THE CATEGORIC AND METRIC INVESTIGATION OF ACTION SELECTION USING THE FEATURE REPETITION PARADIGM

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The Categoric and Metric Investigation of Action Selection Using,

the Feature Repetition Paradigm

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DECLARATION OF ORIGINALITY

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ABSTRACT

The Categoric and Metric Investigation

of Action Selection Using the Feature Repetition Paradigm

Theory of Event Coding (TEC) suggests that all stimulus features and associated action patterns are bound together in an event file, which is reactivated even when a single feature therein is repeated. Partial repetition cost is the decrease in performance when some features of a stimulus-response pair are repeated in the next pair as opposed to the complete repetition or alteration of the features. Currently, a contradiction in the literature is that studies using metrical rather than categorical features fail to replicate the effect. Since TEC does not discuss the effect of different feature types (categorical versus metrical) on action selection, this thesis aimed to investigate the role of stimulus type in the formation of action files using metrical (luminance, duration, speed) and categorical (hue, shape) features in nine combinations in forced-choice and estimation tasks in which participants responded to the task-relevant feature with a keypress or mouse movement, respectively. Performance was analyzed based on the intertrial feature repetition/change. The results demonstrated that the inclusion of features in event files depends not only on task-relevancy and saliency, reaffirming the literature, but also on the type of stimulus feature (metrical versus categorical) and response (forced-choice versus continuous). In forced-choice tasks, categorical features were prioritized over metrical ones and only completely categorical stimuli varying in hue and shape showed a TEC-congruent pattern. Results from the estimation tasks could be explained by a common magnitude system in the dorsal visual stream.

ÖZET

Hareket Seçiminin Özellik Tekrarı Paradigması ile Kategorik ve Metrik İncelemesi

Olay Kodlama Teorisi (TEC) bir uyaran-tepki ikilisindeki tüm uyaran ve hareket özelliklerinin bir olay dosyasında bağlandığını ve bir özellik bile tekrar edildiğinde tüm dosyanın aktifleştiğini iddia eder. Kısmi tekrar hasarı, bir uyaran-tepki ikilisindeki uyaran ve motor hareket özelliklerinin bazılarının bir sonraki ikilide tekrar etmesi durumunda, tamamının tekrar etmesi veya değişmesine kıyasla görülen performans düşüşüdür. Metrik özellikler kullanan çalışmaların etkiyi tekrarlayamaması literatürde tespit edilen bir çelişkidir. TEC literatüründe farklı uyaran çeşitlerinin (kategorik veya metrik) hareket seçimine etkisi tartışılmadığı için bu tezde, uyaran çeşidinin olay dosyalarındaki rolü; metrik (parlaklık, süre, hız) ve kategorik (renk, şekil) uyaran özellikleri dokuz çiftte eşlenip, katılımcıların görevle ilgili uyaran özelliğine tuşa basarak (zorunlu tercih görevi) veya bilgisayar faresini hareket ettirerek (değerlendirme görevi) tepki verdiği görevlerde incelenmiştir. Katılımcı performansı, denemeler arası özellik tekrarı/değişimi üzerinden analiz edilmiştir. Sonuçlar, uyaran özelliklerinin olay dosyalarına dahil edilmesinde sadece görevle ilgililik ve dikkat çekicilik değil uyaran (kategorik/metrik) ve hareket (zorunlu tercih/sürekli) çeşidinin de önemli olduğunu göstermiştir. Zorunlu tercih görevinde kategorik özelliklerin öncelikli olduğu ve sadece tamamen kategorik uyaranların (renk ve şekilleri değişen) TEC'ye uygun sonuçlar verdiği gözlemlenmiştir. Değerlendirme görevinin sonuçları ise dorsal görsel yolakta bulunan bir ortak büyüklük sistemi ile açıklanabilir.

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CHAPTER 1

INTRODUCTION

Sensory stimuli in our environment are most often associated with certain actions. When we hear the doorbell ring, for example, we rise from our seats to open the door. The traffic light turning green, in another case, signals us to cross the street. Apart from these long-term, established associations between stimuli and responses, research has shown that even a single experimental trial may be enough to form short-term connections (Hommel, 1998). When these associations are violated - even by task-irrelevant stimulus features -, reactions become slower and more erroneous (Fitts & Seeger, 1953; Hommel, 1998; Simon & Rudell, 1967). The theory of event coding (TEC; Hommel, 2019; Hommel et al., 2001) suggests that the features of sensory stimuli and following actions in a stimulus-response episode are temporarily bound together in an “event file” and that the selection of the following action is determined by the connections formed between these stimuli and actions. Which or what type of stimulus features are given more weight in forming event files and hence, action selection, though, is still a controversial question that requires further investigation.

1.1 Stimulus-response associations

Strongly established, long-term connections between stimuli and actions such as picking up the phone when we hear a notification are called “stimulus-response associations" and are among the factors that guide our daily actions by automatically triggering certain responses. Because of these automatic processes, in experimental settings, instructing participants to respond to stimuli in a manner incompatible with

their readily established associations is known to slow down the response times, a finding which was originally demonstrated by Fitts and colleagues (Fitts & Deininger, 1954; Fitts & Seeger, 1953). In these early works, participants were instructed to point to a location in a spatial configuration (e.g. a circle) either compatible (e.g. down) or incompatible (e.g. up) with the one indicated by a particular visual cue (e.g. a digital clock indicating 6.00 o'clock), where the incompatibility between the stimulus and the response resulted in slower responses. Later studies have shown that this effect is not only limited to the spatial domain, but also applies into the temporal domain, where participants respond to a long interval using a rather brief keypress or vice versa (Grosjean & Mordkoff, 2001) or to an intense signal with a weak handgrip and vice versa (Romaiguère et al., 1993). The contradictory relationship between the magnitudes of sensory stimuli and the duration or intensity of the action in these studies all led to slower response times as opposed to conditions, where the relationship was rather matched.

One experimental paradigm, where the association between stimuli and responses are clearly observed is the Simon task (Simon, 1982; Simon & Rudell, 1967), in which the task-irrelevant spatial cues such as the location of the stimulus or a monaurally presented task-irrelevant sound affects action selection. When the task-irrelevant cue is congruent with the required response, participants react faster. The same effect can also be seen when participants are asked to react to discrete stimulus colors with either a short or long keypress irrespective of the stimulus duration, taking shorter or longer durations irrelevant to the task (Kunde & Stöcker, 2002). In this setup, when participants are instructed to make a longer keypress after a short stimulus or a shorter keypress after a long stimulus, they initiate the action slower and make more mistakes as opposed to conditions with congruent pairings.

1.2 Stimulus-response associations in a single repetition

In addition to stimulus-response compatibility (Fitts & Deininger, 1954; Fitts & Seeger, 1953; Grosjean & Mordkoff, 2001; Romaiguère et al., 1993) and Simon effects (Kunde & Stöcker, 2002, Simon, 1982; Simon & Rudell, 1967) which demonstrate that long-term, established stimulus-response associations influence action selection, there is evidence that random stimuli and responses can also be bound with one another even in a single trial (Hommel, 1998). In Hommel's experimental paradigm, participants were presented with a precue (P) that determined whether to react using the left or right keypress, followed by a go-signal (S1), the form, color and location of which could vary between two different levels. The instruction was to react according to the precue (P) with either a left or right keypress as soon as the go-signal (S1), the stimulus features of which (i.e. form, color and location) were asked to be disregarded appeared on the screen. After the participant has responded (R1) to the go-signal (S1) with the keypress indicated by the preceding cue (P), another stimulus (S2) has appeared, the form, color and location of which could also vary freely between two levels. This time, the form of the stimulus (S2) was relevant to the task, though, such that the participant was instructed to respond with a lateral keypress (R2) based on the form of S2 (in Experiments 1 and 3, or its color in Experiment 2). Color and location of S2 was uninformative, thus, they were allowed to be ignored according to the instructions. Hommel's assumption which is also the basis of TEC (Hommel, 2019; Hommel et al., 2001), was that due to the temporal proximity between S1 and R1, the task-relevant and -irrelevant features of S1 would not only be bound with each other to form an "object file" (Kahneman et al., 1992), that represents each object by a spatial

index, but would also be bound with the following R1 to form an “event file”, which additionally includes action patterns directed onto that object. If that were the case, indeed, it would suggest a high degree of autonomy and automaticity of event integration. The reaction time and accuracy of R2 were analyzed based on whether the features of S1 (form, color, location) and R1 were repeated or changed in the S2 and R2 relationship. In line with the idea of an event file, participants showed the best performance in two specific conditions (1) when all features of the S1-R1 pair were fully repeated in the S2-R2 pair and (2) when all features were rather alternated. In the former case, according to the theory, the event file could be quickly re-activated to trigger R2 since all features were common between the S1-R1 and S2-R2 episodes. Similarly, in the latter, the newly activated features in the S2-R2 episode could also connect with each other quickly but this time it is because none of these items were occupied by a previously formed event file. What was the most interesting condition was when the features were repeated partially, where subjects demonstrated the worst performance due to the “partial repetition cost” (Fig. 1). Hommel and colleagues claimed that when some features were repeated and others were not, the repeated features re-activated the old event file while the new features triggered the formation of a new one. This conflict required some time to be resolved and led to erroneous responses through the spreading activation in the event files (Frings, Hommel, et al., 2020; Frings, Koch, et al., 2020; Hommel, 1998; Hommel, 2004). The spreading activation account was also supported by an EEG neuroimaging study (Kühn et al., 2011) in which participants responded to a precue with a left-hand or right-hand keypress after a go-stimulus which was either a house or a face photograph. Researchers analyzed the activation of left and right motor cortices, parahippocampal place area and the fusiform face area based on the

repetition and alternation of features. For instance, after a house picture and a right-hand response are connected, repeating the house picture in the next trial activated the left motor cortex. These results demonstrated that neural activation also supports TEC's claim that stimuli and the responses following them are bound together in an event file and that the replication of an item from this file triggers the entirety of the file.

1.3 Metric features in stimulus-response associations

Though the findings of Hommel (1998) were replicated several times with different clinical populations (Colzato et al., 2012; Zmigrod et al., 2013), age groups (Hommel et al., 2011), fluid intelligence levels (Colzato et al., 2006), and in an inter-lab collaborative replication study with more than a hundred participants (Janczyk et al., 2023) and TEC could explain partial repetition costs when Hommel's (1998) original paradigm was used, experiments with slightly different methodologies yielded some results that could not be explained by the basic assumptions of TEC. Bogon and colleagues (2017), for instance, tried to replicate partial repetition costs by incorporating duration as a task-irrelevant feature to test whether duration, as a feature, could also be included in the event files formed in the auditory domain. Their results demonstrated that loudness and duration interacted in line with the predictions of TEC, whereas the alternation of pitch eliminated the effect of duration. In another study (Zmigrod & Hommel, 2009), where loudness and pitch were used as stimulus features, pitch was found to be integrated into the event file even when it was irrelevant to the task but loudness, as a task-irrelevant feature, did not interact with action patterns. Since TEC does not make a claim with respect to the different weights given to different stimulus features in the event files, the core assumptions of

TEC are not capable enough to explain these confusing results. Here, we suggest that the reason why different kinds of stimulus features interact with action patterns in a dissimilar manner may be rooted in the way sensorimotor integration takes place in the brain for metrical versus categorical properties.

There is evidence showing that loudness and duration are both processed in the parietal cortex (Alexander et al., 2005; Belin et al., 1998; 2002) while pitch is processed in the temporal cortex (Griffiths & Hall, 2012). This distinction is also congruent with the dual stream model of auditory processing (Ahveninen et al., 2006; Alain et al., 2001; Arnott et al., 2004; de Santis et al., 2007; Kaas & Hackett, 1999; Maeder et al., 2001; Rauschecker & Tian, 2000; Tian et al., 2001; Warren & Griffiths, 2003) in which "what" and "where" information relating to a sound is processed in parallel in the ventral and dorsal streams, respectively. This dual pathway structure was first proposed in the visual system based on the increased fMRI signal of the parietal and temporal lobes during location change detection and identity change detection tasks, respectively (Mishkin et al., 1983). Later studies have demonstrated that the two streams in the visual system are not just segregated in the cortex, but begin as separate pathways in the retina. Rod cells transduce luminance/light intensity and this activation travels downstream through parasol retinal ganglion cells, the magnocellular layers of the lateral geniculate nuclei of the thalamus, Layers 4Cα and 4B of the primary visual cortex V1, and reach the parietal lobe via the occipito-parietal/dorsal or "where" pathway. Short, mid or long wavelength-sensitive cone cells respond roughly to blue, green and red light. This hue-related information is processed further in midget retinal ganglion cells, the parvocellular and koniocellular layers of the lateral geniculate nuclei, Layers 2 and 3 of V1 and finally in the occipito-temporal/ventral or "what" pathway (Cloutman,

2013; De Valois et al., 2000; Livingstone & Hubel, 1988; Ungerleider & Haxby, 1994; Vaina, 1994; Wiesel & Hubel, 1966). Behavioral and neural data support the idea that metric features like location in space, motion direction, speed, duration, size, amount, number, luminance and loudness are processed in the parietal lobe, using a common magnitude system within the dorsal pathway (Alards-Tomalin et al., 2015; Ayhan et al., 2009; Bueti & Walsh, 2009; Burr et al., 2010; Gulhan & Ayhan, 2019; Serrien & Spapé, 2022; Walsh, 2015) as is suggested by a theory of magnitude (ATOM; Walsh, 2003). The proposition that hue and shape information is processed in the ventral pathway and the temporal lobe is also supported by neuroimaging studies (Liu et al., 2020; Pulvermüller & Hauk, 2005). Therefore, within this thesis, the terms "categorical" and "metrical" will be used interchangeably with "ventral" and "dorsal" respectively.

To explain the controversial findings in the motor-visual priming studies, in 2012, Thomaschke and colleagues proposed the planning and control model (PCM) which suggests that when an action and a coinciding metric feature of a stimulus are congruent, the stimulus is perceived and reacted to faster than when the congruent action-stimulus pair is categorical, which, contrarily leads to an impairment in the perception of the stimulus (for a detailed review, see Thomaschke, 2012). According to the PCM, categorical stimulus features like color and shape are used in "action selection" and when they are bound with a selected action, their connections with other cognitive processes are inhibited, leading to an impaired perception when an action feature is congruent with a co-occurring stimulus feature. Metric features, on the other hand, are used for "action control" and their connections with other processes are not inhibited but enhanced during action execution, resulting in an improved/faster perception of a stimulus sharing a congruent feature. In the context

of ATOM and PCM, in the current behavioural study, for the first time in the literature, we aim to systematically investigate the role of categorical versus metrical visual features, known to be physiologically processed either in the ventral or dorsal pathways in the brain, in forming single-trial-based short-term associations with specific actions.

1.4 Continuous actions

So far in the literature, the feature repetition paradigm and partial repetition cost studies focused solely on categorical (and mostly dichotomous) actions. Our literature review on a continuous response feature – namely, response duration, yielded only two studies. Mocke and colleagues (2022) used response duration in a two-alternative forced-choice task to measure action-action interaction in a delayed response task, which is outside the scope of the current study. Pfister and his group (2022), on the other hand, measured response duration as an irrelevant response feature while the participants were pressing left or right keys to see if an irrelevant metric response feature is also encoded within the same event file. They showed that when all stimulus features in a previous trial are repeated in the current trial, participants generate similar response duration to that in the previous trial, suggesting that response duration could also be re-triggered alongside the other features in an event file. There are, to the best of our knowledge, no studies focusing on the selection of continuous actions using the feature repetition paradigm. The lack of continuous actions in the literature poses a problem in the interpretation of the results. Since TEC suggests that actions are encoded in the brain with their sensory precedents and consequences, it would be a reasonable conclusion to state that categorical and continuous actions are selected based on categorical and metric

stimulus features, respectively. If this is the case, the prevalence of categorical stimulus features can be due to the categorical nature of the actions rather than categorical stimulus features having inherently more weight in the action selection processes.

In opposition to PCM, many other models and theories of action selection turn the spotlight on the dorsal pathway and parietal cortex processing. Cisek (2007), for instance, in his affordance competition hypothesis, proposes that the dorsal visual stream creates a list of affordances, i.e. possible actions towards an object, by using the metrical features such as location, size and orientation. These affordances, then, compete against each other through lateral inhibition in the dorsal pathway to trigger a single action. Our research group (Joy et al., 2022) has previously shown that eliminating the graspability affordance by making the hand avatars in the virtual reality unable to grasp led participants to react quicker compared to the condition, where the participants were assigned normal, capable hand avatars. The elimination of the graspability affordance in this setup sped up the competition in the parietal cortex, leading to faster reaction times in the capsule hand condition, providing further support for Cisek's affordance competition hypothesis. In fact, in 1992, Goodale and Milner reported that parietal lobe damage leads to motor problems like ataxia but temporal lobe damage leaves action-related processes mostly intact but impairs object recognition. They, hence, concluded that the dorsal pathway is better characterized as a "how" pathway rather than a "where" pathway as previously suggested by Mishkin and Ungerleider (1982). This idea is further developed by Rauschecker (2018) who suggested that the dorsal streams of different modalities merge in the parietal cortex to form a unified sensorimotor interaction system. All of these models expect some input from the ventral stream to the dorsal stream,

especially for complex actions or actions that require semantic knowledge about the object (see Cloutman, 2013 for a review of cross-pathway interactions) but the selection process is still centralized in the dorsal stream.

1.5 The present study

The major aim here is to examine how ventral/categorical (hue and shape) and dorsal/metric (luminance, duration, speed) features differ in their involvements in forming event files by investigating how partial repetition costs differ based on categorical vs metrical features in different action types. The study was based on the methodology of Bogon and colleagues' (2017) experimental paradigm. The forced-choice experiments closely followed their methodology with two key differences: 1) we used visual instead of auditory stimuli and 2) we determined the two levels of each feature by measuring the individual discrimination thresholds through psychophysical experiments and multiplying them by a constant in order to ensure that the subjective differences between the two levels of each feature are perceptually equated across different conditions, a crucial experimental control which have been ignored in the previous literature. The estimation experiments, on the other hand, did not employ psychophysical methods but the stimuli were generated randomly on a continuous scale instead of on two categorical levels.

With the basic assumptions of TEC, features cannot be distinguished based on their tendency to interfere with action selection as irrelevant features since there is no claim as to how different features differ in the strengths of feature-response or feature-feature bindings. PCM, an extension of TEC, suggests that categorical features should take precedence during action selection. This would mean that, in the forced-choice task, fully categorical stimuli (varying in hue and shape) would result

in the partial repetition cost pattern predicted by TEC i.e., partial repetition conditions (relevant feature repetition + irrelevant feature alternation; relevant feature alternation + irrelevant feature repetition) will have higher reaction times than complete repetition and complete alternation conditions. Another implication of PCM is that a task-irrelevant metric feature would not lead to a partial repetition cost when paired with a task-relevant categorical feature. Since metric stimulus features are processed in the same magnitude system as ATOM suggests, one can expect that fully metric stimuli would show some sort of interaction since they are processed by a common system but the exact nature of this interaction is hard to ascertain. If PCM's claim that categorical stimulus features are used for action selection is correct, the results of both tasks should be similar and the completely categorical experiment with hue and shape as stimulus features should show stronger interactions. However, if the important feature type is determined by action type, partial repetition-like effects should not be seen in the hue-shape experiment and the combination of metric features should show the most consistent interactions.

CHAPTER 2

FORCED-CHOICE TASKS

2.1 Methods

2.1.1 Participants

23 participants took part in nine within-subject experiments but one participant was excluded from the analyses because their error rate reached up to 50% in some conditions. The resulting sample of 22 had a mean age of 24.5 (*SD* = 8.55, range = [19 58]) and consisted 59.1% of women. The study was compliant with the Bogazici University research ethics requirements (Appendix A), as well as the Declaration of Helsinki. All participants read and signed the consent form (Appendices B and C) and agreed to participate in the study.

Using MorePower 6.0.1 (Campbell & Thompson, 2012), we have concluded that a sample size of 14 was enough to detect an interaction effect with a .4 partial eta-squared (smaller than Bogon et al. 2017's effect sizes whose methodology is taken as the base for the current study) in a 2x2 repeated-measures ANOVA. Since we expect to see smaller interactions when categorical and metric features are combined, we aimed to surpass 14.

2.1.2 Apparatus

The experiments were run in a dark and sound-attenuated room in Vision Lab at Boğaziçi University. The experimental stimuli and tasks were programmed on MATLAB using Psychtoolbox (Brainard, 1997). The stimuli were presented on an LED monitor (Eizo Foris FG2421 with 120 Hz frame rate and 1920x1080 pixel resolution) calibrated with a Spyder4 calibration device. The participants were seated

50 cm away from the monitor and their heads were resting on a chinrest to minimize head movements.

2.1.3 Stimuli

The stimulus presented to the participants was a circular array of 400 dots with a .3-degree radius (or plus shapes with the same surface area in one experiment). The array had a 10-degree radius and the dots were moving either towards or away from the center with a constant speed. In each frame, 5% of the dots were destroyed and reappeared in a random position in the array area. A white fixation point was present during the course of the experiment at the center of the screen. The background was gray with a 33% luminance in all experiments. The colors of the stimuli were created based on the CIELAB color space (Kovesi, 2015) to better control their luminance.

2.1.4 Procedure

After participants have read and signed the informed consent form and demographic data (age, gender, self-reported handedness) were recorded, they took part in three types of experiments in the following order: three-down-one-up psychophysical procedure (3D1U), a staircase procedure with a confirmation algorithm, and the feature repetition experiments. Four (3D1U) experiments were run for the determination of the discrimination thresholds for luminance, duration, speed and hue. The thresholds were used to calculate the higher levels of stimulus features for each participant to ensure that differences between levels were perceptually equal for each participant. Since faster stimuli are perceived to be longer in duration (Kanai et al., 2006; Kaneko & Murakami, 2009), a staircase procedure was run to measure the point of subjective temporal equality between different speed levels and shorter

stimuli were lengthened to equate their perceived durations to those of faster stimuli. After the psychophysical procedures, the nine feature repetition experiments were conducted in a counterbalanced order (luminance-duration, duration-luminance, luminance-speed, speed-luminance, duration-hue, speed-hue, hue-duration, hue-speed, hue-shape).

2.1.4.1 Psychophysical measures

The first type of psychophysical experiments were conducted to find individual difference thresholds for luminance, duration, speed and hue using a three-down-one-up (3D1U) procedure (Levitt, 1971), modified to quickly approach the threshold (Amitay et al., 2006). In each trial, the participant was presented with two consecutive stimuli (the standard and the target in random order) and was asked to report which of these two stimuli was dimmer - or in different experiments: shorter, slower or greener - using a keypress (left arrow for the first stimulus, right arrow for the second stimulus). Algorithmically, experiments started out as normal staircase procedures with the difference between the standard and the target being halved for each trial until the participant's first incorrect response. Afterwards, has begun the normal 3D1U procedure and the step ratio was changed to 1.5 i.e., the difference between the standard and the target was divided by 1.5 after three consecutive correct responses and it was multiplied by 1.5 after one incorrect response. The psychophysical experiments continued until 12 reversal points were recorded and the difference thresholds were calculated by averaging the last 10 reversal points. The order of the 3D1U experiments was counterbalanced through a Latin square. The difference thresholds were multiplied by four to determine the second levels of stimuli to be used in the following experiments. The standard values in the

luminance, duration, speed and hue experiments were 66% (66, 0, 0 in CIELAB color space), 100 ms, 3 °/s and green (33, -128, 0 in CIELAB color space) and the starting values of the target stimuli were 100% (100, 0, 0 in CIELAB color space), 400 ms, 10 °/s and blue (33, -128, -128 in CIELAB color space).

Duration of a high-speed stimulus is known to be perceived as longer than a low-speed counterpart (Kanai et al., 2006; Kaneko & Murakami, 2009). To prevent duration from co-varying with speed and to find how much the perceived duration of fast stimuli was dilated compared to slow stimuli, an additional staircase with a confirmation algorithm (Meese, 1995) was run. In a trial, the participant saw the 100 ms fast standard stimulus and the slow stimulus with variable duration (starting value of 400 ms). In the first part of the staircase procedure, the difference between the standard and target durations was halved as long as the participant's answer was correct (slow long stimulus is judged to be longer than the fast 100 ms standard). After the first response stating that the standard is longer, the step ratio was changed to 1.5 and the confirmation algorithm began, meaning that unlike a normal staircase experiment, the participant must give the same response twice for the stimulus level to change (one correct response does not lead to a decrease in the difference between target and standard, two consecutive correct responses leads to a decrease. The experiment stopped after 12 reversal point were recorded and the point of subjective equality was calculated by taking the mean of the last 10 reversal points.

2.1.4.2 Feature repetition experiments

All feature repetition experiments had the same structure adapted from Bogon et al. (2017). In each experiment, the stimuli consisted of two varying features: the relevant feature (RF) and the irrelevant feature (IF). The participant was instructed

(in Turkish) to press the right or left arrow key based on the level of the RF after stimulus offset e.g., “Throughout the experiment, you will see stimuli consisting of moving dots on the screen. Press the left arrow key after a fast stimulus and the right arrow key after a slow stimulus.” The response mappings were randomly determined at the beginning of each experiment. There was no instruction about the IF. In a trial, the participant saw the stimulus and had to press one of the arrow keys after the stimulus had disappeared. Reaction time (RT) was recorded as the interval between stimulus offset and the keypress response and the accuracy in each trial was recorded to calculate error rate in each condition (ER). After incorrect responses, participants received a 1500 ms feedback with “Incorrect response” written in the center of the screen. The new trial started after a 500 ms inter-trial interval. The experimental conditions were the repetition and alternation of RF and IF compared to the previous trial (See Fig. 1a for examples). Every experiment consisted of a practice block with each condition repeating five times (20 trials) followed by three blocks with 80 trials each (20 repetitions of each condition). At the beginning of an experiment, the conditions were distributed randomly within each block and the stimulus levels were computed based on the repetition/alternation conditions. If the ratios of stimulus levels were not between .4 and .6 in each block and condition, the conditions were distributed again. The instructions were presented again at the beginning of each block. The experiments are referred to with their RF and IF in the following sections

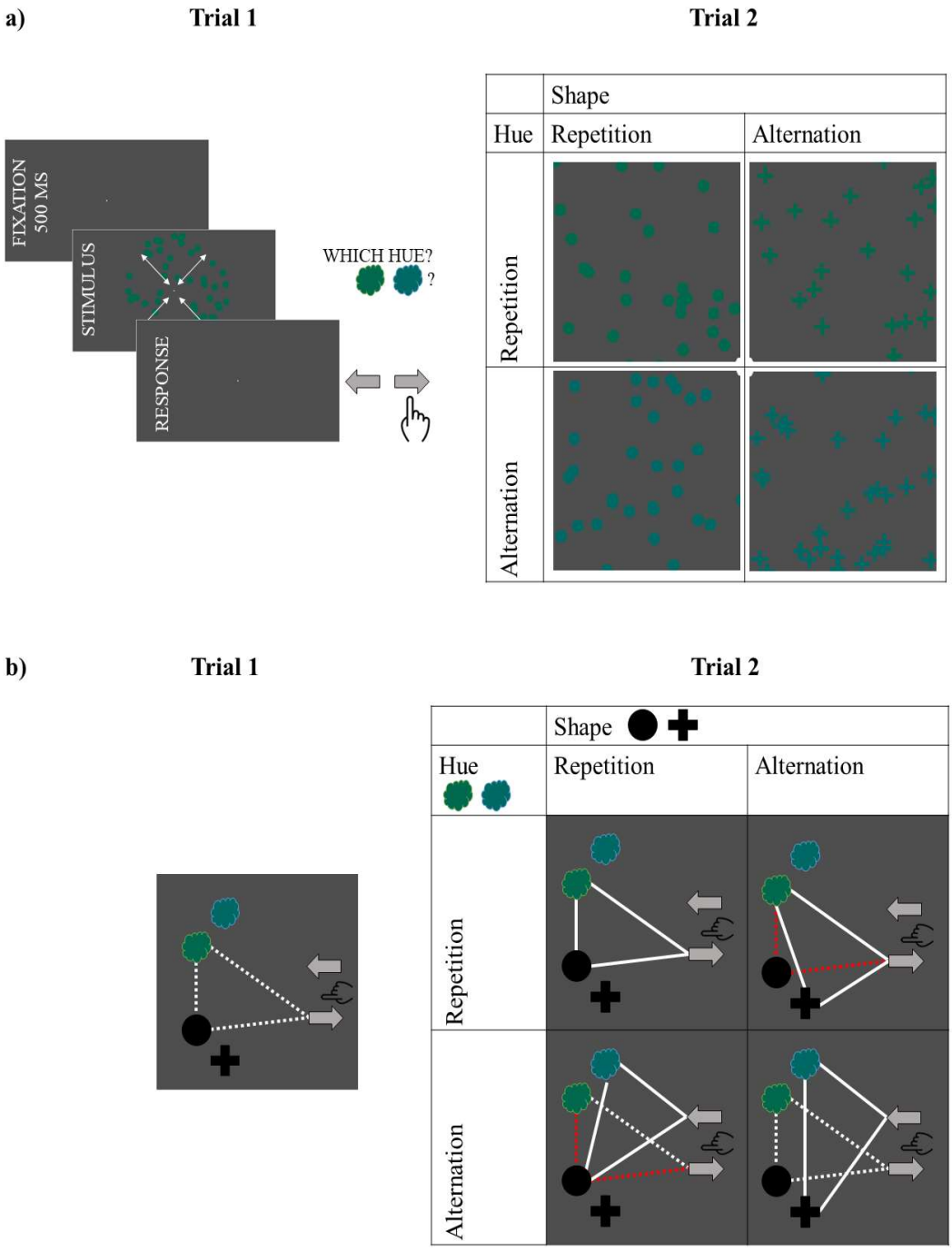


Figure 1. Timeline of experiments, experimental conditions and event files formed in example conditions

a) Timeline of experiments and example stimuli from each condition: Each trial started with a 500 ms inter-trial interval (ITI) with the fixation point which was

followed by the stimulus. The participants responded with a left or right keypress after stimulus offset. The stimulus in each trial is generated based on the stimulus of the previous trial and the experimental condition of the current trial. Example stimuli are shown under Trial 2.

b) Event files formed in the example trials above: The dashed lines show the residual connections between green hue, round shape and right keypress formed in Trial 1. The new connections formed in Trial 2 are shown with a solid white line. The residual connections to the alternated features need to be inhibited for the event file to be formed in Trial 2. These connections are shown in red. In particular, let us assume that the participant was presented with an array of green, round dots and was instructed to press the right arrow key in response to green stimuli in Trial 1. In this case, according to the TEC, the features GREEN, ROUND, and RIGHT would be bound together in an event file (File 1) and their connections outside of File A would be inhibited. In the complete repetition condition as the next trial (Trial 2), the decaying traces of File 1 could be reactivated, resulting in a quick response. Similarly, if the next trial is the complete alternation condition, the new file (File 2) would need to include the features BLUE, PLUS, and LEFT. Since none of these features were in File 1, their connections in File 2 could also be formed quickly to trigger an action. In case of a partial repetition condition, on the other hand, at least one of the features in File 2 would be common with File 1. Thus, the decaying residual connections from the common feature to the items in File 1 would have to be inhibited, delaying the formation of File 2 and the action.

to ease communication e.g., an experiment in which speed was the RF and luminance was the IF is named the speed-luminance experiment.

During an experiment, data were recorded in MATLAB. At the end of the experiment, the raw data and a re-formatted version were recorded to be analyzed in jamovi 2.3.21 (The jamovi Project, 2023).

The reports of the forced-choice tasks are, as the time of the submission of this thesis, under-review for publication in the *Journal of Experimental Psychology: Human Perception & Performance*. A pre-print is available at the Social Sciences Research Network with the Abstract ID 4808496 at https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4808496. The data and a sample of the codes are uploaded to the Open Science Framework, available at https://osf.io/n2dgr.

2.2 Results and conclusion

In the first experiment, our specific hypotheses were:

Hypothesis 1: In the completely categorical hue-shape experiment, the partial repetition conditions (RF repetition + IF alternation; RF alternation + IF repetition) will have higher reaction times than complete repetition and complete alternation conditions.

Hypothesis 2: The other experiments (experiments involving metric stimulus features) will show the benefit of the complete repetition condition but not the benefit of the complete alternation condition.

First, the mean reaction times (RT) were analyzed with three-way repeated-measures ANOVAs with block (1, 2, 3), relevant feature (RF; repetition, alternation)

and irrelevant feature (IF; repetition, alternation) as within-subjects factors. There was no significant three-way interaction, meaning that the theoretically important interaction between RF and IF did not change based on blocks. However, block number interacted with RF in the duration-luminance experiment, $F(1, 15) = 3.554$, $p = .041$, $\eta^2_p = .192$ for RT and $F(1, 15) = 5.270$, $p = .011$, $\eta^2_p = .260$ for ER. Simple main effect analyses showed that the RT and ER difference between RF (duration) alternation and repetition increased as the blocks progressed with alternation leading to slower responses and more errors. Since this interaction is not theoretically relevant, the analyses were re-run excluding block as a factor and reported as such.

The mean RTs are calculated excluding incorrect responses and the trials directly following the incorrect responses as in Bogon et al. (2017). A two-way repeated-measures ANOVA with RF (repetition, alternation) and IF (repetition, alternation) as factors and RT as the dependent variable was run for each experiment. Significant and close to significant RF x IF interactions are analyzed with simple main effect analyses. The effect of IF on RT is analyzed with a repeated-measures t-test for each RF condition (repetition, alternation). Table 1 contains the descriptive statistics for each experimental condition and in Table 2 are the significance values of all RF x IF interactions and the following simple main effect analyses.

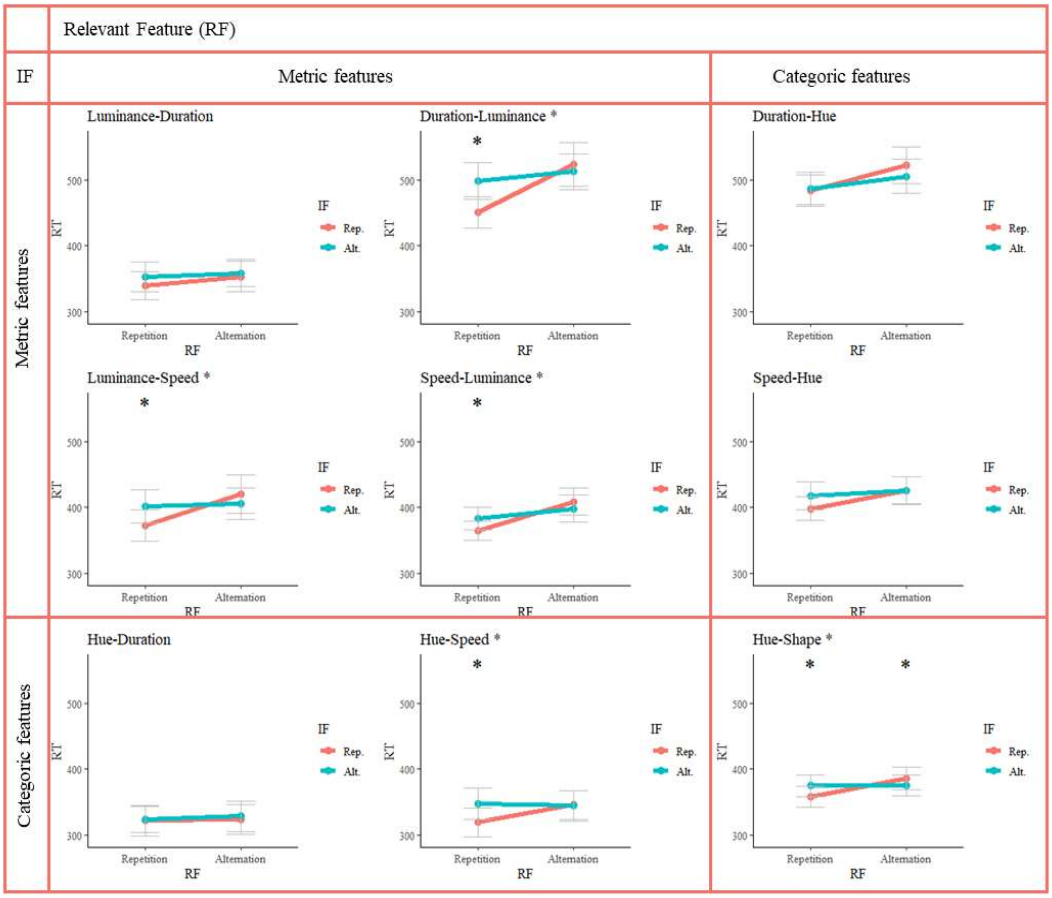


Figure 2. Mean reaction times (RT) as a function of relevant feature change RF) and irrelevant feature change (IF) in each experiment

Note: Error bars indicate standard errors of the mean. Significant RF:IF interactions and significant simple main effects of IF are marked with an asterisk, * $p < .05$.

Table 1. Means (and standard deviations) of mean reaction time in each experimental group of the main (normal cells) and control (shaded cells) experiments

Relevant-feature	Repetition		Alternation	
Irrelevant-feature	Repetition	Alternation	Repetition	Alternation
Luminance-Duration	339 (100)	353 (103)	353 (109)	359 (96.4)
Duration-Luminance	451 (111)	498 (129)	523 (155)	512 (129)
Luminance-Speed	373 (111)	401 (117)	421 (135)	405 (113)
Speed-Luminance	365 (67.2)	383 (81)	409 (96.9)	398 (94.6)
Duration-Hue	484 (113)	487 (113)	522 (132)	506 (123)
Speed-Hue	398 (82.5)	418 (97.2)	426 (96.1)	425 (98.7)
Hue-Duration	322 (109)	324 (95)	324 (104)	329 (109)
Hue-Speed	319 (102)	348 (113)	346 (103)	345 (109)
Hue-Shape	358 (74.4)	375 (7.8.7)	386 (79.1)	375 (74.7)
Luminance-Duration	367 (91.8)	401 (93.4)	393 (95.3)	391 (73.2)
Duration-Luminance	446 (116)	483 (128)	509 (122)	509 (146)
Duration-Hue	430 (74.8)	462 (77.6)	489 (78.6)	481 (81)
Hue-Duration	335 (117)	365 (108)	361 (102)	366 (114)

Table 2. Significance values of RF x IF interactions (int.) In all RT analyses and of the simple main effect analyses on IF for RF repetition (RF rep.) and RF alternation (RF alt.) conditions

	Main Experiments			Saliency Control Experiments		
Experiment	Int.	RF rep.	RF alt.	Int.	RF rep.	RF alt.
Luminance-Duration	.546			.004*	<.001*	.853
Duration-Luminance	.018*	.002*	.402	.001*	<.001*	.523
Luminance-Speed	.011*	<.001*	.259			
Speed-Luminance	.018*	.008*	.167			
Duration-Hue	.310			.019*	.026*	.430
Speed-Hue	.057*	.013*	.880			
Hue-Duration	.765			.801		
Hue-Speed	.008*	<.001*	.877			
Hue-Shape	<.001*	.002*	.002*			

2.2.1 Metrical-metrical combinations

The interaction between the RF and IF was not significant in the luminance-duration experiment, $F(1, 20) = .377$, $p = .546$, $\eta^2_p = .018$, but significant in the duration-luminance, $F(1, 15) = 6.98$, $p = .018$, $\eta^2_p = .318$, luminance-speed, $F(1, 21) = 7.88$, $p = .011$, $\eta^2_p = .273$, and speed-luminance, $F(1, 15) = 7.01$, $p = .018$, $\eta^2_p = .318$,

experiments. Simple main effect analyses showed that all interactions had the same pattern: the alternation of IF increased RT only when RF repeated but the effect of IF was insignificant when RF alternated (Fig. 2).

2.2.2 Metrical-categorical combinations

The interaction term was insignificant in the duration-hue experiment, $F(1, 21) = 1.08$, $p = .310$, $\eta^2_p = .049$, and marginally significant in the speed-hue experiment, $F(1, 21) = 4.07$, $p = .057$, $\eta^2_p = .162$. The trend in the speed-hue experiment reflected the pattern in other experiments (Fig. 2).

2.2.3 Categorical-metrical combinations

RF and IF did not interact in the hue-duration experiment, $F(1, 20) = .092$, $p = .765$, $\eta^2_p = .005$. The hue-speed experiment, on the other hand, showed a significant interaction between RF hue and IF speed, $F(1, 21) = 8.69$, $p = .008$, $\eta^2_p = .293$, with the alternation of IF speed increasing RT when RF hue repeated but not when it alternated (Fig. 2).

2.2.4 Categorical-categorical combination

In the hue-shape experiment, the interaction term between RF and IF was significant, $F(1, 21) = 38.25$, $p < .001$, $\eta^2_p = .646$. The pattern of the interaction was different from the other experiments. The alternation of IF shape increased RT when RF hue repeated but it decreased RT when RF hue also alternated (Fig. 2).

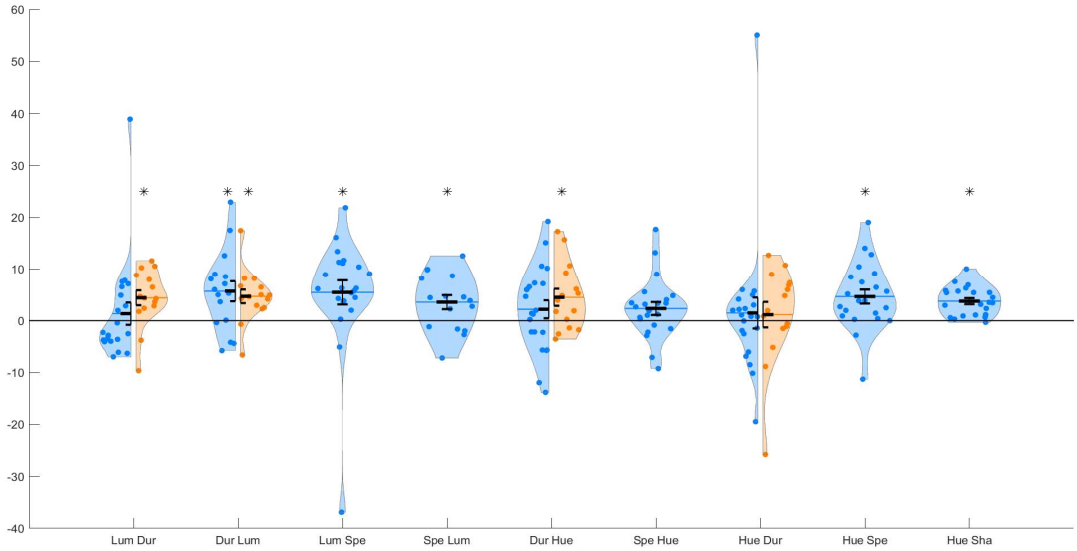


Figure 3. Violin plots of rt costs in the main (blue) and saliency control (orange) experiments

Note: Error bars indicate the standard errors of the mean. Significant one-sample t-tests are indicated with asterisks, * $p < .05$.

Abbreviations: Lum: luminance, Dur: duration, Spe: speed, Sha: shape. The first feature is the relevant feature and the second irrelevant.

2.2.5 Partial repetition costs

Mean RT values of each individual was used to calculate a RT cost with the following formula:

RT cost = 100 * (average of partial repetition RTs – average complete repetition and alternation RTs) / average complete repetition and alternation

RT cost is the percent increase in RT caused by partial repetition as opposed to complete repetition or alternation and allows an indirect analysis of the RF x IF interaction (see Fig. 3 for violin plots of all observations; Bechtold, 2016). RT costs are analyzed in one-sample t-tests or Wilcoxon rank test since luminance-duration,

Table 3. Descriptive statistics (mean, M; standard deviation, SD) of RT costs and the test statistics of one-sample t-test and Wilcoxon tests.

	Main Experiments			Saliency Control Experiments		
Experiment	M (SD)	t or W	p	M (SD)	t (W)	p
Luminance-Duration	1.36 (9.88)	W =115	1	4.72 (5.61)	3.052	.009*
Duration-Luminance	5.71 (7.82)	2.92	.011*	4.71 (5.12)	3.560	.003*
Luminance-Speed	5.48 (11.03)	W = 224	<.001*			
Speed-Luminance	3.59 (5.48)	2.617	.019*			
Duration-Hue	2.2 (8.18)	1.261	.221	4.52 (6.41)	2.730	.016*
Speed-Hue	2.35 (5.89)	1.871	.075			
Hue-Duration	1.49 (13.74)	W =119	.919	1.16 (9.55)	W = 79	.303
Hue-Speed	4.67 (6.38)	3.431	.003*			
Hue-Shape	3.77 (2.77)	6.377	<.001*			

luminance-speed and hue-duration data were not normally distributed. We opted to keep the outliers in the data to protect the data set from the interaction analyses. Descriptives of RT costs and test statistics are provided in Table 3. The statistically significant experiments in one-sample tests are the same ones that yielded statistically significant RF x IF interactions in two-way ANOVAs, providing convergent evidence with a simpler dataset.

2.2.6 Discussion

In the hue-shape experiment, IF had significant effects in both RF repetition and RF alternation conditions. IF alternation increased RT when RF repeated and IF repetition led to higher mean RT when RF alternated i.e., partial repetition conditions had significantly higher RTs than complete repetition and alternation conditions. In other pairings of feature types, there was no difference between IF repetition and alternation under the RF alternation condition. We name this type of interaction the complete repetition benefit since the complete alternation condition does not have any advantage over the RF alternation IF repetition condition. These findings support our first hypothesis and indicate a more direct connection between categorical features and action selection congruent with PCM. The exact mechanisms are discussed in the General Discussion section.

The second pattern to take notice of is that experiments involving duration yielded results different than experiments involving speed did. Though luminance-speed, hue-speed and speed-hue experiments showed significant or close to significant RF x IF interactions, luminance-duration, duration-hue and hue-duration experiments did not yield significant interactions. This mismatch between speed and duration can be due to the saliency of the features. Although we have measured the difference thresholds for each feature and matched the perceptual differences between levels, duration itself may not be salient enough to be included in event files when it is irrelevant to the task or when it is coupled with a categorical feature. Though completely metric experiments show more consistent interactions than mixed pairs of categorical and metrical features, the possible impact of the duration saliency makes it harder to assess whether the results support Hypothesis 2.

To control the possible impact of saliency on the inclusion of features in event files, we designed another set of experiments. In these experiments, we have fixed the short- and long-duration stimuli to 50 and 200 ms to increase the saliency of the level difference in compliance with the methodology of Bogon and colleagues (2017).

2.3 Saliency control experiments

By increasing the difference between levels, we aim to increase their respective saliency and the strength with which they are bound to other features in the event file (Hommel, 2004). Therefore, fixing the duration of stimuli to 50 and 200 ms should lead to more robust RF:IF interactions. Since there are no fully categorical feature pairs, these interactions will show the complete repetition benefit rather than the partial repetition cost pattern.

2.3.1 Methods

2.3.1.1 Participants

The saliency control experiments had 16 participants one of which was excluded from the analyses because of high reaction times. The final sample of 15 (53.3% women) had a mean age of 21.1 (*SD* = 1.53, range = [19 23]). Two participants who took part in the main experiments also took part in the saliency control experiments.

2.3.1.2 Procedure

The apparatus and stimuli were the same as the main experiments. The overall procedure was also similar. A participant first took part in two 3D1U experiments for

luminance and hue difference thresholds, and then the four feature repetition experiments: luminance-duration, duration-luminance, hue-duration, and duration-hue. Since speed is not a feature used in this experiment, the staircase procedure was skipped. The luminance and hue levels in the feature repetition experiments were computed based on the difference thresholds obtained from the 3D1U procedure but the duration levels were fixed to 50 and 200 ms. The four feature repetition experiments were run in counterbalanced order.

2.3.2 Results and conclusion

In the saliency control experiments, the hypothesis was that increasing the difference between long and short durations will lead to significant RF:IF interactions.

2.3.2.1 Interaction analyses

All control experiments were analyzed with a two-way ANOVA with RF (repetition, alternation) and IF (repetition, alternation) as factors and mean RT as the dependent variable. The mean and standard deviations statistics are provided in Table 1 and the significance values of the RF x IF interactions and the simple main effects analyses of significant interactions can be found in Table 2. The RF and IF interaction in the luminance-duration, $F(1, 14) = 12.17$, $p = .004$, $\eta^2_p = .465$, duration-luminance, $F(1, 14) = 13.7$, $p = .001$, $\eta^2_p = .345$, and duration-hue, $F(1, 14) = 7$, $p = .019$, $\eta^2_p = .333$, was significant. In all experiments, IF alternation increased RT when RF repeated but its effect became insignificant when RF alternated. The hue-duration experiment did not have a significant RF-IF interaction, $F(1, 14) = .066$, $p = .801$, $\eta^2_p = .005$. See Figure 4 for line graphs of saliency control experiments.

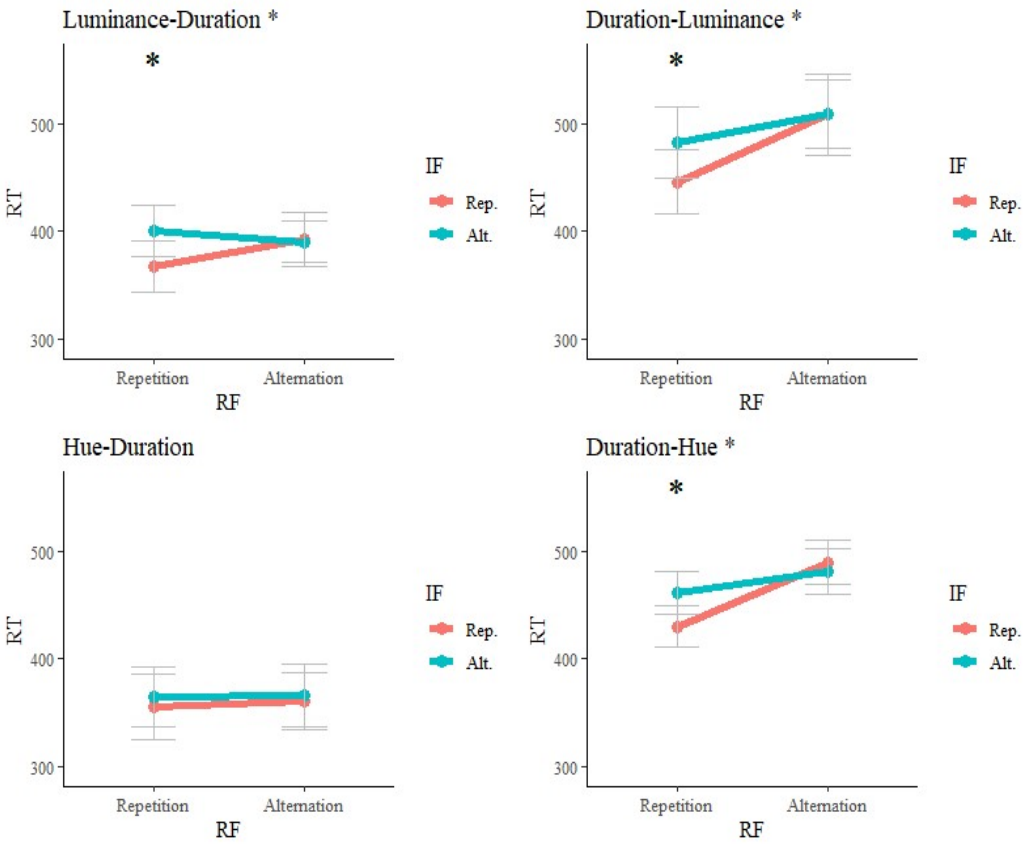


Figure 4. Mean reaction times (RT) as a function of relevant feature change (RF) and irrelevant feature change (IF) in each saliency control experiment

Note: Error bars indicate standard errors of the mean. Significant RF:IF interactions and significant simple main effects of IF are marked with an asterisk, * $p < .05$.

2.3.2.2 RT cost analyses

RT costs are calculated the same as in the main experiments (see Fig. 3) and analyzed with one-sample t-tests or Wilcoxon test since the hue-duration data were not normally distributed. The descriptive and test statistics are provided in Table 2.

2.3.3 Discussion

RF and IF did not interact in the main luminance-duration and duration-hue experiments but increasing the difference between short and long stimuli made these interactions significant, supporting our hypothesis. However, the hue-duration interaction remained insignificant. Therefore, increasing the difference between the levels did make duration more accessible for action selection processes but it remained inaccessible when duration was the irrelevant feature in a hue-based task. The difference between the duration-hue and hue-duration control experiments provides further evidence that categorical stimulus features are given more weight in action selection and a task-irrelevant metric feature can be ignored more readily.

2.4 Forced-choice task discussion

The planning and control model (PCM) theory proposes that while categorical features are used in action selection, their connections outside of an event file, which was previously formed in the presence of an association with an action pattern, are inhibited throughout the execution of the action. The external connections of metric features, on the other hand, are not inhibited because metric features are used in the continuous control of action execution and need to be constantly updated (Thomaschke et al., 2012). That partial repetition costs in the predicted pattern (with partial repetition conditions having greater reaction times than both complete repetition and complete alternation conditions) were only seen when the stimulus varied in categorical features in our hue-shape experiment and that none of the other conditions involving metric stimulus features replicated this pattern in our current study provide further support for the PCM theory.

Our study is the first in literature, where the role of categorical versus metrical features on action selection was systematically investigated in a single experimental setup. Our results demonstrated that in the presence of metrical features, be it relevant or irrelevant to the task, the benefit of complete alternation on reaction times disappears. Assuming that metrical features are used in action control as the PCM theory (Thomaschke et al., 2012) suggests, here is how we explain our current findings: The main presumption is that the scales/systems measuring metric features are constantly updated with the most recent information and that the activation of the last activated region on the scale is inhibited. In fact, if the system did not update metric information as such, action could not be controlled based on the latest available information but an average of past activation. This type of constant updating hypothesis is also supported by perturbation paradigms in which changing the orientation, location or size of a target stimulus during a reaching or grasping movement results in a quick adjustment of the movement to fit the change in the environment (Fan et al., 2006; Flash & Henis, 1991; Hesse & Franz, 2009). With the constant update of metric information in mind, now, let us assume that the participant is in a duration-luminance experiment, where they are presented with a long-interval, high-luminance stimulus in Trial 1 and respond with a right keypress (See Fig. 5). In the complete repetition condition, in Trial 2, File 1 could be reactivated to trigger a quick action. In any other condition, on the other hand, a change in the activated region of the continuous metric would inhibit the previously activated region of the scale resulting in the absence of the decaying residual connections we see in the categorical-categorical hue-shape experiment, where the decaying residual connections from the common feature to the items in File 1 would have to be inhibited, delaying the formation of File 2 and the action (Figure 1). Thus,

because “continuous” scales would need to be updated “as a whole” in the case of metrical features, the complete alternation condition would be stripped from having a reaction time benefit. The same mechanism would also prevent the complete alternation from having any reaction time benefit in the metrical-categorical and categorical-metrical combinations, as these would also require a complete update on the metrical scale. This pattern is better described as a complete repetition benefit than a partial repetition cost since the complete alternation condition does not show a benefit like the complete repetition condition does.

In our current study, in the main experiments, partial repetition costs were absent in either when duration was the irrelevant feature or when it was paired with a true categorical feature: hue. Increasing the difference value between the long-interval and short-interval stimuli in the saliency control experiment, on the other hand, led to significant partial repetition costs for the luminance-duration and duration-hue conditions. These results demonstrate that the saliency of a feature is one of the factors that determine whether a feature would be involved in an event file or not. This is in line with Hommel (2004)’s suggestion that task-relevance and saliency are the two factors determining a feature’s inclusion in an event file. Interestingly, though, increased saliency of duration in our study led to a significant interaction in the luminance-duration but not in the hue-duration condition although duration is the task-irrelevant feature with identical values in both experiments. We suggest that this difference could be due to the metrical and categorical characteristics of luminance and hue, respectively. Confirming both ATOM (Walsh, 2003) and PCM (Thomaschke et al., 2012), it is possible that two metrical features – luminance and duration – interacted with each other, whereas when a categorical

feature – hue – was relevant to the task, duration as a metrical feature was not involved in the event file. The exact nature of such intricate interactions between metrical, particularly temporal and categorical features in action selection deserves further research.

Our results and aforementioned approach (Fig. 5) in explaining the role of

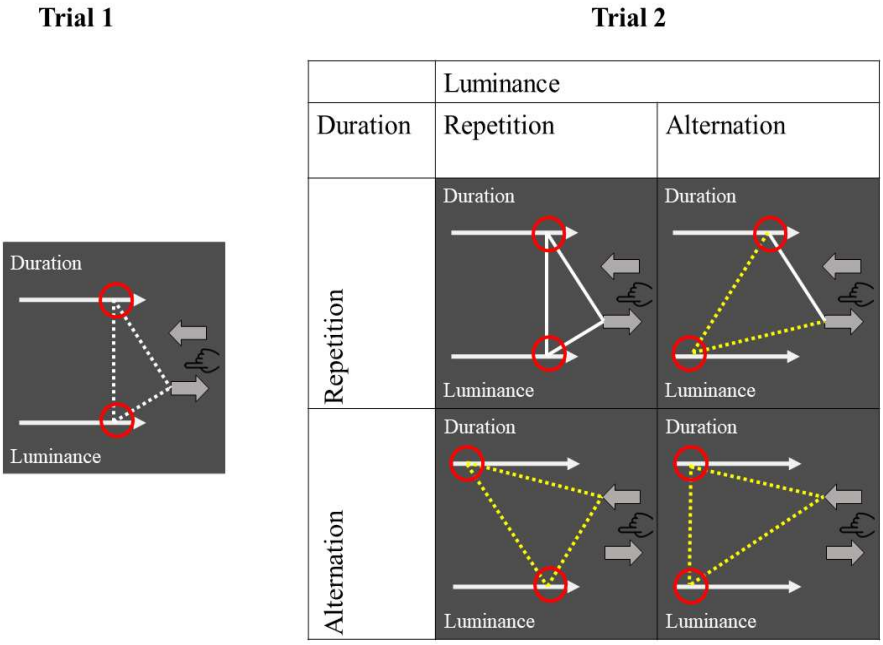


Figure 5. Event files formed in a metric-metric features experiment

Note: On the left side is the residual connections (dashed white line) from Trial 1 in which the participant sees a long-duration high-luminance stimulus and responds with a right keypress based on the duration. The white arrows represent the scales/systems measuring metric stimulus features with the red circles showing the activated regions. On the right side are different diagrams of experimental conditions. Solid white lines are the connections that are common between Trials 1 and 2 and yellow dashed lines are the connections that need to be rebuilt after the scales/systems are updated.

categorical and metrical features in action selection and execution can also explain

the previous, seemingly contradictory results from the literature. Zmigrod and Hommel (2009) were able to find a significant partial repetition cost in a condition, where loudness was the relevant and pitch was the irrelevant feature (loudness-pitch) but not in the reverse condition, where pitch was the relevant and loudness was the irrelevant feature (pitch-loudness). Similar to our findings, we propose that loudness as a metrical feature could not interfere with action selection when pitch as a categorical feature was task-relevant. In parallel, Bogon et al.'s (2017) pitch-duration experiment did not create a partial repetition cost, either, but rather a complete repetition benefit. It is important to note that their loudness-duration condition did show a significant partial repetition cost despite being completely metric, though, unlike our experiments with duration, speed and luminance which showed a complete repetition benefit. This difference between our current findings and Bogon et al.'s (2017) results may be due to the saliency of the features employed in both studies. We have used psychophysical methods to find the difference thresholds and matched the perceptual differences across different stimulus features, whereas Bogon and colleagues (2017) chose stimulus intensities so as to ensure maximum discriminability. At this point, it is critical to consider that no matter whether a feature is metrical, the subjective experience across extreme ends of the scale may feel like a qualitative, categorical difference. Visual speed, for example, although a metrical feature, is perceived as categorically different when presented at two extreme ends (e.g. gratings drifting at very fast versus very slow rates). Thus, future studies should be careful in determining the stimulus levels of metrical features, ensuring that the percept is not qualitatively different enough to make a categorical rather than a metrical decision.

Theory of event coding (TEC) claims that not only perceptual features are bound together to form object files, as Kahneman and colleagues (1992) suggest, but there is also a common coding scheme for perception and action, where features are associated with certain action patterns (Hommel, 2019; Hommel et al., 2001). To the best of our knowledge, though, no previous study used the psychophysical methodologies to determine stimulus levels used in this line of research in the literature. In our current study, we measured individual difference thresholds for each and every visual feature, separately, in order to make a well-matched comparison across different visual features. More studies bridging the gap between psychophysics and motor action literature are needed to truly test the connection between perception and action by examining how stimuli are perceived, represented and included in event files. More importantly, we need more studies to investigate the implications of the neural structure of the perceptual systems like dual pathway model that can be seen in auditory (Ahveninen et al., 2006; Alain et al., 2001; Arnott et al., 2004; de Santis et al., 2007; Kaas & Hackett, 1999; Maeder et al., 2001; Rauschecker & Tian, 2000; Tian et al., 2001; Warren & Griffiths, 2003), visual (Cloutman, 2013; De Valois et al., 2000; Livingstone & Hubel, 1988; Mishkin et al., 1983; Ungerleider & Haxby, 1994; Vaina, 1994; Wiesel & Hubel, 1966), and tactile (Reed et al., 2005) modalities in action selection. If perception and action are the same processes as the TEC suggests, then, the neural hierarchy of perceptual and motor systems should be taken into account for action selection to be more properly explained.

Though the contrasting connection types of categorical and metric features as proposed in PCM can explain our results, there is one other alternative explanation that should also be considered. Almost the whole literature on partial repetition costs

uses categorical stimulus features. The only studies that we are aware of using metrical features are those of Bogon et al. (2017) and Zmigrod and Hommel (2009), which both showed unexpected patterns in conditions involving metric features. Despite these results bringing evidence for PCM and the claim that action selection is based on categorical features, a major limitation of our study and the literature we surveyed is that all partial repetition cost studies used categorical actions (almost always two-choice lateral keypresses) as the response. Assuming that the proposal of TEC that actions are represented by stimuli that precede or follow them (Hommel et al., 2001) is correct, then actions could also interact with these different types of stimuli depending on their own nature being either dichotomous/ categorical (as in left or right press) or continuous (as in continuous rotation or press). It would be critical, thus, to involve this parameter to study the dynamics of partial repetition costs.

Our results, in addition to shedding some light on and bringing forth new questions about action selection, provide evidence for another debate in perception: is time processed in a supramodal central clock in the brain (Creelman, 1962; Treisman, 1963) or is it processed in each sensory modality as a separate stimulus feature? The former models of time perception posits that duration is processed in a supramodal, central clock (Creelman, 1962; Treisman, 1963), although more recent evidence, including our own body of work points to a modality-specific, content-dependent processing (Johnston, 2010), where duration is processed as a metrical stimulus feature in the magnocellular (Ayhan et al., 2009; 2011; Bruno & Johnston, 2010) and dorsal visual pathway (Ayhan & Ozbagci, 2020; Gulhan & Ayhan, 2019). Supporting this theory, duration acts similar to other dorsal/metric features in Weber's law (Gibbon, 1977), is affected by the magnitude of other metrical features

(Walsh, 2015) and shows similar sensorimotor interactions like sensory attenuation (Ayhan & Ozbagci, 2020) and saccade-induced compression (Burr et al., 2010). Within this context, our current study provides further evidence that time is an attribute of a visual stimulus like any other low-level features such as color or motion (Nishida & Johnston, 2002; Johnston, 2010) and that one could use it as a visual metric stimulus feature to see if its effect on action selection is similar to any other metrical features, namely luminance and speed. Duration and speed acting very similarly in our current data, especially after the difference between two duration levels were increased in the saliency control experiment provides further support that duration is processed as a content-dependent stimulus feature rather than a separate supramodal cognitive construct.

The results of analyses on error rate are reported in detail in Appendix D but a summary of the results is that the experiments that showed a significant or close to significant RF:IF interaction in RT also showed significant or close to significant results in error rate analyses. The simple main effect analyses, on the other hand, showed a different pattern than the RT analyses. The hue-shape experiment showed a complete repetition benefit on error rate and all other experiments demonstrated partial repetition costs (in both main and saliency control experiments). Therefore, the involvement of metric features led to higher error rates in partial repetition conditions only but fully categorical stimuli showed only a complete repetition benefit. Considering the proposition that categorical and metrical features are used for action planning and control, and our finding that they lead to partial repetition costs in RT and error rates, respectively, these measures might be influenced by different cognitive processes and using RT and error rate as almost interchangeable

measures of action selection or human performance might be an oversimplification of the underlying processes of action selection and control.

CHAPTER 3

ESTIMATION TASKS

3.1 Methods

3.1.1 Participants

31 participants (61.3 % female) with a mean age of 21.59 years old (SD = 1.9) joined the study with 24 participants joining every experiment. All but one participant reported being right-handed. A participant was not included in the reported sample due to experimental hardware malfunction. Each participant has read and signed a consent form before participation. The study was approved by Boğaziçi University Social and Human Sciences Human Research Ethics Committee (Appendix A) and compliant with the Declaration of Helsinki. Participants signed the informed consent form before the experiment (Appendices B and C). The sample size was aimed to surpass the forced-choice task to ensure that power was high enough to detect the effect in this novel methodology.

3.1.2 Apparatus

The experiments took place in a sound-attenuated, dark room in the Vision Lab at Boğaziçi University. The experimental procedure was programmed in MATLAB and Psychtoolbox (Brainard, 1997) and presented on an LED monitor (Eizo Foris FG2421, 120 Hz frame rate, 1920x1080 resolution) calibrated with Spyder4. The participants rested their head on a chinrest positioned 50 cm away from the monitor throughout the study to reduce head movements.

3.1.3 Stimuli

Throughout the experiment, a white fixation point was present in the center of the screen. The background was a solid gray with a 33% luminance in the CIELAB color space (Kovesi, 2015). All stimuli were formulated using the CIELAB color space to better control their luminance levels.

The target stimulus was composed of 400 dots randomly generated within a 10° radius circular array. The dots had a radius of .3° and moved either towards or away from the screen center to make sure there is no motion adaptation in either direction. In each frame, 5% of the dots were moved to a different position in the array. The luminance, duration, speed, hue and shape of the dots varied between trials. Luminance values ranged between 66-100% ([66, 0, 0] and [100, 0, 0] in CIELAB), duration between 100-400 ms, speed between 3-10°/s, and hue between green and blue ([33, -128, 0] and [33, -128, -64] in CIELAB). The shape of the dots was either a dot or a plus sign with the same surface area.

At the target stimulus offset, participants were presented with a response scale - a horizontal 27.5°-long (half the screen width) line with a width of .14° appeared 13.75° (quarter of screen height) below the fixation point, centered on the midline of the screen. A rectangular slider of size .28°x.57° was presented on the leftmost side of the response scale. The slider's position on the line changed based on the mouse movements of the participants. After the response was given, a feedback slider appeared on the response scale, indicating the correct required response.

3.1.4 Procedure

The metrical (luminance, duration, speed) and categorical (hue, shape) stimulus features were combined in nine experiments and experiments were named after their

relevant features (RF) and irrelevant features (RF) in order. For instance, in the speed-hue experiment, participants were instructed “Click the mouse and drag it to the right to judge how fast the stimulus was as fast and accurately as possible” but there was no instruction about hue which could range from green to blue. The resulting nine experiments were: luminance-duration, duration-luminance, luminance-speed, speed-luminance, duration-hue, speed-hue, hue-duration, hue-speed, and hue-shape. Each experiment was made up of a practice block with 20+1 trials and three blocks with 80+1 trials each. The first trials of blocks were not included in the analyses and the instructions were repeated at the beginning of each block.

Each trial (Fig. 6) began with the random generation of two numbers which were used in the generation of the RF and IF after a 500 ms inter-trial interval. At stimulus offset, a response scale with a slider on its leftmost side was presented. Participants clicked the left mouse button and dragged the mouse to the right to move the slider. Releasing the left mouse button or dragging the slider to the rightmost end registered as a response. A new slider appeared on the scale as soon as the response was given. The color of the slider turned from yellow to red as error (the distance between the required and actual responses) increased. The feedback slider stayed on screen from 500 to 3000 ms with its duration increasing with error. In each trial, the difference between the RF levels of the current and previous trials was recorded as RF change and IF change was calculated similarly. When shape was the IF, the random numbers could be either 0 or 1 and IF change was calculated as a repetition-alternation dichotomy. RF change and IF change were used as independent variables in the analyses. The interval between stimulus offset and response was recorded as response time (RT) and the distance between the required response and given

response from the participant was recorded as error in each trial to be analyzed as dependent variables.

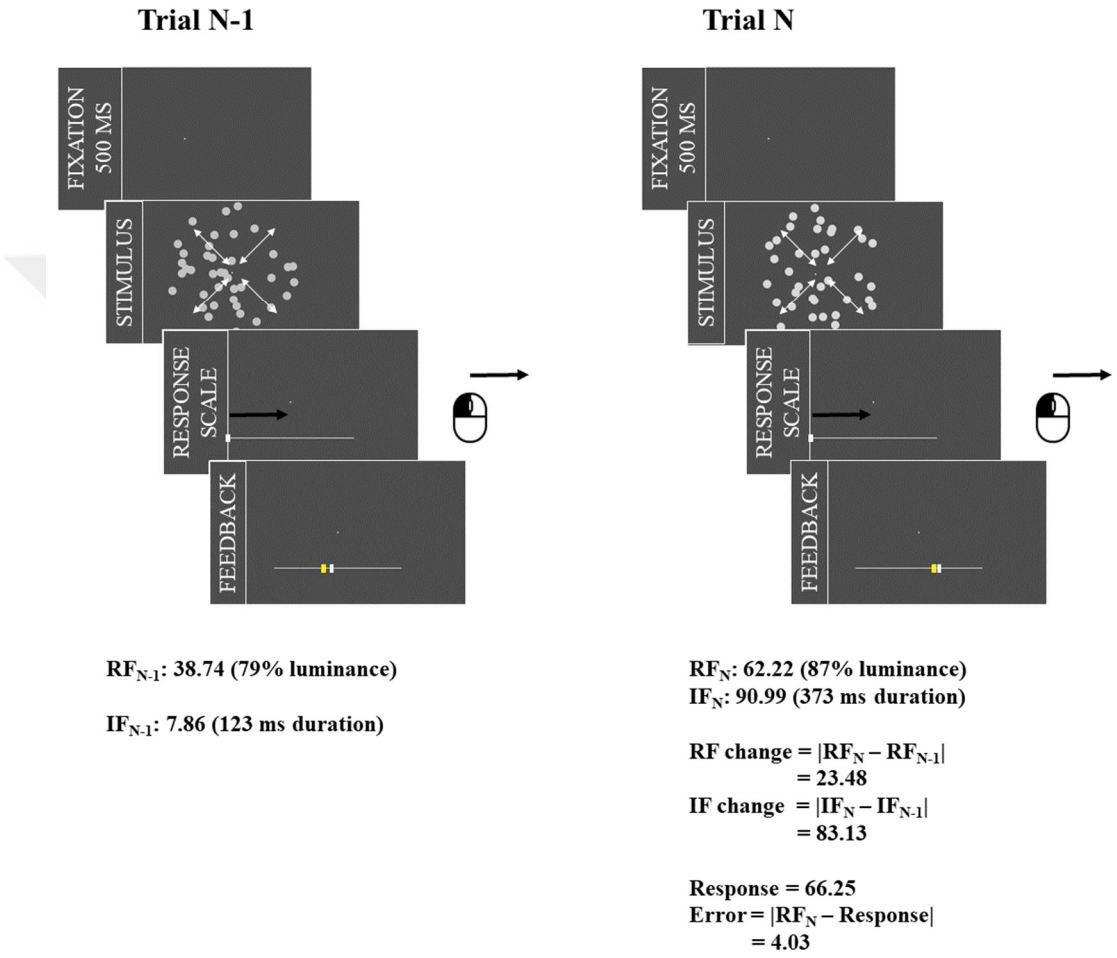


Figure 6. The trial structure in the luminance-duration experiment

At the beginning of a trial, two random numbers from 0 to 100 were generated to be used in the generation of the stimulus. The first number was used to determine the level of the relevant feature (RF) and the second number was for the irrelevant feature (IF). Since the predetermined ranges of luminance and duration were 66 to

100% and 100 to 400 ms, respectively, the random values from 0 to 100 were converted into these scales to generate a 123 ms stimulus with 79% luminance. At stimulus offset, a response scale with a slider on its left end was presented. Participants pressed the left mouse button and dragged the mouse to the right to move the slider on the scale and released the button to give their answer. A yellow-to-red slider appeared on the scale, indicating the correct response.

The next trial followed the same structure with two new random numbers. The difference between the RF and IF levels of the current and previous trials were recorded as RF change and IF change, respectively. Change values were calculated based on the 100-unit scale to put every variable in the same scale and make interpretation easier. The distance between the correct response and the given response is used as the error measurement.

3.2 Results

The data were analyzed using the brms package (Bürkner, 2017) on R 4.3.0 (R Core Team, 2023) with a Bayesian generalized linear mixed-effects model using Markov chain Monte Carlo. We ran a mixed model analysis because mixed models eliminate the need to aggregate the data and reduce the number of data points. Using mixed-effects modeling, one can analyze all trials at once without violating the assumption of independence by entering clustering variables like participant ID number. We have opted for a Bayesian framework instead of a frequentist one because Bayesian model fitting has less problems with model convergence. See the tutorial by Vasishth and his team (2018) for an introduction to Bayesian mixed-effects modeling and the brms package.

RT was entered as the dependent variable with a log-linked gamma distribution family which is suitable for the analysis of positively skewed data with only positive values like response times (Lo & Sally, 2015). Standardized intertrial RF change (RFc) and standardized intertrial IF change (IFc) and the interaction term were entered as fixed effects. IFc in the hue-shape experiment was entered as a sum-coded dichotomous variable with -1 coding for shape repetition and 1 coding for shape alternation. The random effects structure was kept maximal with by-participant varying intercept and slopes to keep Type I error to a minimum (Barr et al., 2013). For each experiment, a second reduced model without the RFc x IFc interaction fixed effect term was created to compare the models and measure the interaction fixed effect (van Doorn et al., 2021).

Exploratory analyses were conducted to investigate if the direction of intertrial RF and IF differences (increase versus decrease) affect responses. To examine this effect, a full Bayesian linear mixed-effects model was created with directional error (given response – required response; positive values indicate overestimation) as the dependent variable and directional intertrial RF and IF differences (RFd and IFd, respectively) as predictor variables. IFd in the hue-shape experiment was entered as a factor with three levels: shape repetition, switch to dot and switch to plus coded as 0, -1 and 1 respectively. The analysis was conducted with shape repetition as the baseline to see if different shape alterations have varying effects. The random effect structure was kept maximal and the reduced model had the same random effect structure but did not include the Rfd x IFd interaction fixed effect as in the RT analyses.

The analyses ran in four chains with 2000 iterations each, 1000 of which were warm-up iterations. The interaction slope estimate and its standard error ($b \pm SE$) and

the 95% confidence interval (*CI*) from the full models were reported. Using the comparison of the full and reduced models, the difference between the leave-one-out information criteria (LOOIC) of the full model and the reduced model (*dLOOIC*) and the Bayes factor for the interaction term (*BF*) were computed. Since lower LOOIC values denote better fits, negative dLOOIC values show support for the interaction. BF is calculated as the ratio of the likelihood of the full model over the likelihood of the reduced model given the current data, hence it provides evidence for the interaction when it is greater than 1 and for the reduced model when it is smaller. Conventionally, a BF between .33 and 3 is regarded as dismissible since the ratio of likelihoods between the models is not high. Values outside of this range are accepted as substantial evidence and values exceeding the [.1 10] range are accepted as strong evidence (Dienes, 2014).

3.2.1 RT analyses

The data from all experiments favored the reduced model over the full model, indicating that the reduced model without the interaction term can explain the data better than the full model, $-.01 \leq b \leq .01$, $-1.8 \leq dLOOIC \leq 1.4$, $.009 \leq BF \leq .07$ (Fig. 7).

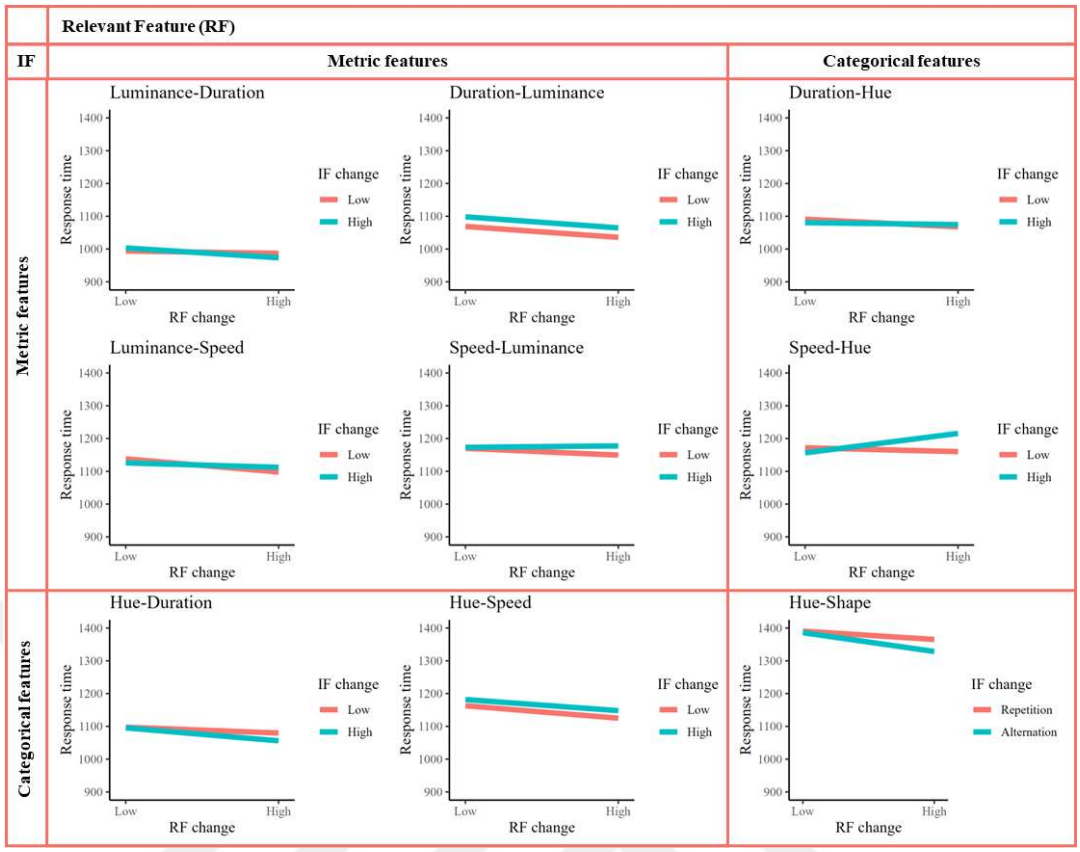


Figure 7. Reaction time as a function of relevant feature (RF) change and irrelevant feature (IF) change in each experiment

Note: Low and high changes indicate changes one standard deviation below and above the mean change, respectively.

3.2.2 Error analyses

The graphs depicting the relationship between RFd, IFd and error can be found in Figure 8.

3.2.2.1 Metric-metric combinations

The data from the luminance-duration, $b \pm SE = 1.34 \pm .32$, $CI = [.69, 1.99]$, $dLOOIC \pm SE = -3.9 \pm 2.9$, $BF = 1090.94$, duration-luminance, $b \pm SE = .81 \pm .41$, $CI = [-.02, 1.62]$, $dLOOIC \pm SE = -1.1 \pm 1.7$, $BF = 11.88$, and luminance-speed, $b \pm SE = .63 \pm .33$, $CI = [-.02, 1.27]$, $dLOOIC \pm SE = -1.3 \pm 2$, $BF = 6.86$, experiments showed strong support for the interaction term but the speed-luminance experiment did not strongly favor either model, $b \pm SE = .25 \pm .48$, $CI = [-.72, 1.19]$, $dLOOIC \pm SE = .8 \pm .5$, $BF = .94$.

RFd had a negative relationship with error in luminance-duration, $b \pm SE = -7.69 \pm .89$, $CI = [-9.46, -5.87.]$, duration-luminance, $b \pm SE = -13.66 \pm 1.06$, $CI = [-15.66, -11.6]$, and luminance-speed, $b \pm SE = -10.34 \pm .99$, $CI = [-12.34, -8.45]$, experiments. A negative RFd-error relationship suggests that increases in RF led to underestimations i.e., the response in the current trial was closer to their previous response. IFd had a positive effect on error in luminance-duration, $b \pm SE = 1.09 \pm .3$, $CI = [.52, 1.68]$, and duration-luminance, $b \pm SE = 1.49 \pm .37$, $CI = [-.76, 2.22]$, experiments but a negative effect in the luminance-speed experiment, $b \pm SE = -1.5 \pm .51$, $CI = [-2.52, -.52]$. The interaction term was positive in all three experiments, suggesting that decrease-decrease or increase-increase conditions led to more positive error compared to mixed conditions.

3.2.2.2 Metric-categoric combinations

The duration-hue experiment showed no interaction, $b \pm SE = .09 \pm .37$, $CI = [-.63, .84]$, $dLOOIC \pm SE = -.2 \pm .4$, $BF = .81$ but the speed-hue experiment showed substantial evidence for a negative interaction term, $b \pm SE = -.78 \pm .42$, $CI = [-1.59, .03]$, $dLOOIC \pm SE = -1.1 \pm 1.6$, $BF = 5.95$.

In the speed-hue experiment, RF increase led to negative errors, $b \pm SE$ = -16.75 ± 1.85, *CI* = [-20.29, -12.96], but IF difference had no effect, $b \pm SE$ = .8 ± .8, *CI* = [-.76, 2.37]. A negative interaction term suggests that mixed trials (increase-decrease and decrease-increase) have more positive errors than decrease-decrease and increase-increase trials.

3.2.2.3 Categoric-metric combinations

Though the hue-duration experiment had a weak positive interaction, $b \pm SE$ = .43 ± .25, *CI* = [-.05, .91], *dLOOIC* ± *SE* = -.5 ± 1.7, *BF* = 3.92, the hue-speed experiment did not favor either model, $b \pm SE$ = .17 ± .3, *CI* = [-.43, .74], *dLOOIC* ± *SE* = .9 ± .5, *BF* = .88.

In the hue-duration experiment, RF increase, $b \pm SE$ = -3.67 ± .72, *CI* = [-5.09, -2.23], and IF decrease, $b \pm SE$ = .41 ± .21, *CI* = [.01, .82], led to overestimations.

3.2.2.4 Categoric-categoric combination

The hue-shape experiment strongly favored the model with the interaction over the reduced model, *dLOOIC* ± *SE* = -.4 ± 1.7, *BF* = 38.27. RF difference had a negative effect on error with hue increase (shift to blue) causing negative errors (greener judgments), $b \pm SE$ = -.49 ± 1.08, *CI* = [-6.92, -2.58]. Neither switches to dot, $b \pm SE$ = -.17 ± .42, *CI* = [-.99, .65], nor switches to plus, $b \pm SE$ = .26 ± .46, *CI* = [-.63, 1.15], affected errors. RFd x dot switch interaction was not strongly different from zero, $b \pm SE$ = .37 ± .53, *CI* = [-.68, 1.43], but RFc x plus switch interaction was positive, $b \pm SE$ = 1.4 ± .61, *CI* = [.21, 2.62].

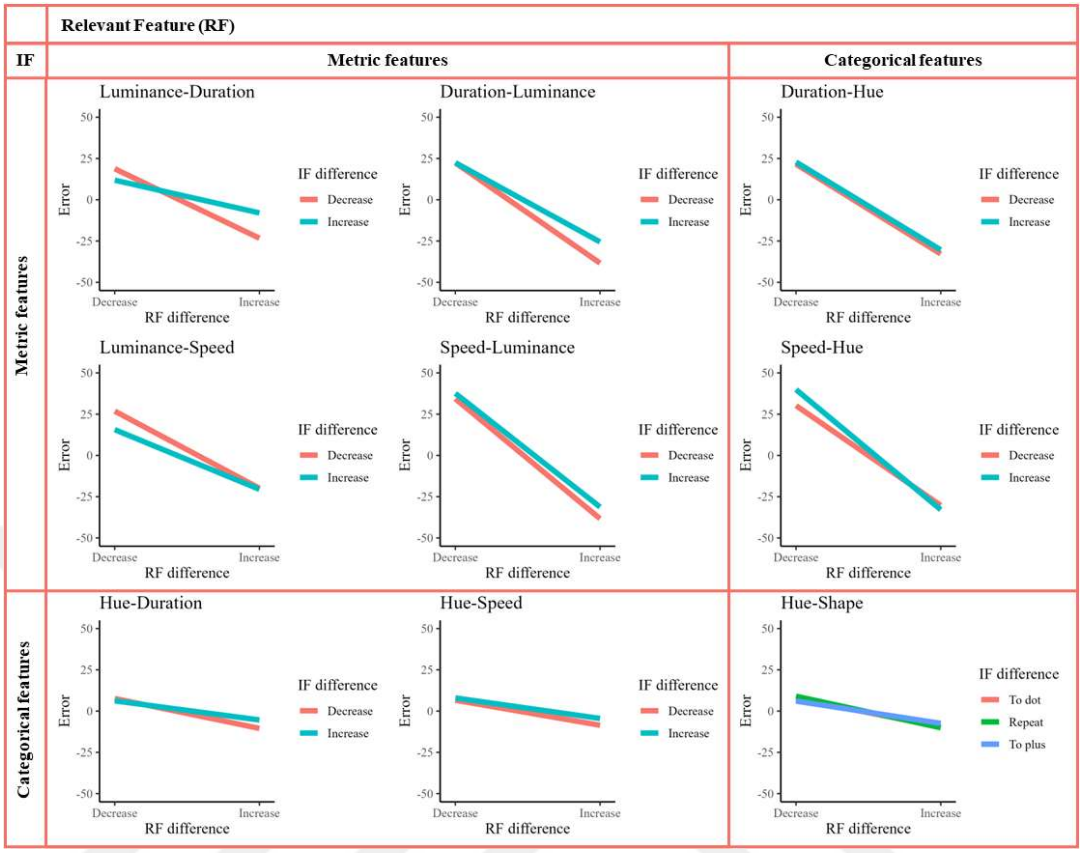


Figure 8. Error as a function of relevant feature (RF) difference and irrelevant feature (IF) difference

Note: Decrease and increase of RF and IF refer to a 100 unit change in the 100-unit scale to depict the most extreme cases of the interaction.

3.3 Estimation task discussion

The previous literature on TEC was dominated not only by categorical stimulus features like color, shape and dichotomous location (e.g. up versus down), but also categorical actions like two-alternative forced-choice keypress tasks which made the interpretation of the forced-choice results harder: Whether the implication of categorical stimuli involving in the action selection processes is due to the choice of

the alternative-forced-choice categorical responses as a bias or a genuine dominance of the categorical stimuli in the action selection governed by relevant neural mechanisms. To disambiguate the results from the forced-choice task and to better understand the selection of continuous actions, the current study adapted the feature repetition paradigm to a continuous framework. Instead of using a two-alternative forced-choice keypress task, we have instructed participants to click and drag a mouse and instead of a dichotomous "feature repetition versus alternation" variable, we have calculated a continuous feature change variable to be used as the independent variable. Since TEC does not discuss metrical stimulus features, we first analyzed the data using feature changes without direction with the assumption that change in any direction would result in a partial repetition cost. Hence, both a switch from 50 to 75 and a switch from 50 to 25 was registered as a 25-unit change. This analysis showed no interaction in any experiment. One major limitation of our study was that the action had to start from the leftmost end of the scale at every trial and participants could keep the mouse button pressed while deciding on their response. This flexibility could be the reason behind the lack of interaction in response times. A different experimental paradigm which would enforce a strict response time limitation or one which would prevent hovering over the response and adjusting the response freely.

To truly reflect the metric characteristics of the stimulus feature in the analyses, we analyzed the errors of the participants with directional feature changes, i.e. a switch from 50 to 25 was registered as -25 and a switch from 50 to 75 was registered as 25. Error was also recorded with its sign to distinguish underestimations (negative errors) and overestimations (positive errors). The results from this analysis

revealed several factors involved in the connection between the features and the response.

The first factor in continuous stimulus-response binding is task-relevancy. In all experiments as can be seen in Figure 8, participants had negative errors (underestimations) when RF increased and positive errors (overestimations) when RF decreased. This suggests that the response was closer to the response given in the preceding trial and can be due to an influence from the previous trial (Fig 9a). For task-irrelevant stimulus features, saliency is an important factor. Despite containing the same features, the luminance-speed and speed-luminance experiments yielded different results with the speed-luminance experiment showing no interaction. We think that the saliency of speed may have overshadowed the effect of luminance. In the current study, whereas the ranges that the stimulus features could take values from were set up to ensure that the far edges of the scale are easily discriminable, equating the perceptual distance of different feature ranges through psychophysical methods (as was done in Exp. 1 of forced-choice study) could control the effect of saliency. Since relevancy and saliency have been suggested as factors that determine the inclusion of features in an event file (Hommel, 2004), it is important that the impact of these factors have been replicated in this continuous framework.

More importantly, a feature being categorical/ventral and metrical/dorsal is also an important aspect of the RF x IF interaction. The most consistent interactions in our data set were observed in completely metrical and completely categorical experiments. Mixed feature pairs, on the other hand, did not show a clear pattern. The pattern of interaction in the current experiments, however, suggest a different mechanism than the spreading activation account. The spreading activation account and TEC in general claim that each sensory and motor feature in an event file is

bound to one another and the activation of one feature triggers the entirety of the event file (Frings, Hommel, et al., 2020; Frings, Koch, et al., 2020; Hommel, 1998; Hommel, 2004). The current experiment, however, suggests that metric stimulus features are processed in a sensory system, presumably the magnitude system as proposed in a theory of magnitude (ATOM; Walsh, 2003). In this magnitude system, metric stimulus features like location, size, distance, luminance, amount, speed, duration and loudness are processed together and the increase in the intensity of one feature can increase the perceived magnitude of other features, too (Alards-Tomalin et al., 2015; Ayhan et al., 2009; Bueti & Walsh, 2009; Burr et al., 2010; Gulhan & Ayhan, 2019; Kanai et al., 2006; Kaneko & Murakami, 2009; Serrien & Spapé, 2022; Walsh, 2015). The interaction within the magnitude system can explain the main effect of IF and the interactive effect of RF and IF on error.

The intensity of IF, generally, has a positive relationship with error, meaning that IF increases lead to overestimations, whereas IF decreases lead to underestimations. I propose that IF may be impacting responses by influencing the perceived magnitude of RF (Fig. 9a). When both features increase, the increase in IF shifts the perceived magnitude of RF to a higher degree and leads participants to a higher response. Since a higher response is aimed, even the shift towards the previous response becomes closer to the required response. A similar mechanism is seen in the opposite direction when both features decrease (Fig. 9b). This mechanism assumes that metric stimulus features can interact with each other in the magnitude system but only the task-relevant features are directly connected to actions. This model needs to be reworked and refined to understand the effect of saliency as well. However, since the current literature does not provide data to test this model, further research on continuous actions is needed.

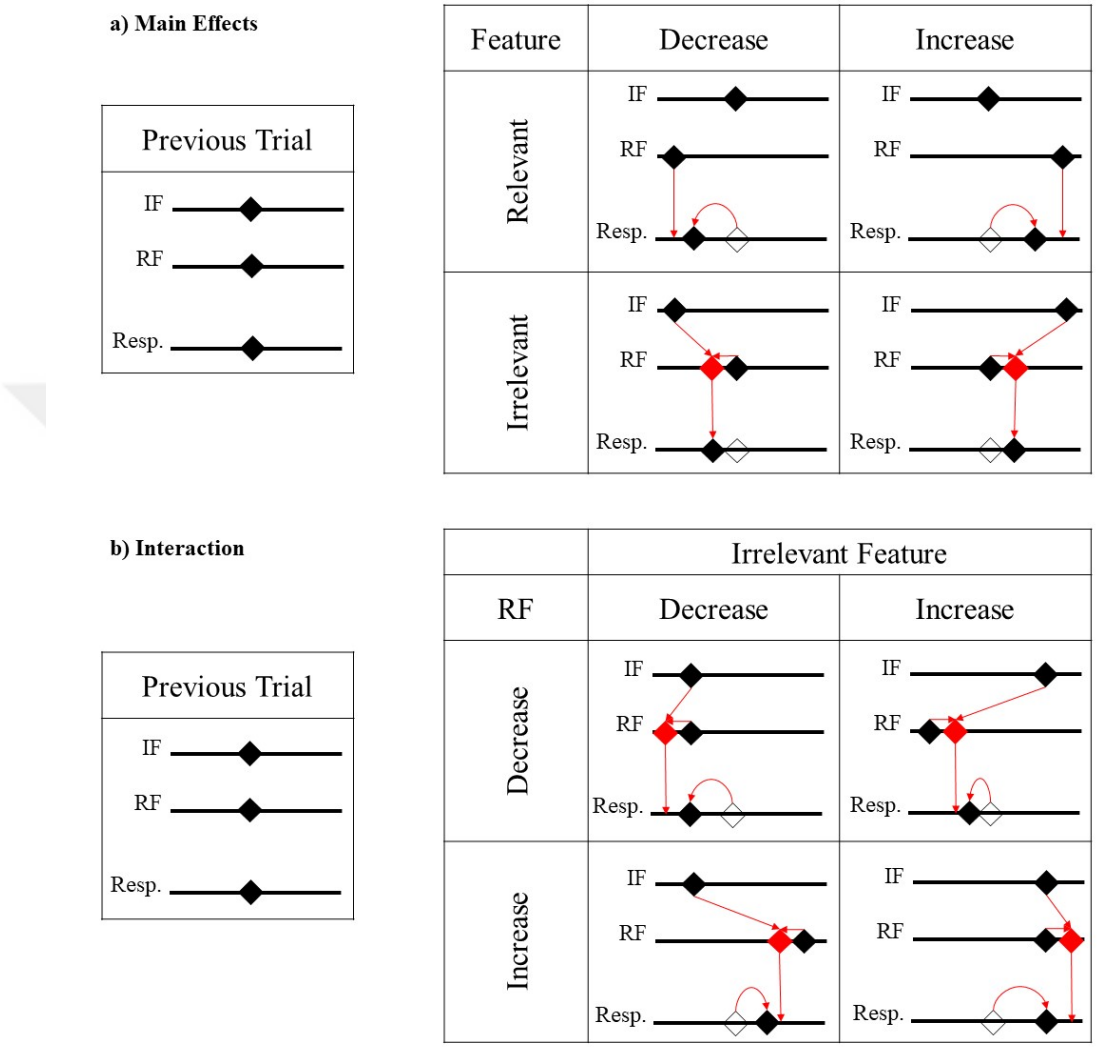


Figure 9. The model explaining how the difference between the intensity of the relevant feature (RF) and that of the irrelevant feature (IF) impacts responses (Resp.)

The proposed mechanisms for the main and interactions effects of RF and IF on responses are depicted. Black lines represent the scales/systems used to measure metric stimulus features and response location. On the left side is the RF, IF and

response observed in the previous trial and on the right side, are different possibilities of the current trial. Red diamonds in the RF scale show the perceived RF and empty diamonds in the Resp. scales show the previous response location. a) When the intensity of the RF increases or decreases, the previous response affects the selection of the current response, resulting in an error towards to previous response. When IF decreases or increases, it affects the perceived magnitude of RF, leading to negative or positive errors, respectively. b) When both features decrease compared to the previous trial, the perceived magnitude of RF decreases even further and causes the participants to aim for a lower response. Combined with the shift towards the previous response, we see a smaller deviation from the correct response as opposed to trials in which one feature increases and the decreases.

Hue and duration interacted with each other to create the pattern proposed by the model above in the hue-duration but not the duration-hue experiment. The opposite pattern (an interaction in the duration-hue but not the hue-duration experiment) was noted in the forced-choice task. Because changing the task from a two-alternative forced-choice to a continuous estimation task caused the pattern to shift, we can more confidently state that action type determines the weight given to different feature types with categorical actions favoring categorical stimulus features and continuous actions prioritizing metric action. The major obstacle to this interpretation is the results from the speed-hue experiment which showed a pattern opposite to all other interactions in our data set. The mechanisms behind this result are unclear. Perhaps most surprisingly, the hue-shape experiment showed a pattern very similar to the other experiments. Since all experiments but hue-shape used only

dots, the plus signs may have been salient enough to bind to the actions. With further studies on the communication between the ventral and dorsal visual pathways, these results could be better understood and explained in the future.

CHAPTER 4

CONCLUSION

To summarize, the forced-choice task demonstrated that the inclusion of a stimulus feature in an event file depends on three factors: relevancy, saliency and as a novel discovery of our current study: feature type. If a feature is relevant to the task, it is necessarily bound to the response and included in the event file. When a feature is irrelevant, its saliency becomes important. If the feature is not salient enough, it could totally be ignored, whereas a salient feature is automatically integrated in the event file. The last factor works in a more complicated manner. Categorical-categorical RF-IF pairs show the strongest integration of a feature, followed by metrical-metrical pairs. Using one pair from each type creates less consistent interactions. Reaction time and error rate analyses show different patterns, suggesting that these two measures may get influenced by action selection and control differently.

The estimation task also supported the previous literature and showed that task-relevancy and saliency determine the inclusion of stimulus feature in the selection of continuous actions and congruent with the forced-choice task, feature type came up as an important factor. The selection of continuous actions gives more weight to metric stimulus features but the mechanisms through which these features impact motor processes seem to be different than the classic connectivist approach proposed by TEC which is better suited to explain categorical features and categorical actions that prioritize them.

To truly understand the difference between categorical and metrical sensory and motor features, future research needs to 1) use varied stimuli to make sure that

effect generalize to different feature types and modalities and 2) adapt conventional experimental paradigms to continuous actions and continuous variables to investigate if phenomena that researchers take for granted are specific to categorical features. Especially for a theory like TEC which suggests that actions are processed based on their sensory precedents, correlates, and consequences, every finding should be scrutinized from a low-level perception perspective with rigorous psychophysical methods and studies should be designed with the neural structure of the sensory systems taken into consideration. Adaptation of classical experimental paradigms to setups with continuous variables was hindered by statistical analysis method but with the help of newer statistical methods like linear mixed models and Bayesian model fitting, the analysis of such experiments has ceased to be a problem. Another option is to conduct classical experimental paradigms and record non-categorical task-irrelevant motor features when possible (such as response duration and response force) and analyze how the experimental paradigms affect continuous motor features.

APPENDIX A

ETHICS COMMITTEE APPROVAL

Evrak Tarih ve Sayısı: 10.11.2022-97038

T.C.
BOĞAZİÇİ ÜNİVERSİTESİ
SOSYAL VE BEŞERİ BİLİMLER YÜKSEK LİSANS VE DOKTORA TEZLERİ ETİK İNCELEME KOMİSYONU
TOPLANTI KARAR TUTANAĞI

Toplantı Sayısı	:	36
Toplantı Tarihi	:	09.11.2022
Toplantı Saati	:	16:00
Toplantı Yeri	:	Zoom Sanal Toplantı
Bulunanlar	:	Doç. Dr. Arhan S. Ertan, Doç. Dr. Senem Yıldız, Dr. Öğr. Üyesi Yasemin Sohtorik İlkmen, Dr. Öğr. Üyesi Ayşegül Metindoğan
Bulunmayanlar	:	Prof. Dr. Feyza Çorapçı, Dr. Öğr. Üyesi Harun Muratoğulları

Batuhan Ayberk Koçak
Psikoloji

Sayın Araştırmacı,

26 Mayıs 2022 tarihinde SBB-EAK 2022/53 sayısı ile onay almış "Uyaran Özelliklerinin Uyaran-Motor Hareket Eşleşmesine Etkisi" başlıklı araştırma projenizde yapmış olduğunuz değişiklikler komisyonumuz tarafından 9 Kasım 2022 tarihli toplantıda incelenmiş ve uygun bulunmuştur.

Bu karar üyelerin toplantıya çevrimiçi olarak katılımı ve oy birliği ile alınmıştır. Onay mektubu üye ve raportör olarak Yasemin Sohtorik İlkmen tarafından toplantıya katılan bütün üyeler adına e-imzalanmıştır.

Saygılarımızla, bilgilerinizi rica ederiz.

Dr. Öğr. Üyesi Yasemin
SOHTORİK İLKMEN
ÜYE

e-imzalıdır
Dr. Öğr. ÜyesiYasemin Sohtorik
İlkmen
Öğretim Üyesi
Raportör

SOBETİK 36 09.11.2022

APPENDIX B

PARTICIPANT INFORMATION AND CONSENT FORM

(ENGLISH TRANSLATION)

Project focus: How the human mind encodes the stimuli in the environment and the responses to these stimuli has always been an attention-grabbing field of research within psychology. Throughout the years, different theories have been proposed to explain the association of stimuli and actions. In this study, two theories on stimulus-response associations will be compared and the possibility of their integration will be investigated. For this purpose, we will ask you to respond via a keypress on the keyboard or a computer mouse movement to the stimuli made up of moving dots on-screen. This study will take place in Vision Lab with the approval of the Boğaziçi University Social and Human Sciences Human Research Ethics Committee.

Consent: We invite you to participate in behavioral and psychophysical experiments which will require you to conduct different actions based on different stimulus features. All experiments in the study are estimated to last 2 hours in total.

Throughout the experiment, the accuracy and timing of your responses will be recorded and your personal information (age, gender, dominant hand) will be asked. You have the right to not disclose your personal information. Your data will not be matched to your name, will not be accessible to anyone other than the experimenters, and will only be used in academic articles and presentations.

The stimuli in the study will consist of only moving dots. There are no foreseen psychological or emotional risks in the experiment. A break every 30

minutes is planned to prevent any fatigue that can arise from staying still and looking at a screen for a long time. However, you can take a break anytime you feel tired. Participation is completely voluntary and you have the right to leave the experiment anytime you wish to. Upon your request, your data will be terminated.

Before signing this form, please ask if you have any questions about the study. If you have any questions later, you can contact Assoc. Prof. İnci Ayhan at any given time. You can also consult Boğaziçi University Social and Human Sciences Human Research Ethics Committee (sbinarek@bogazici.edu.tr) regarding your rights in this study.

I understood what was told to me about the study and what is written above. I have received a copy of this form.

I agree to participate in the study.

Participant Name & Surname	
Date (DD/MM/YYYY)	
Signature	

APPENDIX C

PARTICIPANT INFORMATION AND CONSENT FORM

(ORIGINAL TURKISH)

Proje konusu: İnsan zihninin dış ortamdaki uyaranları ve bu uyaranlara verilen tepkileri nasıl kodladığı psikoloji biliminde hep ilgi çeken bir araştırma alanı olmuştur. Uyaranlar ve motor hareketlerin etkileşimini açıklamak için yıllar içinde farklı kuramlar ortaya atılmıştır. Bu çalışmada hareket-uyaran eşleşmesiyle ilgili önermelerde bulunan iki kurama odaklanılıp bu kuramlar birbirleriyle karşılaştırılacak ve entegrasyonlarının ne kadar olası olduğu incelenecektir. Bu incelemenin yapılabilmesi için sizden ekrana gelecek noktalardan oluşan uyaranlara, klavyedeki tuşlara basarak ya da bilgisayar faresine tıklayıp sürükleyerek tepki vermeniz istenecektir. Bu çalışma Sosyal ve Beşeri Bilimler İnsan Araştırmaları Etik Kurulu onayıyla, Görsel Algı Laboratuvarı'nda gerçekleştirilecektir.

Onam: Sizi farklı uyaran özelliklerine göre farklı motor hareket örüntüsünde bulunmanızı gerektirecek davranışsal ve psikofiziksel deneylere davet ediyoruz. Çalışmadaki tüm deneylerin toplam süresinin yaklaşık 2 saat sürmesi öngörülmektedir.

Deney sırasında tepkileriniz doğruluğu ve süresi kaydedilecek ve kişisel bilgilerinizden sadece yaşınız, cinsiyetiniz hangi elinizin baskın olduğu sorulacaktır. Kişisel verilerinizi paylaşmama hakkına sahipsiniz. Veriler adınızla eşlenmeyecek ve deney yürütücülerinden başka kimsenin erişimine açık olmayacaktır ve sadece akademik makale ve sunumlarda kullanılacaktır.

Çalışmada sunulacak uyaranlar sadece hareketli noktalardan oluşacaktır. Deneyin size psikolojik veya duygusal bir risk getirmesi beklenmemektedir. Uzun süre sabit kalmanın ve ekrana bakmanın yol açabileceği yorgunluğun önüne geçmek için yarım saatte bir ara verilmesi planlanmaktadır. Ancak kendinizi yorgun hissettiğiniz her an ara verilebilirsiniz. Katılım tamamen gönüllülük esasına dayalıdır ve istediğiniz zaman deneyden çıkma hakkına sahipsiniz. Talep ettiğiniz takdirde sizden toplanan tüm veri silinecektir.

Bu formu imzalamadan önce, çalışmayla ilgili sorularınız varsa lütfen sorun. Daha sonra sorunuz olursa, Doç. Dr. İnci Ayhan'a sorabilirsiniz. Araştırmayla ilgili haklarınız konusunda Sosyal ve Beşeri Bilimler İnsan Araştırmaları Etik Kurulu'na (sbinarek@boun.edu.tr) da danışabilirsiniz.

Bana anlatılanları ve yukarıda yazılanları anladım. Bu formun bir kopyasını aldım.

Çalışmaya katılmayı kabul ediyorum.

Katılımcının Adı Soyadı	
Tarih (gün/ay/yıl)	
İmza	

APPENDIX D

ERROR RATE (ER) RESULTS

B.1. Main Experiments

B.1.1. Metric-Metric Combination

In the luminance-duration experiment, the interaction between RF and IF did not affect ER, $F(1, 20) = .024$, $p = .879$, $\eta^2_p = .001$. This interaction was significant in other metric-metric combinations, $F(1, 15) = 10.515$, $p = .005$, $\eta^2_p = .412$ for duration-luminance, $F(1, 21) = 20.65$, $p < .001$, $\eta^2_p = .496$ for luminance-speed, and $F(1, 15) = 5.94$, $p = .028$, $\eta^2_p = .284$ for speed-luminance. Unlike the interaction in RT analyses, IF had opposite and significant effects in RF repetition and alternation conditions i.e., IF alternation increased ER when RF repeated but decreased ER when RF also alternated.

B.1.2. Metrical-Categorical Combination

RF-IF interaction was insignificant in the duration-hue experiment, $F(1, 21) = 1.292$, $p = .269$, $\eta^2_p = .058$. The speed-hue experiment showed a significant interaction between RF and IF, $F(1, 21) = 5.477$, $p = .029$, $\eta^2_p = .207$. Simple main effects of the irrelevant feature hue were similar to the metric-metric experiments with opposite simple effects but the effects were only marginally significant, $t(21) = 1.854$, $p = .078$ for RF repetition and $t(21) = 1.915$, $p = .069$ for RF alternation.

B.1.3. Categorical-Metrical Combination

RF and IF did not interact in neither the hue-duration experiment, $F(1, 20) = 1.479$, $p = .238$, $\eta^2_p = .069$, nor the hue-speed experiment, $F(1, 21) = 3.433$, $p = .078$, $\eta^2_p = .140$.

B.1.4. Categorical-Categorical Combination.

The hue-shape experiment had a significant interaction term, $F(1, 21) = 7.008$, $p = .015$, $\eta^2_p = .250$. Shape affected PE if hue repeated, $t(21) = 2.57$, $p = .018$, but not when hue alternated, $t(21) = 1.374$, $p = .184$.

B.2. Saliency Control Experiments

RF and IF interacted significantly in the duration-luminance, $F(1, 14) = 12.845$, $p = .003$, $\eta^2_p = .478$, and duration-hue experiments, $F(1, 14) = 7.701$, $p = .015$, $\eta^2_p = .355$. In both cases, IF alternation increased ER when coupled with RF repetition and decreased ER when coupled with RF alternation. The interaction was not significant in the luminance duration, $F(1, 14) = 2.462$, $p = .139$, $\eta^2_p = .150$, and hue-duration experiments, $F(1, 14) = .475$, $p = .502$, $\eta^2_p = .033$.

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