incongruent (triangle) orientation: congruent (left)					
shape: congruent (circle) orientation: incongruent (right)					
shape: congruent (circle) orientation: incongruent (left)					
shape: congruent (triangle) orientation: incongruent (right)					
shape: congruent (triangle) orientation: incongruent (left)					
shape: incongruent (circle) orientation: incongruent (right)					
shape: incongruent (triangle) orientation: incongruent (right)					
shape: incongruent (circle) orientation: incongruent (left)					
shape: incongruent (triangle) orientation: incongruent (left)					

Note. In the experimental condition, stimulus-congruent trials comprise configurations in which every stimulus in the array is similar on the relevant stimulus feature. The table displays congruency levels of the two relevant stimulus features shape and orientation.

Appendix B

Task Programming Description

The experiment was programmed in PsychoPy (version 2023.2.3) using the builder view. Each routine and component in the builder had a distinct name to avoid interference and ensure smooth operation. This also applies to columns in the conditions file, which will be described in the following.

Conditions Files

The conditions file was an Excel sheet listing block type (pure or mixed), relevant feature (shape or orientation), central stimulus (image file name), flankers (image file name), correct answers for both relevant and irrelevant features ("a" or "l"), and stimulus congruency for both relevant and irrelevant features (congruent or incongruent). All sixteen possible trial combinations were created (see Appendix A) and copied six times to make 96 trials per block. Note that the stimuli for the present experiment were drawn by hand and inserted as images into the program. Thus, in the conditions file, the name of the image file would be included for the central target and flanker columns (e.g., CircleLeft.png).

Overall, for this experiment, one experiment and corresponding conditions file per block type were created (shape, orientation, and mixed). To account for counterbalancing conditions, an additional experiment with its respective conditions file was prepared for the reversed stimulus-key mapping. On the day of the experiment, the order of the pure blocks was counterbalanced by alternating whether the shape or orientation blocks were administered first for each participant.

Creating the Routines in PsychoPy

To create the experiment in PsychoPy, three separate routines were created for the components of a trial (i.e., S-R mapping, stimulus array, and feedback). These routines were then combined by means of a loop. The components are outlined as follows.

S-R Mapping

The routine for the S-R mapping included three components. First, a fixation cross was inserted as text (“+”) at 0, 0 degrees. Then, depending on the relevant feature either two polygons (circle and triangle) or the two images for orientation (hand-drawn rhombus with lines oriented to the left or right) were inserted at -13, -6 and 13, -6 degrees. The placement of the respective shapes and orientations depends on the stimulus-key mapping of the specific block. In the basic settings, the duration for each component was set from zero to 1.5 seconds. Importantly, when using images for the orientation cues, the name of the image file

must be denoted under “image” in the basic settings and “set to every repeat”. Note that the mixed blocks included a slightly different set-up which will be described at the very end.

Stimulus Array

The second routine for the stimulus array featured the same fixation cross as described above. Additionally, the central target is displayed above the fixation cross (0, 2 degrees) with two flankers on the left (-8, 2 degrees and -4, 2 degrees) and two flankers on the right (8, 2 degrees and 4, 2 degrees). Here, instead of referring to the image files directly, the conditions file is referenced for the central target and flankers (e.g., “\$flankers_mixed” in the “image” row in the basic settings) and is also “set to every repeat”. This way, PsychoPy can randomly alternate between trials specified in the conditions file.

Moreover, the stimulus array featured a keyboard response component. The basic settings of the keyboard component were set to start at 0 seconds with no upper limit, allowing only keys “a” and “l”, and set to register the keypress on press. Furthermore, for the data settings, it was set to store the first key, sync timing with the screen and discard the previous. Lastly, the column with the correct answer from the conditions file was referenced in the correct answer row alongside ticking the box to store the correct answer. This way, not only the key press of the participant will be stored, but also an additional binary variable indicating whether the response was correct or false.

All components in the routine were set to start at 0 seconds until 2 seconds except for the keyboard component, which had no upper limit specified to ensure that the next trial would only be initiated after a response was registered.

Feedback Routine

For the final feedback routine, the fixation cross component was added alongside a custom code in the “each frame” tab, which checked for the correct response based on the conditions file and accordingly illuminated the fixation cross red or green, depending on whether the keypress was correct or incorrect. Both components in this routine were set to 0.25 seconds.

Loop

Finally, a loop was inserted that included all three routines. The loop type was set to random with the “is trials” box checked. Moreover, nReps was set to one as all trials are already included in the conditions file, meaning that no repetition of the conditions file was needed. In the conditions row, the name of the conditions Excel file was simply added.

Additional Routine in the Mixed Blocks

Note that for the mixed blocks, an additional routine was created, and the S-R mapping routine was also slightly different from that of the pure blocks. Instead of using separate images or polygons for the cues, the S-R mapping routine in the mixed blocks consisted of two screenshots of the S-R mapping display for shape and orientation, set to full-screen size. In order to ensure that the correct cue was displayed for each trial, an additional routine including a custom code was included at the very beginning of the loop before the routine for the S-R mapping. The custom code placed in the “begin routine” tab, adjusted which of the two S-R mappings would be visible based on the relevant feature specified in the conditions file.