Task Switching in the Simon Task

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Abstract

The present study aimed to investigate how manipulating the requirements of a Simon task, guided by the predictions of the Affordance Competition Hypothesis (ACH), affects the performance of participants. The study specifically examined the interplay between natural affordances, as demonstrated by the Simon effect, and acquired affordances represented by newly acquired stimulus-response links. By incorporating a task-switching paradigm, the study attempted to understand how these acquired affordances compete and influence participant performance. Participants took part in pure and mixed block phases, where they responded to stimuli based on either their shape or their line orientation. Results showed that natural affordances led to faster reaction times in spatially congruent trials as compared to spatially incongruent trials consistent with the Simon effect. Task-switching introduced significant residual switch costs, reflecting the cognitive effort required to inhibit residual activation of previous affordances while activating new ones. Incompatible responses of affordances further increased cognitive load, highlighting the complexity of resolving competing affordances. These findings underscore the ACH's ability to explain the complex dynamics of action selection, demonstrating how natural and acquired affordances compete and influence performance. Overall, the ACH serves as a comprehensive framework for understanding the intricate balance and cognitive effort involved in resolving competing affordances.

Task Switching in the Simon Task

Every day, we are confronted with decisions to make. Imagine, for example, you help your friend move to a new apartment and accidentally knock over their cactus. You are immediately faced with two options: Either reach for the cactus to save it from smashing into the floor or pull your hands away to prevent harming them. Both are valid on-the-spot responses to the same stimulus—the falling cactus. They reflect different actions based on individual concerns. In an experimental setting, the Simon task illustrates a similar competition, in which the spatial location of stimuli and the task instructions are in competition (Simon, 1969; Hommel, 2011). Here, spatial information apparently aids to make a decision faster, a phenomenon also known as the Simon effect (Hommel, 2011). Both the Simon effect and the falling cactus are part of the (broader) cognitive mechanism that regulates, action selection (Cisek, 2007; Jamone et al., 2018). Research on this mechanism focuses on what action we select and how we select which action to take (Cisek, 2007; Kim et al., 2021). There is, however, uncertainty surrounding the research of action selection, and what theoretical framework governs it (Wispinski et al., 2018; Hommel et al., 2019), especially when instructions are competing among each other (Wispinski et al., 2018; Koch et al., 2018).

To further investigate these questions, the Affordance Competition Hypothesis (ACH) (Cisek, 2007) offers a valuable framework. This hypothesis proposes that in any given situation multiple potential actions are processed in parallel and compete for execution. The Simon task, known for its examination of spatial stimulus-response compatibility, provides an ideal experimental setup to explore these dynamics (Hommel, 2011). By modifying the Simon task and incorporating a task-switching design to induce competition, as well as incompatible responses to stimuli, this paper aims to delve deeper into how the competition between affordances is resolved by examining the reaction time and accuracy of participants completing an accordingly adjusted Simon task. Ultimately, this may offer insights into the cognitive processes underlying action selection.

Affordance Competition Hypothesis

The ACH argues that *action selection* (which action to take) and *action specification* (how to perform the action) occur simultaneously in a continuous, ongoing process, rather than sequentially (Cisek, 2007). In this process, one stimulus triggers multiple affordances - potential actions defined by environmental opportunities - which then compete with each other to be put into action (Gibson, 1979; Cisek, 2007; Cisek and Kalaska, 2010). These affordances are learned through an interaction with the environment, involving a process of gathering information about the consequences of one's actions (Tillas et al., 2016), and ultimately, after evaluating relevant sensory input, internal goals, and contextual constraints, a decision is reached.

Evidence supporting the ACH comes from a neurophysiological perspective. For instance, Cisek and Kalaska (2005) found in their studies on the premotor cortex of monkeys that during a delay phase, (i.e., a phase before a cue signaling which action to take) the researchers could observe neural activity that suggested that the monkeys were preparing for multiple potential movements. Only with the cue did the neural activity adjust towards one single movement (Cisek & Kalaska, 2005; Cisek, 2007). A comparable study conducted in humans reaffirmed a similar pattern as observed in primates (Calderon et al., 2015). Cisek (2007) argues that this kind of activity reflects that the brain of a monkey - and possibly humans (Calderon et al., 2015) - simultaneously processes multiple affordances in parallel, thus supporting the idea behind the ACH. Overall, the ACH emphasizes that performed actions are a result of continuous interaction with the surrounding world and a competition process between potential affordances that are defined by the environment.

Simon Task

The Simon task serves as a tool to investigate the ACH as it is often used to investigate cognitive control, attention, and perception (Van der Lubbe & Verleger, 2002; Hommel, 2011; Proctor, 2011; Hübner & Többel, 2019). In its most basic form, the Simon task requires participants to react to stimuli that are spatially congruent or incongruent with their expected response. For example, participants receive instructions that they have to press a button on the left every time they see the target stimuli “X” appear on the screen when the X can appear on the left side (congruent) of the screen or on the right side (incongruent) (Proctor, 2011; Hommel, 2011). The usual observation of this task is the so-called Simon effect. This phenomenon shows that participants respond faster to spatially congruent stimuli as compared to incongruent stimuli (Proctor, 2011; Hommel, 2011).

From the perspective of the ACH, the Simon task could theoretically suggest the involvement of two types of affordances: one that may be referred to as acquired affordances, which are induced by the task instructions, and one that may be referred to as natural affordances, which are activated by the position of the stimulus. The Simon effect can be considered as an example of the latter. Simon (1990) himself referred to the influence of the task irrelevant spatial information - the Simon effect - as “(...) a natural tendency to react toward the source of stimulation.” (Simon, 1990, p. 34). This notion of naturality can be stressed, with the underlying rationale being that throughout our lives, we have been conditioned to respond to the spatial origin of a stimulus, as this is contextually the most relevant response. It would be counterproductive to facilitate a response into every possible direction when the origin is clear. Thus, when the stimulus and the response are congruent the natural affordance is pronounced, thus facilitating the reaction time because the competition can be clearly resolved due to the natural tendency.

In contrast, when stimulus and response locations are incongruent, the brain faces a more complex competition. The natural affordance triggered by the spatial position of the stimulus suggests one response (e.g., responding with the right hand when the stimulus appears on the right), while the acquired affordance through the task instructions suggests a different response (e.g., responding to the relevant feature, like colour or shape, ignoring the position). This competition would theoretically, lead to increased reaction time and error rates. In conclusion, the perspective of the ACH on the Simon task and its usual observations, like the Simon effect, highlights how the competition between natural and acquired affordances could affect performance and competition resolution.

Task switching

To explore the notion of competing affordances further, applying it to a task-switching paradigm could provide new insights into how affordances compete. Typically, task switching refers to a task layout that requires participants to alter between two or more different tasks, which are performed in sequence to another (Koch et al., 2018; Muhmenthaler & Meier, 2019). In the Simon task, this could mean to switch from reacting to the shape of stimuli to responding to their colour. In order to maintain randomized trials, task-switching involves employing cues, signaling the rules that govern the subsequent task (Kiesel et al., 2010). Through this, participants are unable to anticipate the coming trial (Monsell et al., 2003), which could bias their reaction times, as they could mentally prepare.

A common observation arising from a task-switching paradigm are switch costs due task-set reconfiguration (Koch et al., 2018; Monsell, 2003). Task-set reconfiguration specifically refers to the cognitive processes involved in preparing for and executing a new task after switching (Monsell, 2003). Switch costs are characterized by increased reaction times and higher error rates when participants switched from one task to another compared to when they repeated the same task (Koch et al., 2018; Schmitz & Krämer, 2023). This observation is usually attributed to the overall inhibitory cognitive effort required to manage multiple competing task demands (Monsell, 2003). Interestingly, there is evidence that, even when participants are given the opportunity to prepare for the upcoming task, for instance in form of a cue, that the switch costs weaken in their effect but a residual, resistant switch cost prevails (Nieuwenhuis & Monsell, 2002; Monsell, 2003). These residual switch costs capture the enduring remaining activation of the affordance and their corresponding responses. This residual activation, in turn, interferes with the new task at hand. For example, in the Simon Task, when participants switch from responding to shape of a stimuli to its colour, the previous acquired shape affordances remains partially activated, disturbing the engagement with the acquired colour affordance causing complex competition among these affordances which leads to increased reaction times and higher errors rates.

Furthermore, the presence of these residual switch costs is particularly of interest as the task-switching paradigm’s dual responses introduce another layer of competition, known as stimulus-response compatibility (SRC). SRC refers to how well a stimulus and its corresponding response align, as seen in tasks like the Stroop effect, and the Flankers effect where participants must inhibit one response in favour of another, that is not spatially induced (Eriksen & Eriksen, 1974; Hommel, 2011; Verghese et al., 2017). In the Simon task with a task-switching paradigm, stimuli could have multiple features that require distinct responses. For instance, a red triangle might prompt a left response based is shape while simultaneously prompting a right response based on colour, creating an incompatible stimulus response mapping (Dreisbach et al., 2006), or a mismatch between acquired affordances responses.

Overall, through the lens of the ACH, residual costs can be considered as the result of competing affordances, namely the a relevant affordance induced by the current task, and the persistent residual activation of previous affordances. More specifically, after a switch, the affordances from the previous task persist and interfere with the response requirements of the new task in form of residual affordance activation. Additionally, this competition in turn leads to an incompatibility between the previously relevant response and relevant response of the new task. Thus the previously relevant affordances responses must be inhibited, while the new affordance of the new task must be activated. This competition between the current task and the previous trial's requirements induces additional competition and necessitates more elaboration to resolve.

Research Question

This study will use a Simon task with two target stimuli features—shape and line grating orientation—to create competing affordances. Initially, participants will undergo a pure block phase, where they will perform tasks based solely on either shape or line orientation. This phase is designed to condition participants to specific responses, establishing acquired affordances related to each feature. Following the pure block, participants will enter a mixed block phase which employs task-switching paradigm. In this phase, participants will switch between tasks that require responses based on either shape or line orientation, thus inducing competition between the previously acquired affordances. The study will measure reaction times and accuracy to investigate how these competing affordances influence action selection. By examining task-switching residual costs and the effect of the natural affordance -Simon effect-, the study seeks to provide insights into the cognitive processes underlying action selection.

First, it is hypothesiszed that participants will exhibit the natural affordance - Simon effect - (Proctor, 2011; Hommel, 2011), where reaction times are faster and participants are more accurate in spatially congruent trials as compared to spatially incongruent trials (Simon, 1990). This effect reflects the natural tendency to react to the task irrelevant spatial location and the influence of natural affordances, where the spatial congruency of a stimulus and response facilitates quicker conflict resolution of competing affordances. It is expected that this natural tendency will be exhibited generally in the pure blocks as well as in the mixed blocks, however in the mixed blocks, it is expected to lessen due to higher competition among affordances.

Second, it is expected that in the mixed block due to the task-switch paradigm, the previous affordance interferes with the activation of the currently relevant affordance. This induces competition between these sets of affordances which is expected to reflect in the performance of participants in form of residual switch costs (Kiesel et al., 2010; Monsell, 2003). Therefore participants are expected to exhibit slower reaction times and higher error rates in the mixed blocks in switch trials compared to non-switch trials.

Third, particularly, the incompatibility of the residual acquired affordances' responses leads to a mismatch in the subsequent reactions, as participants have to inhibit the previously relevant response keys in order to answer correctly to currently relevant stimulus. This incompatibility between responses theoretically will have more of an effect in incompatible trials - a mismatch of response keys- compared to compatible trials -match of response keys- in the mixed block, and not in the pure block, as the acquired affordances are repeated. Therefore, it is hypothesized that in the mixed trials involving task-switching, participants will exhibit increased reaction times and higher error rates due to the competition induced by the incompatibility of the remaining residual responses of the affordances.

Methods

Participants

In total, 24 participants were recruited through convenience sampling, based on availability to the researcher as well as through the subject recruitment pool of the University of Twente. To be included in the study, participants had to be between the ages of 18 and 30 years, in good health, and free of any cognitive or medical condition that could compromise their reactions. This also implied that participants had to be well rested and should not have consumed alcohol 24 hours prior to the experiment. Four of the twenty-four participants had to be excluded due to software complications that compromised the collection of the RT. In the final sample, 35% were German, 40% were Dutch, and 25% came from various other countries. 90% of participants identified themselves as female, 10% identified themselves as male, while no one identified as others. The age range of the participants spanned from 20 to 25 years, with a mean age of 21.85 (SD = 1.98). All of the participants were university students, and all participants reported having normal visual acuity. This research was approved by the BMS Ethics Committee. Approval was obtained on 27.02.24 (nr. 240159). Each participant provided verbal or written consent to partake in this study.

Task and Stimuli

Each trial consisted of three components: an instruction-display, a target-display, and a feedback-display. Figure 1 illustrates one example of a mixed block trial sequence. First in the sequence of each trial was the instruction-display. This display showed the key-side (S-R mapping), the corresponding target feature, the fixation cross, and the specific shape. For example, in Figure 2 the triangle on the left implied that the left key, namely "A" should be pressed every time a triangle was present in the target-display, while the circle in the bottom right implies that the key "L" should be pressed when a circle is present in the target. The target-display showed the target stimuli and the distractor shape. As shown in Figure 1, the target would be a circle shown left of the fixation cross with the distractor shape to the right. Here the correct response would have been "L" for the circle. After this, the feedback-display was shown, in which the fixation cross changed color depending on the answer, red for incorrect and green for correct responses. Subsequently a new trial sequence commenced. For the mixed trial, the sequence was randomized if the next trial was another shape trial or a line orientation trial. Solely the pure blocks targeted the same feature throughout the block.

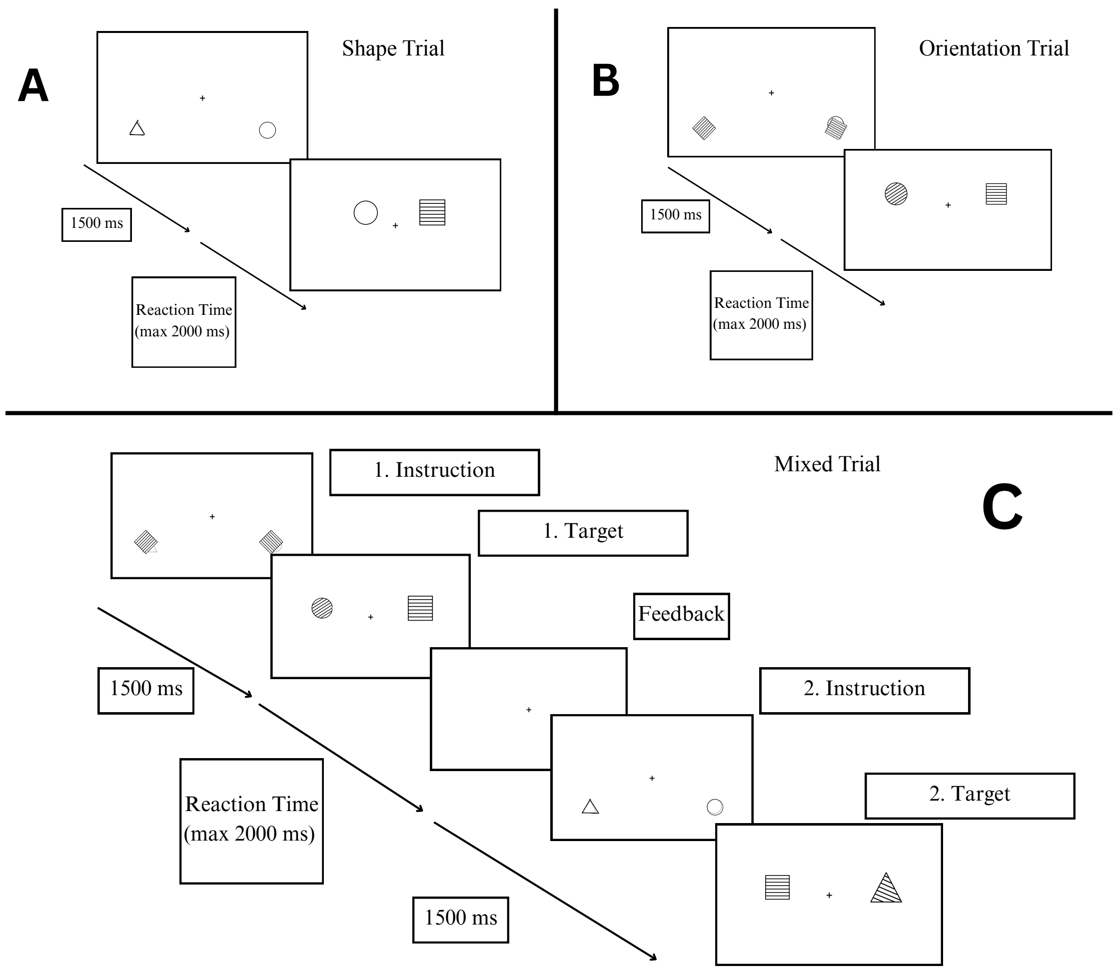
Each instruction-display was visible for 1,500 ms while the target display depended on the reaction time of the participant, but it was only visible for a maximum of 2,000 ms. The duration of the feedback-display lasted for 200 ms. The experiment took for each participant approximately one hour to complete.

The stimuli for the experiment consisted of three geometrical shapes: squares, circles, and triangles. Each shape was displayed with one of three possible line orientations: horizontal, angled up/right, or angled down/left. Each stimulus therefore had two target features, either shape or line orientation.

Shapes and line orientations: Figure 1 displays each stimulus. The square posed as a distractor mask and was only displayed with a horizontal line orientation. It was therefore never a target for the participants. The circle was used as a target shape, and was presented with either an up/right or down/left line orientation.

Figure 1

Sequence of Stimuli for (A) Shape Trial, (B) Orientation Trial and (C) the Mixed Block



Note: This figure displays sequence of stimuli for (A) shape trial, (B) orientation trial and (C) the mixed block**.** The first part in the mixed block sequence illustrates the cue-display for the line orientation trial, after which the target is presented. Once the target has been presented, the feedback-display, depending on the answer of the participant is shown. Lastly, the last two images display the shape cue-display. Note that the pure blocks shown in A and B targeted only one feature, either shape or line orientation. This, in turn, meant that the trials did not switch.

Design

The experiment utilised a block design and within-subject design. The task for each participant consisted of eleven general blocks: three practice blocks, four pure blocks, and four mixed blocks, with breaks scheduled in between every block.

The practice blocks included 8 trials to familiarise participants with the following pure block. Each pure block encompassed 96 trials with either shape or line orientation as the target features. Each feature had two corresponding pure blocks, resulting in two pure blocks of 96 trials, or 192 trials for the feature shape and two pure blocks of 96 for the feature of line orientation, resulting in 192 trials for the feature of line orientation. Each participant had 384 pure block trials in total. Meanwhile, the mixed block included four blocks with 96 trials each, resulting in 384 mixed block trials. The chance of either feature or line orientation to appear was 50/50%. Overall each participant had 792 trials, including the practice blocks.

Procedure

Each participant was given brief verbal instructions in person or brief written instructions through the SONA advertisement, which stated that this study involved the Simon task, task switching and required them to react via key presses to certain stimuli. Each participant was also informed that the study would take approximately one hour.

Participants were seated on a chair in one of the BMS lab rooms in front of the monitor. Prior to the task it was verified whether the participant met the inclusion criteria, and basic demographics, such as age and gender, were collected. Afterwards, each participant was asked to sign the consent form.

The task introduction included a short written description on the screen explaining the target and the task for the participants. It was further explained that each participant needed to place one finger from each hand on the "A" and "L" keys. These instructions were repeated verbally by the researcher. Participants were further instructed to react as fast and as accurate as possible. Subsequently, the target-display and the cue-display were briefly explained. This explanation included a description of the placement of cues at the bottom right and left of the screen, the purpose of the cues, the placement of the fixation cross, and the subsequent placement of the target stimuli. The explanation of the cues also demonstrated that, for instance, if the cue triangle was at the bottom left, the “A” key would be associated with it; similarly, if the cue showed a triangle on the right, the “L” would be associated with it.

After this explanation, the task sequence started. The researcher remained in the room during each practice block to aid if questions arose, but left for the pure blocks and the mixed blocks. In between each block, the researcher entered the experimental room in order to start the programme for the next block. Once all blocks were finished the experimenter re-entered the room in order to answer questions, receive feedback, and thank the participants for taking part in the study.

Materials

The experiment was coded using version 2023.2.3 of PsychoPy Builder. Furthermore, the experiment used two well-lit rooms, each with an approximate space of 8 square metres. Inside the rooms, the study utilised either of two computer setups: (1) the first setup encompassed an HP Z1 G9 computer using an EIZO Flexscan EV2436W monitor with a refresh rate of 60Hz; (2) the second setup had a Dell OptiPlex 7050 computer with an AOC G2460PG monitor which had a 144Hz refresh rate. Participants used a standard QWERTY keyboard, but only the letters “A”, “L”, the spacebar, and the “ESC” key were enabled.

Data Analysis

The reaction times (RT) were collected and measured through the PsychoPy environment. The start of the measurement of the Reaction times began with the presentation of the stimuli, and ended, either through key response or if it participant waited 2000ms

To clean the data and prepare it for further analysis, reaction time (RT) that deviated more than 2 standard deviations (SD) from each participant’s mean were excluded, based on a similar study with a comparable experimental design (D’Ascenzo et al., 2020). This exclusion criteria resulted in the removal of 4.13% of RTs, leaving 14,817 trials for analysis.

The study investigated the effects of these independent variables: Block type: either the pure block, or the mixed block, Feature: shape or orientation, Congruency: either incongruent or congruent depending on the spatial local of stimuli and response, Compatibility: either incompatible or compatible, if target response aligned with other affordances responses, and for the switch trials in the mixed block: task switch or no task switch before the trail, on these dependent variables: RT and accuracy.

A variety of repeated measures analyses of variance (RM-ANOVA) were conducted to account for the dependence of repeated observations from the same participants (Park & Schutz, 1999). RM-ANOVA is robust in handling violations of normality (Blanca et al., 2023), which is common for reaction time data (Jaśkowski, 1983). To address the lack of sphericity, the Greenhouse-Geisser correction was applied (Greenhouse & Geisser, 1959). For the proportion of correct responses (accuracy), an arcsine transformation was used to stabilize the variance and normalize the data distribution.

To gain an overall understanding of the data, a 2x2x2x2 repeated measures ANOVA was conducted on RT and accuracy. The within-subject factors included Block Type (Mixed vs. Pure), Feature (Shape vs. Orientation), spatial Congruency of response on stimulus (Congruent vs. Incongruent), and affordances stimulus response Compatibility (Compatible vs. Incompatible). A similar model was run for the proportion of correct responses. Furthermore, for each Block Type a 2x2x2 RM-ANOVA was conducted, with effects of Feature (Shape vs. Orientation), Congruency (Congruent vs. Incongruent), and Compatibility (Compatible vs. Incompatible.

Results

All blocks

The ANOVA revealed no significant main effect of Block Type on RT, $F(1,19) = 0.9088$ $p = .352$, $\eta p^2 = .0457$, with a mean RT of 627 ms (*SD* = 257 ms) in the pure blocks while in the mixed blocks participants had a mean RT of 643 ms (*SD* = 288 ms). However, the block type exhibited a significant effect on accuracy, $F(1,19) = 11.35$, $p = .003$, $\eta p^2 = .374$. Participants had a mean proportion of correct answers of 95.7% in the pure blocks and in mixed blocks an average of 92.5%.

In line with the first hypothesis, the overall analysis of congruency revealed a main effect on RT, $F(1, 19) = 6.81$, $p = .01$, $\eta p^2 = .262$. The average RT of the participants was significantly slower for incongruent trials (*M* = 641 ms, *SD* = 272 ms) than in congruent trials (*M* = 629 ms, *SD* = 274 ms). There was no significant difference in average correct responses by participants overall in congruent and incongruent trials, $F(1, 19) = 2.02$, $p = .172$, $\eta p^2 = .096$. With a mean accuracy in congruent trials was 94.7% and in incongruent trials it was 93.4% correct responses.

Additionally, the analysis also revealed a significant main effect of compatibility, $F(1, 19) = 10.37$, $p = .004$ $\eta p^2 = .35$, on RT. Participants were significantly slower in incompatible trials (*M* = 643 ms, *SD* = 277 ms) in comparison to compatible trials (*M*= 628 ms, *SD* = 269 ms). Compatibility also had a significant main effect on accuracy, $F(1,19) = 43.57$, $p < .001$, $\eta p^2 = .696$, participants reacted significantly less accurate in the incompatible trials (92.1%) compared to the compatible trials (96.1%).

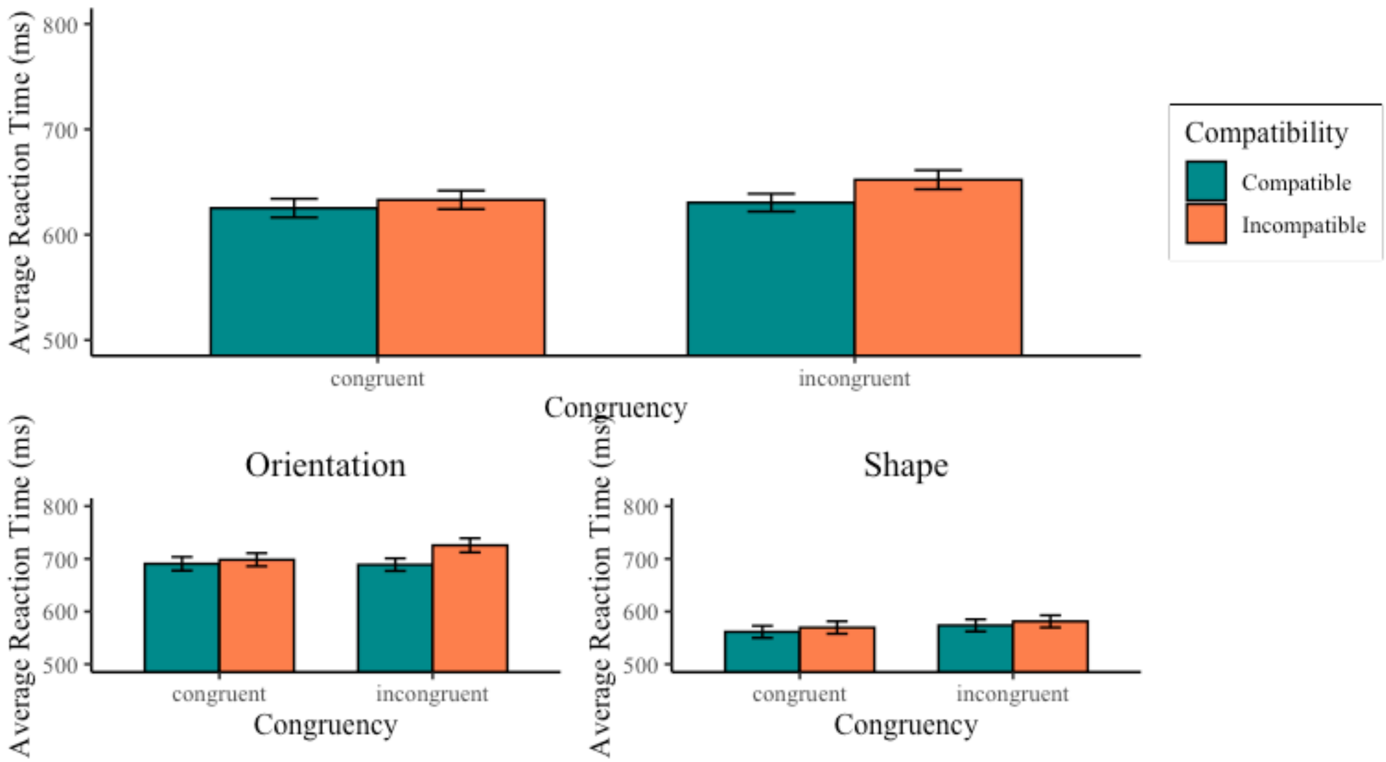
Additionally, the ANOVA revealed a three-way interaction effect between congruency, compatibility, and feature on RT, $F(1,19) = 6.7429$, $p = .0177$, $\eta p^2 =.262$, Furthermore, it revealed a marginally significant interaction between compatibility and feature of RT, $F(1,19) = 3.19$, $p = .143$, np2 = .09.

The top portion of Figure 2 displays the average RT of congruent and incongruent trials, divided by compatibility (compatible and incompatible). Overall the mean RT of congruency compatible trials was 625 ms (*SD*= 276 ms) while congruent incompatible trials had a mean RT of 633 ms (*SD* = 272 ms). For incongruent compatible trials participants had a mean RT of 630 ms (*SD* = 261 ms), and lastly for incongruent and incompatible trials the mean RT of 652 ms (*SD* = 281 ms). Post-Hoc analysis revealed a significant interaction between compatible incongruent and incompatible incongruent trials $t(19) = -3.525$, $p = .011$, but not for compatible congruent and incompatible congruent trials, $t(19) = -1.508$, $p = .453$

Additionally, given the interaction of feature, the figure also includes congruent and incongruent trials divided by feature. Notable was that participants were in incongruent orientation trial (*M* = 689 ms, *SD* = 258 ms) slightly faster than those of a congruent orientation trial (*M* = 691 ms, *SD* = 282 ms). Post-Hoc analysis revealed a significant difference between incompatible incongruent orientation trials compared to incompatible congruent orientation trials $t(19) = -3.898$, $p = .017$.

Figure 2

Average Reaction Time Across Congruency, Compatibility and Feature



Note: Figure 2 shows the average reaction time across feature, congruency, and incompatibility. The y-axis represents the mean reaction time of each participant overall, the x-axis of the graph in the top portion represents the overall RT of compatibility and congruency, while the lower portion depicts these values decomposed for feature, namely orientation and shape. The error bars show the lower and upper bound of the 95% confidence intervals.

The ANOVA revealed several significant interaction effects including block type on both RT and accuracy. These will be listed in the following and elaborated upon in the sections below divided for each block type. Firstly, there was a three-way significant interaction effect of block type, feature and congruency on RT, $F(1,19) = 7.07$, $p = .02$, $\eta p^2 = .27$. Secondly, there was a significant interaction between block type and compatibility on accuracy, $F(1,19) = 18{,}12$, $p < .001$, $\eta p^2 = .488$. Thirdly, an interaction between block type, feature, and compatibility and accuracy, $F(1,19) = 4.63$, $p = .045$, $\eta p^2 = .196$, was revealed. Lastly, a significant three-way interaction effect for block type, feature, and congruency on accuracy, $F(1,19) = 6.69$, $p = .018$, $\eta p^2 = .260$. However, further analysis through post-hoc analysis revealed no meaningful significant differences.

Pure Blocks

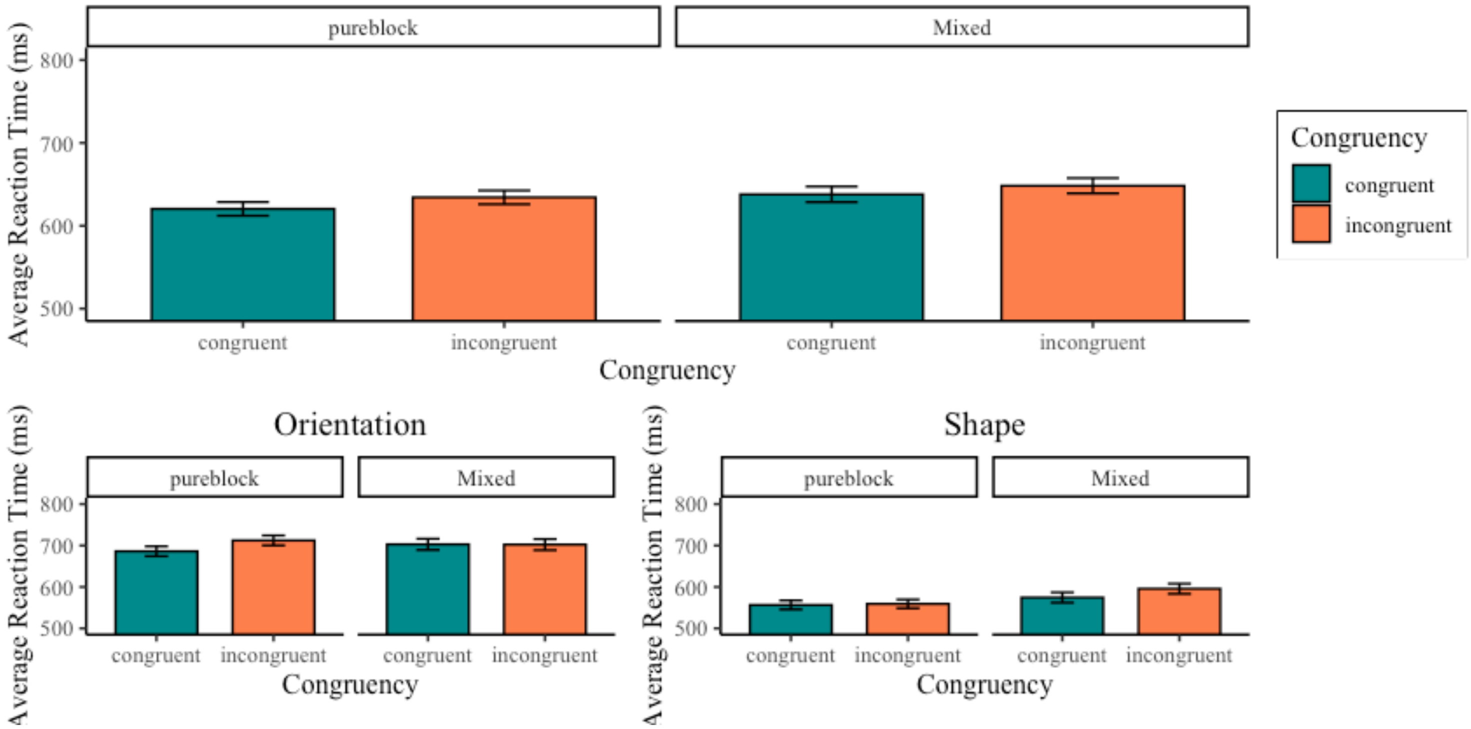
In order to establish a baseline for the mixed blocks the pure blocks were analysed in isolation. For this RM-ANOVA 2x2x2 was conducted, with the effects of feature, congruency, and compatibility on RT and Accuracy. The ANOVA revealed a significant main effect of feature on RT, $F(1, 19) = 28.77$, $p < .001$, $\eta p^2 = .602$, with an average RT of 699 ms (*SD* = 258 ms) and 558 ms (*SD* =236 ms), respectively.

In line with the first hypothesis, the analysis also revealed a significant main effect of congruency on RT, $F(1, 19) = 8.70$, $p = .008$, $\eta p^2 = .314$. Showing that participants were on average faster in congruent trials (*M* = 620 ms, *SD* = 256 ms), compared to incongruent trials (*M*= 634 ms, *SD* = 257). Lastly, not in line with hypothesis three was a significant main effect of compatibility, $F(1,19) = 4.97$, $p = .038$, np2 = .21. In compatible trials the participants average RT was 622 ms, (*SD* = 254 ms) while in incompatible trials the mean RT was 632 ms, (*SD* = 260 ms). Conversely, the ANOVA investigating the effects on accuracy did not yield significant main effects and interaction effects.

Figure 3 displays the observed patterns in the data for block type, feature, and congruency. Overall participants in the pure block had a mean RT of 620 ms (*SD* = 256 ms) in congruent trials while in incongruent trials participants reacted slower on average (*M = 634 ms, SD* = 257 ms). Furthermore, The RTs were higher for incongruent orientation trials in the pure block (*M* = 712 ms, *SD* = 258 ms) compared to congruent trials (*M* = 686 ms, *SD* = 258 ms), while in the shape feature of pure block trials, was only a slight difference between incongruent (*M* = 559 ms, *SD* = 233 ms) and congruent trials (*M* = 557 ms, *SD* = 239 ms). Post-hoc analysis revealed that the difference between the congruent orientation trials and incongruent trials in the pure block was significant $t(19) = -3.483$, $p = .042$.

Figure 3

Average Reaction Time Across Block Type, Feature and Congruency

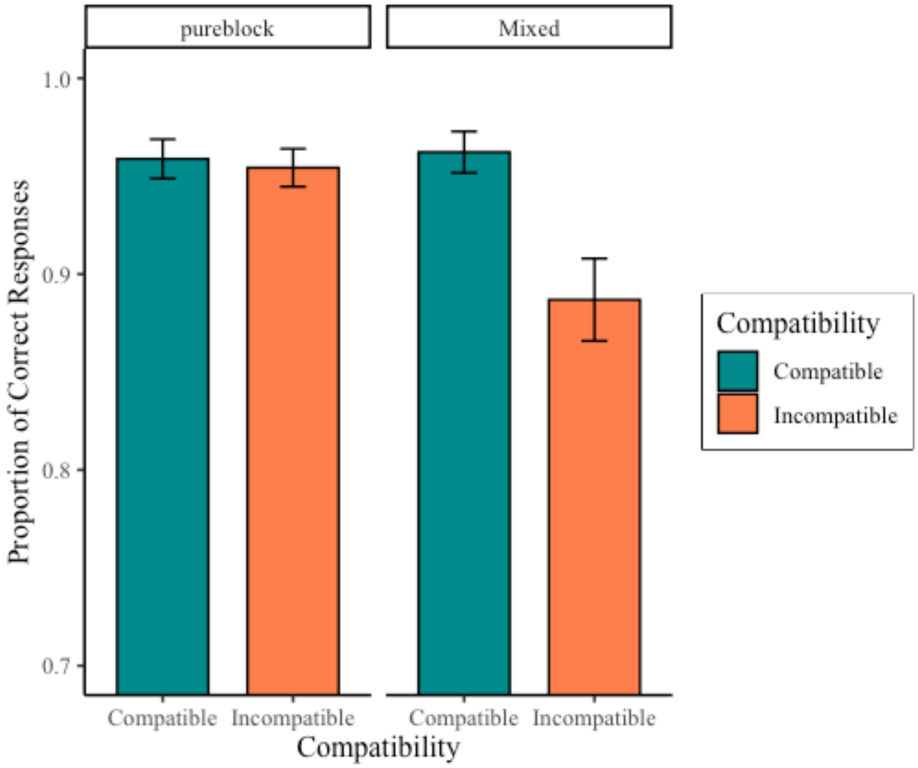


Note: This Figure depicts the average congruency RT across congruency, block types, and feature. Illustrating the difference RTs between congruent and incongruent trials overall in the top portion while these are decomposed into orientation and shape trials in the lower portion. The error bars represent the upper and lower bounds of the 95% confidence interval.

Furthermore, Figure 4 captures the average accuracy across for compatibility and block type, showing that in the pure blocks participants were slightly more accurate in incompatible trials (95.4%) than in compatible trials (95.9%). Post-Hoc analysis revealed no significant difference between compatible and incompatible in the pure block, $t(19) = 0.668$, $p = .9078$.

Figure 4

Average Accuracy Across Block Type, Compatibility.

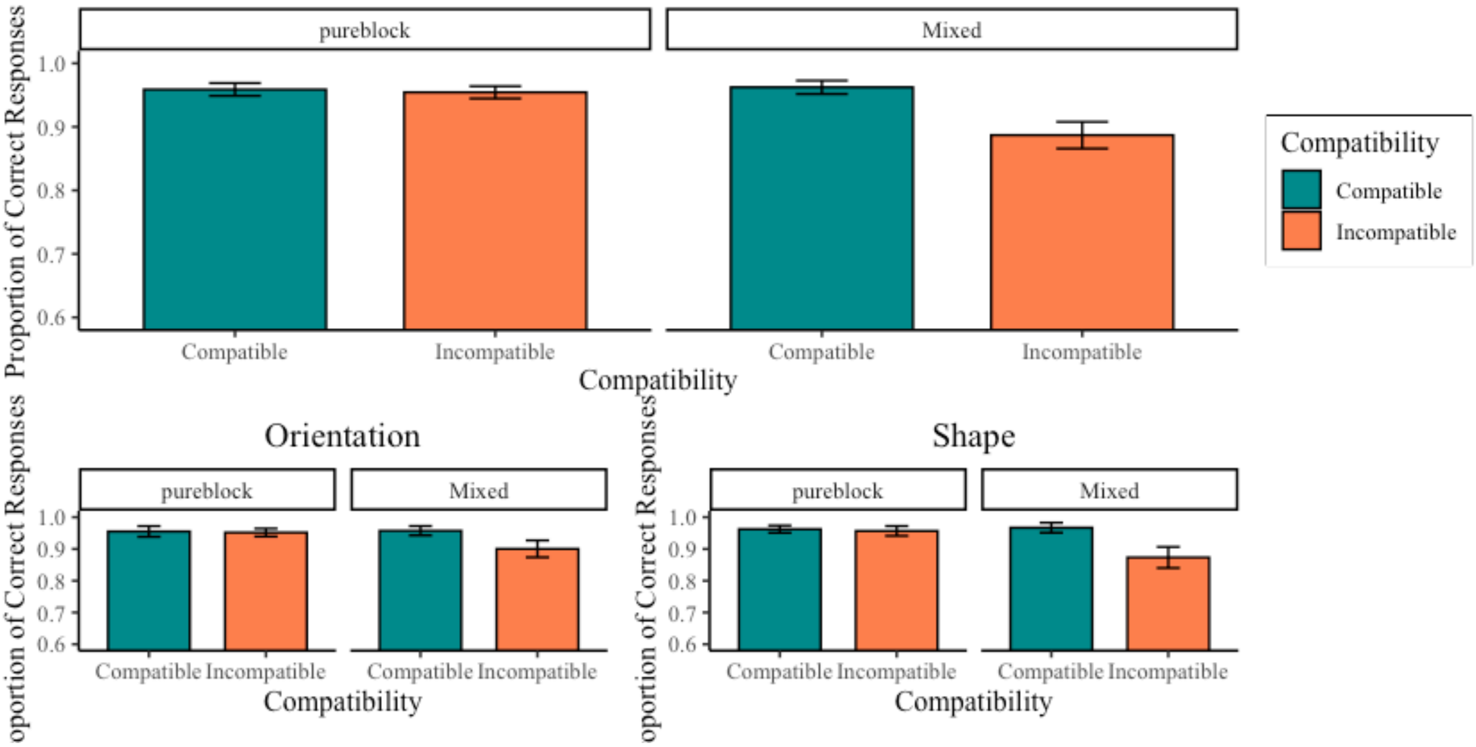


Note: This graph illustrates average accurate responses across between block type and compatibility. The y-axis represents the proportion of correct responses for compatible trials and incompatible trials. The error bars represent the upper and lower bounds of the 95% confidence interval.

Moreover, Figure 5 illustrates the observed patterns in the data for block type, feature, compatibility, and accuracy. It shows that in compatible orientation trials (95.5%), participants were slightly more accurate than in the incompatible equivalent (95.2%). Similarly, in compatible shape trials (96.2%), participants were more accurate compared to incompatible trials (95.7%) of the same feature. Post hoc analysis showed no significant effect for the trials in the orientation feature, $t(19) = 0.61$, $p = .998$, and for the shape feature, $t(19) = 0.548$, $p = .999$.

Figure 5

Average Accuracy Across Block Type, Feature, and Compatibility



Note: This Figure depicts the average accuracy of feature and congruency for each block type. The top portion illustrating the difference RT's between compatible and incompatible trials divided by block type. While the lower portion decomposes these further into orientation and shape trials. The error bars represent the upper and lower bounds of the 95% confidence interval.

Mixed blocks

To analyse the mixed block a 2x2x2x2 RM-ANOVA was conducted to examine the effects of location congruency, feature, and response compatibility and task switch (no-switch vs. switch) on RT and accuracy. The ANOVA revealed significant main effects for all factors on RT, except for congruency, which was marginally significant for RT, $F(1,19) = 3.89$, $p = .06$, ηp2 = .17 as well as for accuracy, $F(1,19) = 3.75$, $p = .068$, ηp2 = .165. Participants were marginally reacting faster in congruent trials (*M* = 638 ms, SD = 264 ms) compared to incongruent trials (M = 648 ms, SD = 262 ms), as well as less accurate in incongruent trials (M = 91.6%) compared to congruent (M = 93.3%).

Furthermore, the effects of feature were significant, F(1,19) = 43.91, p < .001, ηp2 = .698. In the mixed blocks participants were significantly faster in reacting to shape (*M* = 585 ms, *SD* = 256 ms) compared to orientation (*M* = 703 ms, SD = 268 ms). Furthermore, participants were also less accurate - but not significantly, F(1,19) = 0.15, p = .70, ηp2 = .008, - in shape (M = 92%) than in orientation trials (*M* = 93%).

Additionally, there was a significant compatibility effect on RT, F(1,19) = 9.85, p = .005, ηp2 = .341, Participants were significantly faster for the compatible trials (*M* = 633 ms, *SD* = 282 ms) in comparison to incompatible trials (*M* = 653 ms, *SD* = 292 ms). Similarly, for accuracy there was also a significant main effect of compatibility, *F*(1,19) = 43,21, p < .001, ηp2 = .695, showing that participants were significantly less accurate in incompatible trials (88.7%) than in compatible trials (96.2%). Lastly, for task-switch there was a significant main effect on RT, *F*(1,19) = 33.84, *p* < .001, ηp2 = .64, as well as marginally for task switch on accuracy *F*(1,19) = 3.57, *p* = .074, ηp2 = .158.

As Figure 3 depicts the average RT across block type, feature and congruency it also shows the mixed block section, showing that there was not a high difference in RT for incongruent (*M* = 703 ms, *SD* = 290 ms) and congruent trials (*M* = 702 ms, *SD* = 292 ms) in the feature orientation, while a higher difference was observed between incongruent (*M* = 596 ms, *SD* = 270 ms) and congruent trials (*M* = 575 ms, *SD* = 273 ms) in the shape feature of the mixed blocks. Post-hoc analysis revealed significant effects for the mixed block in shape, t(19) = −3.414, p = .048.

Moreover, Figure 4 illustrates the interaction effect of block type and compatibility for the mixed block. In contrast to the pure block, in which no significant difference between compatibility was revealed. Participants reacted significantly, as indicated by post hoc analysis t(19) = 6.22, p < .0001, less accurate in the incompatible trials than in compatible trials in the mixed blocks.

Lastly, Figure 5 depicts the mean accuracy divided by block type, feature, and compatibility. In the mixed block, participants were less accurate in incompatible orientation trials (90.%) compared to compatible trials with the same block type of the same feature (95.7%). A similar pattern was observed in incompatible trials (87.3%) of the shape feature in the mixed block, compared to compatible equivalent (96.7%). Post-hoc analysis revealed a significant difference between mixed blocks compatible and incompatible shape trials, t(19) =

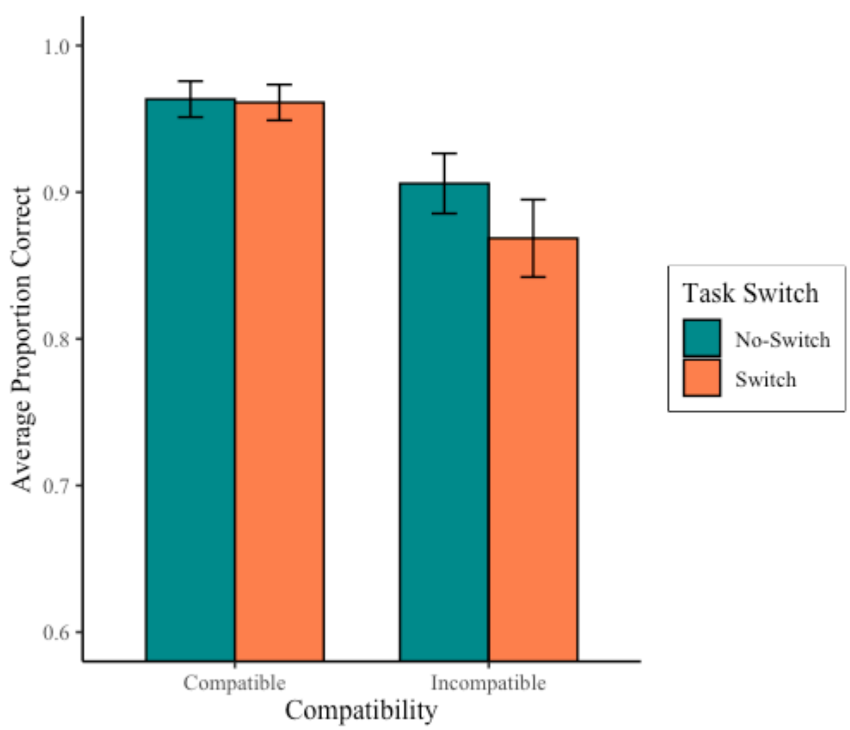
6.1, p < .0001, as well as between compatible and incompatible orientation trials in the mixed block, *t(*19) = 4.477, *p* = .005.

Additionally, the ANOVA revealed a three-way interaction effect between feature, congruency and compatibility *F*(1,19) = 8.66, *p* = .008, ηp2 = .313. Post-hoc analysis revealed no meaningful significance. The ANOVA also revealed a significant interaction effect between feature and compatibility on accuracy, *F*(1,19) = 5.49, *p* = .030 ηp2 = .224, for compatibility and task switch, *F*(1, 19) = 5.23 *p* = .034, ηp2 = .216, as well as a three-way interaction between feature, compatibility, and task switch, *F*(1, 19) = 6.31, *p* = .021, ηp2 = .249.

Figure 6 displays the average accuracy for compatibility and task switch trials. Participants showed in compatible trials similar accuracy, regardless of a switch or no switch prior to the trial, with an average of 96.3% correct responses for compatible no switch trials, and an average of 96.1% for compatible switch trials. Moreover, in incompatible trials, participants were less correct in their responses to switch trials (M = 86.9%) compared to no switch trials (M = 90.6%). This observation is in line with the second and third hypothesis dealing with residual switch costs, and the compatibly, respectively. Post-Hoc analysis revealed that the difference between compatible and incompatible trials bordered significance, *t*(19)= 2.79, *p* = .053.

Figure 6

Mean Accuracy by Task Switch and Compatibility in the Mixed Block

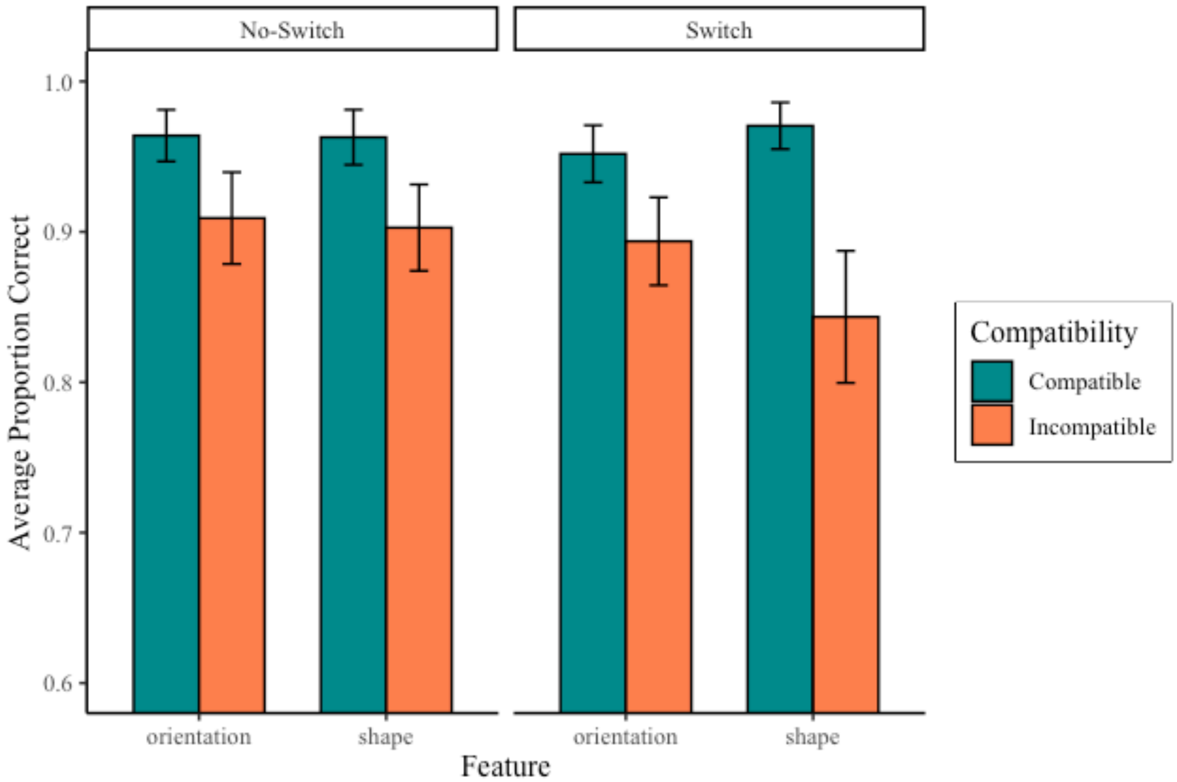


Note: Figure 6 shows the mean Accuracy by compatibility and task switch. The y-axis represents the proportion of correct responses while the x-axis represents the level of compatibility, divided by whether or not the trial was a switch trial or not. The error bars represent the upper and lower boundaries of the 95% confidence interval.

Figure 7 depicts the average accuracy across feature, compatibility, and task switch. Participants were more accurate in compatible, no switch orientation trials (M = 96.4%) while they were less accurate in incompatible, no switch orientation trials (M = 90,9%). Similarly, participants were more accurate in no switch compatible shape trials (M= 96.3%), than in no switch incompatible shape trials (M = 90.3%). A similar pattern is visible for switch trials: for compatible orientation switch trials, participants were more accurate (M= 95.2) compared to incompatible orientation switch trials (M= 89.4%). For switch compatible shape trials, participants had a mean accuracy of 97%, while in incompatible switch shape trials they had an accuracy of 84.3%. These observations are also in line with the second and third hypothesisPost-hoc analysis revealed that all differ significantly, $t(19) = 4.48$, $p = .005$ for no switch compatible orientation trials compared to no switch incompatible orientation trials. Similarly for shape with no switch and compatibility, compared to the incompatible equivalent, $t(19)= 4.03$, $p = .013$. For switch orientation trial comparing compatible and incompatible switch orientation trials, $t(19)= 3.62$, $p = .03$ Lastly, a compatible shape trial with switch compared to a shape incompatible trial with also switch differed also significantly, $t(19) = 6.83$, $p < .0001$.

Figure 7

Mean Accuracy Across Compatibility, Feature, and Task Switch.



Note: This figure displays the interaction effect of feature, compatibility, and task switch. The x-axis shows the average proportion of correct responses for compatible and incompatible trials, divided by the feature and between no-switch and switch. The error bars represent the upper and lower boundaries of the 95% confidence interval.

Discussion

The aim of the present study was to examine how manipulating the requirements of a Simon task, guided by the theoretical framework of the affordance competition hypothesis (ACH; Cisek, 2007), would be reflected in the reaction times (RT) and the accuracy of participants. Specifically, the competing interplay between the natural affordance - the Simon effect - and acquired affordances, represented by the newly learned stimulus-response links, was investigated. The introduction of a task-switching paradigm, as well as incompatibility among responses, was used to observe how these affordances compete and ultimately affect the performance of the participants.

Natural Affordances/Congruency

First, it was hypothesized that the natural affordance - congruent trials - would, throughout the experiment generate shorter RTs than incongruent trials. The results do seem to affirm this hypothesis, which is in line with the literature regarding the Simon effect (Simon, 1990; De Jong et al., 1994; Hommel, 2011; Proctor, 2011; Hübner & Töbel, 2019). In the current study, participants reacted faster to the stimuli spatially congruent to their required response than to spatially incongruent stimuli. This main effect was visible in the pure blocks as well as in the mixed blocks, while in the mixed blocks the effect was only marginally present. This is in line with the hypothesis showing that increased task demands lessen the effect of congruency.

These marginally mixed effects may be further explained by the interaction of the other factors involved. Figure 3, for example, illustrates the interplay of the block type demands, the feature and congruency. In pure blocks the natural affordance was present to relieve the competition, in orientation trials, demonstrating shorter RTs for congruent trials compared to incongruent trials. However, in mixed blocks, the same effect was present for shape trials but not for orientation trials. From the perspective of the ACH, it could be that the increased competition induced by the mixed blocks demands, like for example the interference of the residual activation of the previous affordances seems to weaken the impact of spatial congruency in resolving the competition among the affordances in the orientation tasks. Thus it seems that the increased complexity and the in turn heightened competition led to overall more inhibition. This could also explain the natural affordance in the mixed shape trials. The increased competition seems to call in this instance for the easiest way to resolve said competition which for shape trials in mixed blocks seems to be the natural affordances and thus the overall inhibition weakens the weight of the acquired affordances. This switch of preference in affordances seems to be induced by the mixed block demands and the higher competition and inhibition.

Furthermore, as shown in Figure 2 the interaction of congruency, feature, and compatibility (i.e., whether the acquired response to shape and orientation was the same) reveals further complexity of the interplay. For congruent trials, RTs for compatible and incompatible orientation trials were similar, suggesting efficient competition resolution, based on congruency of responses rather than compatibility indicating the effect of the natural affordances.

Conversely, once the natural affordance is not a valid/effective option, namely in incongruent trials, the participants are faster in compatible orientation trials compared to incompatible trials. This suggests that, once congruency is not a given, the compatibility of the acquired affordances prevails as the easiest way to resolve the competition. A similar tendency is visible in shape trials, but not significantly. Overall, these findings suggest that there are different competition resolution strategies that are being employed when weighing compatibility, feature and their influence on modulating the natural affordance in the competition evaluation process.

Task Switching

The second hypothesis dealt with the residual switch costs observed in the task-switching paradigm and how these costs are linked to the residual activation of previous affordances. It is hypothesized that inhibiting the remains of previous affordances sets while activating new ones results in slower reaction times and higher error rates immediately following a task switch (Monsell, 2003; Ellefson et al., 2006; Schmitz & Krämer, 2023). The results of this study affirm this expectation, as they are less accurate in the mixed block and have slower reaction times overall. Showing that the previous activation link of the affordance (n-1) interferes with the present affordance (n) posing as an aspect to be inhibited while concentrating on the new task.

Figure 6 further illustrates this by showing the interaction between compatibility and task switch trials. In compatible trials, participants maintained high accuracy regardless of a switch, suggesting efficient resolution of affordances even when switching tasks. This aligns with the ACH, as it demonstrates that when affordances are compatible, the brain is able to easily transition between tasks, effectively dealing with the competition between affordances. Thus the alignment of acquired affordances seems to facilitate a smoother resolution of the competition, reducing the complexity and mitigating the impact of task switching.

Notably, however, Figure 7 shows that participants were less accurate in the shape trials within the mixed blocks compared to the orientation trials, despite shape trials being easier for participants, as shown by higher speed and accuracy in the pure blocks. Conversely, the orientation trials, which were more challenging, did not show this high decrease in accuracy. This observation could be explained by asymmetrical switch costs (Ellefson et al., 2006). According to Ellefson et al. (2006), asymmetrical switch costs are observed when switching between two tasks that vary in difficulty, with higher switch costs occurring when switching to an easier task from a harder one. This might explain the unexpected accuracy results in shape versus orientation trials.

This explanation still aligns with the ACH. From the perspective of the ACH, it might be that the acquired affordance activated by the orientation task, due to its difficulty, requires more inhibitory cognitive resources and exhibits more residual switch cost, which makes the residual activation more severe and prolonged. These demands of the harder orientation affordance therefore persist and interfere with the subsequent shape task. This increased competition caused the need to suppress the remains of orientation affordance, which led to higher error rates and reduced accuracy in the shape trials during the mixed blocks. This could explain why participants perform worse in the easier shape task under these conditions.

In a similar vein the third hypothesis dealt with the residual switch costs of the responses of the other irrelevant acquired affordances and how these compete with each other in the mixed blocks. It was hypothesized that an alignment - compatibility - of the responses of the two affordances would facilitate shorter RTs as well as more accuracy, while the incompatibility would increase the reaction time and decrease accuracy (Verbruggen et al., 2004; Hommel, 2011; Wright, 2016). The results of this study are to some extent in line with the expectations. Overall there was a significant main effect of compatibility in the mixed trials, which is noticeable by the increased error rates as well as the increased reaction times for incompatible trials.

Surprisingly, however, there was also a significant main effect of compatibility in the pure blocks, as well as a three-way interaction with feature, compatibility, and block type. This suggests that the incompatibility stimuli carried competition resolving information, even when it theoretically should not, as shown by the significant main effect in the pure blocks. It is possible that line orientation provided spatial information cues, akin to arrows (Luo & Proctor, 2020), introducing a new form of affordance that interferes with the competition process. Similar observations were made by Van der Lubbe, et al., (1996) in an experiment using lambda as targets, due to the pointy orientation of the letter similar interaction effects emerged. This is further underlined by the difference in incongruent incompatible orientation trials elaborated upon before. Here if the trial is congruent the compatibility played a little role in reacting, this could mean from the perspective of the ACH, that the spatial congruency signaled by the congruent trials might be more effective in weighing the evaluation process of the competition, than the potential arrow like spatial information shown by the lines. Without such congruence, line orientation “arrows” could have served as a substitute spatial cue.

Additionally, in incompatible trials, accuracy significantly dropped in switch trials compared to no-switch trials, highlighting the increased competition from residual switch cost activation of previous affordances responses. These residual responses shows that irrelevant affordance are still active and must be inhibited to resolve the new task's demands. This scenario aligns with the ACH's, illustrating that the brain struggles more with reaching consensus when affordances are incompatible, particularly post switch. The necessity to inhibit the previous, irrelevant residual affordance and activate the new one increases the competition and results in lower accuracy.

Overall, the ACH seems to serve as a pertinent framework to interpret how we select which action to take. Showing through a dynamic and continuous weighing process how different competition between multiple affordances posed by the environment, may be resolved. Its utility is particularly evident when considering the complex paradigms and interplay between interactions, such as task switching costs, congruency and compatibility.

Limitations

A limitation of this study could be the differences in difficulty between the orientation feature and the shape feature. If one feature is inherently more challenging than the other, it may introduce an unwanted bias that could affect the results. For example, if the orientation tasks are harder than the shape tasks, participants might exhibit slower reaction times (RT) and lower accuracy solely due to the increased difficulty of the feature, not due to the competition among affordances, or only slightly. Such an imbalance could skew the results, making it difficult to link the data to the proposed theoretical framework. Therefore, it would be ideal to use features that are similar in difficulty, for example, colour and shape.

Similarly, line orientation might provide a spatial cue to participants, similar to an arrow (Van der Lubbe, et al., 1996; Luo & Proctor, 2020). This assumption is based on the results and feedback received from participants after the experiment, explaining the strategies they used to answer correctly and fast. Some participants mentioned therefore that they frequently used strategies such as associating the lines with spatial directionally cues such as: going up, down, left, or right. This could again bias the observed data.

Future Research

This study solely investigates the outward behavioural characteristics of the affordance competition hypothesis (ACH) in an experimental setting. Through this, a key aspect of the ACH remained untouched, namely, the neurophysiological underpinnings of it. In this vain, it would be compelling to conduct an EEG study to investigate the activation of different affordances in the Simon task, particularly focusing on the interval before instruction or cue, the delay phase, similar to Cisek (2007) with primates and Calderon et al. (2015) with humans. It would be particularly interesting to do so with a task-switching paradigm. Theoretically, this could potentially illustrate how residuals of affordances remain active to prepare for the coming unknown trial. This could enhance our understanding of the neural mechanisms underlying action selection and cognitive control, providing valuable information on how the brain resolves competition among multiple affordances in real time.

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