THE ROLE OF TIME PERCEPTION IN GOAL-DIRECTED ACTION

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The Role of Time Perception in Goal-Directed Action

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DECLARATION OF ORIGINALITY

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ABSTRACT

The Role of Time Perception in Goal-Directed Action

In pursuit of a desired future state, much of human behavior is geared toward achieving certain goals. How are these goals represented in the cognitive system, and how do they gain the power to control bodily movements? According to the ideomotor theory, whenever actions are performed, they become bi-directionally associated with the accompanying perceptual effects. These action-effect associations are suggested to form the basis of goal-directed actions. By anticipating the perceptual effects related to intended goals, associated goal-directed actions can be generated. The claims of ideomotor theory received substantial empirical support in recent years. However, previous studies primarily used momentary effects, and whether temporal effect features can also be associated with and used in performing goal-directed was not directly investigated. The present study utilized a two-staged ideomotor learning paradigm to address this gap. In the acquisition stage, participants established action-effect associations by performing actions and experiencing their dynamic effects, which specifically involved duration as the contingent feature. In the subsequent test stage, participants were instructed to respond to the previously associated action-effects. Overall, the actions compatible with the acquired action-effect mapping were facilitated. However, this facilitation appeared to rely on the saliency of the to-be-acquired dynamic effects compared to already present body-related effects during acquisition. The findings indicate that people can anticipate how long the effects of their actions will last and that the temporal effect features might play an important role in goal-directed action control.

ÖZET

Zaman Algısının Hedef Odaklı Eylem Üzerindeki Rolü

İnsan davranışlarının büyük bir kısmı gelecekte oluşması istenen bir durumu elde etmek için belirli hedefler tarafından yönlendirilir. Bu hedefler bilişsel sistemde nasıl temsil edilirler, ve bedensel hareketleri kontrol edebilme gücüne nasıl erişirler? İdeomotor teoriye göre eylemler gerçekleştirildiğinde onları takip eden algısal etkiler ile iki yönlü olarak ilişkilendirilirler. Bu eylem-etki ilişkilerinin, hedef odaklı eylemlerin temelini oluşturduğu öne sürülmektedir. Ulaşılmak istenen hedefe yönelik algısal etki aktifleştirilerek ilişkili eylem istenen hedef odağında gerçekleştirilebilir. Son yıllardaki deneysel araştırmalar ideomotor teorinin bu önermelerini destekler niteliktedir. Ancak, önceki çalışmalar genellikle anlık etki özelliklerini kullanmış ve zamansal boyutta farklılaşan etki özelliklerinin de hedefe yönelik eylemlerde kullanılabileceği olasılığı doğrudan incelenmemiştir. Mevcut çalışmada bu konuyu ele almak için iki aşamalı ideomotor öğrenme paradigması kullanıldı. Edinim aşamasında, katılımcılar eylemlerinin sonucunda oluşturdukları dinamik etkileri deneyimlediler. Akabindeki test aşamasında katılımcılar ilk aşamada ilişkilendirilmiş etkilere yönelik eylemler yaptılar. Çalışma sonucunda önceden edinilmiş eylem-etki ilişkileriyle uyumlu olarak gerçekleştirilen eylemlerin performansının arttığı, fakat bu performans artışının edinim aşaması süresince edinilen yeni etkilerin halihazırdaki dokunsal etkilere göre belirginliğine bağlı olabileceği gözlenmiştir. Bulgular, insanların eylemlerinin etkilerinin zamansal özelliklerini önceden tahmin ettiklerini ve zamansal etki özelliklerinin hedefe yönelik eylemlerin gerçekleştirmesinde önemli bir rol oynayabileceğini göstermektedir.

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To my dear wife, Elif

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CHAPTER 1

INTRODUCTION

People do not require an external stimulus to initiate actions. Instead, we possess a remarkable ability to direct our actions toward achieving desired goals in the future. However, the representation of these goals in the cognitive system, and the mechanisms under which they acquire the capacity to direct our bodily movements, remains an intriguing puzzle in the action control literature.

By implication, goal-directed actions depend on a knowledge of which actions lead to which outcomes. With this knowledge, an agent may then anticipate the desired outcomes to select appropriate actions to achieve them. This dynamic calls for an explanation of the cognitive mechanism that binds goals with actions and of the translational mechanism that can turn the goals in mind into observable behaviors. The ideomotor theory (Shin et al., 2010) and its more recent formulations (Hommel, 2019; Hommel et al., 2001) provide a straightforward explanation for these mechanisms by suggesting that whenever an action is performed, people automatically create bidirectional associations between the motor codes and the codes of their perceived perceptual effects (i.e., action-effects). Once these associations are formed, people can initiate the desired movement by simply activating or "imagining" the associated perception, which, in turn, activates the internal representation of motor codes and subsequently primes the associated action. The associative part of this process is usually termed ideomotor learning (Elsner & Hommel, 2004; Pfister et al., 2011; Wolfensteller & Ruge, 2011), whereas the anticipation part is usually described as effect-based action

control (Eder & Dignath, 2017; Kunde et al., 2011; Pfister, 2019). These processes are typically investigated with two distinct experimental paradigms: The response effect compatibility paradigm (REC) and the two-stage ideomotor learning paradigm (IML) (Shin et al., 2010). In the REC paradigm, participants perform actions that produce contingent sensory effects that share either compatible or incompatible features on a spatial (Janczyk et al., 2015; Kunde, 2001) or temporal dimensions (Kunde, 2003) with the actions. For instance, a left action can produce visual effects on the left (compatible) vs. on the right (incompatible) in separate experimental conditions. Then, the reaction times of the actions that produce compatible effects are contrasted with the ones that produce incompatible effects.

As compatible or incompatible action effects appear only after action execution, the facilitation of actions that produce compatible effects is considered as a straightforward measure of anticipative processes assumed by ideomotor theory (Pfister et al., 2014). Moreover, the IML paradigm is used to investigate whether novel compatibilities can be forged between actions and effects that do not inherently share a common feature. This investigation is conducted in two separate stages. In the acquisition phase, actions are contingently followed by auditory (Elsner & Hommel, 2001; Pfister et al., 2011) or visual (Herwig & Horstmann, 2011; Hommel et al., 2003) effects. For instance, a left action can be contingently followed by a low-pitch tone, and the right action can be followed by a high-pitch tone. In the subsequent test phase, the compatible responses to the previously paired effects (low tone - left response, high tone - right response) are contrasted with the incompatible responses (low tone - right response, high tone - left response). Typically, these studies report that the responses in compatible conditions are facilitated, whereas incompatible actions are hindered (i.e.,

the ideomotor effect). Previous studies using the IML paradigm have shown that people can associate actions with various novel outcomes in visual and auditory domains (Moeller & Pfister, 2022), even after experiencing the contingency 12 times in the acquisition phase (Wolfensteller & Ruge, 2011).

Notably, the effects used in these studies were exclusively momentary or instantaneous (e.g., hearing a tone or seeing a letter). However, merely considering the momentary features of the goals we intend to achieve may not suffice for retrieving suitable actions when we are in an environment that is constantly changing or, in any event that requires actions to be performed with a consideration of the ongoing temporal flow. Therefore, the apparent focus in the literature on the effects that do not have temporal features contrasts with the nature of the effects that our actions produce in daily life. It seems possible that we also anticipate the temporal features of the goals we want to achieve, and this possibility is the focal point of this thesis. Using the two-phased action-effect learning paradigm, the aim is to uncover whether actions can be associated with the temporal features of their outcomes and whether these temporal features can facilitate the associated actions.

CHAPTER 2

LITERATURE REVIEW

This section aims to provide a clear background and context for the research questions of the thesis. First, the key concepts from the relevant literature and the theoretical framework underpinning goal-directed actions will be introduced. Then, the experimental paradigms that were used to investigate these actions will be systematically described. Finally, the gap in the existing literature that this research aims to address will be presented.

2.1 Two modes of action control: Stimulus-based vs. effect-based actions

People perform actions to either realize the effects they desire to produce in the environment or to respond to the environmental requirements. For instance, the action of reaching for a cup can be endogenously activated by the agent's intention to drink the coffee inside it. In contrast, the action of letting it go after realizing that the cup is too hot occurs as a response to an external physical stimulus registered through the sense of touch. In our daily life, we perform many actions like these, some to produce stimulus and some to respond.

Different terminologies have been used to address these two types of actions in the literature. Typically the terms “intentional,” “instrumental,” or “operant” have been used to address goal-directed actions, while “response” or “reaction” is used to define stimulus-based actions (Waszak et al., 2005). Although the executed movements may appear the same for both action types, neuroscientific evidence suggests that when

subjects perform goal-directed actions compared to stimulus-based actions. For example, by contrasting goal-directed actions and the actions in a choice reaction time task, Mueller et al. (2007) reported selective activation of the rostral cingulate zone (RCZ) for goal-directed actions. Apart from the distinct brain loci, the primary contrast of being activated by either external or internal factors implies that goal-directed actions are initiated by the mental visualization of desired future outcomes rather than by observation of external stimuli. In other words, stimulus-based action can be considered as a response to a sensation present during action selection, whereas goal-directed actions involve an intention to bring about an effect that is absent during action selection (Gozli et al., 2016). This conceptualization further asserts a difference in methodological matters of studying these action types (Hommel et al., 2001). Obviously, it is more convenient to design and manipulate external stimuli and explain the actions in physical terms instead of dealing with internal representations of goals that are not directly observable due to their implicit nature. As a consequence, attempts to develop a mechanistic understanding of how humans translate representations of goals into bodily movements were scarce in the early days of experimental psychology, or they were even actively suppressed throughout the dominance of behaviorist tradition (Stock & Stock, 2004).

Even after the cognitive revolution, which expanded the scope of psychological research beyond stimulus-response relationships and included internal perceptual processes and cognitive operations to experimental psychology, researchers have continued to utilize paradigms based on the standard model of information processing (Miller, 1956). This approach renders actions as the outcomes of sensory information that is processed within the cognitive system (Hommel, 2022), and it is reasonable to

study a proportion of human behavior by assuming that actions result from the flow of information through stimulus input to motor output, after all, people do really act in response to external stimuli in certain conditions. However, a considerable proportion of human behavior does not arise from observing an external stimulus. Therefore, a crucial part of human behavior would be left unexplored if actions were only considered as responses to the outputs of mental operations that are sourced from registering external stimuli. As Hommel (2013) previously noted:

> Most stimuli we are exposed to are generated by our actions: we smell the cologne because we have put it into our face, taste the marmalade because we dipped our croissant into it . . . Hence, we do not passively await stimuli to get us going but actively generate and seek the stimuli we intend to perceive. (p. 2)

Considering the importance of goal-directed actions for the human condition (Pennartz, 2018), how do we find a way to put internal sources of actions under experimental investigation, and how do we operationalize the goals as cognitive contents that direct our behavior? It would be helpful if goals were directly linked to the motor code that reliably produces them. Perceiving or imagining the goals would then be a way to perform actions that actually produce these goals. This is precisely what ideomotor theory proposes. In the following, the principles of ideomotor theory and the two paradigms that test its assumptions will be reviewed.

2.2 Ideomotor theory: Goals are represented as action-effects

People can effortlessly exert voluntary control over their bodily movements. However, this mechanism that explains voluntary actions, such as grasping a cup of coffee, pressing a key, or turning a bicycle, can be done without the agent having to calculate and coordinate the multitude of muscles involved. Even when there is an intention to

identify the motoric operations underlying these movements, it is possible to see that people are genuinely unaware of how exactly they conduct these operations. In order to steer a bicycle, for instance, the rider must push the handlebars toward the intended turning direction (i.e., countersteer) instead of the commonly conceived notion of pulling it backward (Muller, 2021). Accordingly, the classical ideomotor theory (Shin et al., 2010) and the more recent common coding principle of the theory of event coding (Hommel, 2019) suggest that actions can be generated through the anticipation of their perceptual effects, bypassing the need for conscious control of the motor apparatus that produce them. Since this suggested mechanism implies that the selection of actions happens through the anticipation of action-effects, it is important to note that ideomotor theory renders all actions, in essence, goal-directed.

As per the representational issue regarding the goals that were discussed in the previous section, the ideomotor theory proposes a cognitive mechanism. Accordingly, the theory suggests that whenever an action is made, it inevitably becomes associated with its contingent sensorial effects. These associations provide people with knowledge about what kind of effects are generated by what kind of actions, and agents can use these associations to anticipate the desired consequence in mind and activate relevant motor codes in order to control actions based on the intended goal. Correspondingly, another critical assumption of the ideomotor theory is that these associations between actions and the following effects are formed bidirectionally: Not only performing an action leads to the integration of its sensory effects with the motor codes involved in the action, but imagining or anticipating an effect can also activate the associated motor codes and generates the respective actions. As a result, when people desire to reach a certain goal, this desire activates the anticipation of the effects to be produced, and this

effect anticipation activates the appropriate actions, regardless of whether the intention is about what is perceived exogenously or whether it is about goals represented endogenously.

Typically, behavioral and neuroscientific evidence for the effect-anticipation process comes from experimental studies that use REC paradigms, while IML paradigms are used for investigating the assumption of bi-directional association. The following section will review the recent empirical evidence supporting both processes.

2.3 Influence of effect prediction on preceding responses: REC paradigms

Since the seminal work of Kunde (2001), a significant body of research that uses REC paradigms reported evidence supporting the idea that mental representations of action-effects are anticipated prior to the execution of the action. An important implication of these studies is that reaction times can be influenced by the events that occur after the actions have been performed, providing a direct observation of the influence of action-effect anticipation on action control. In essence, the REC paradigm utilizes the dimensional overlap between the features of actions and the features of action effects that happens right after action. The ideomotor effect in this paradigm refers to the phenomenon where reaction times take longer when there is an incompatibility between the response and the action outcome features compared to when there is compatibility.

The investigations using the REC paradigm have a similar reasoning as those on stimulus-response compatibility studies. The typical finding of these studies is that when there is any overlap between the stimuli and responses on a particular dimension, responding is generally quicker (and more precise) as opposed to having incompatible features on that dimension (Alluisi & Warm, 1990). For example, a right key press is

performed faster in response to a stimulus that is presented on the right compared to the left visual field, rendering action and stimulus spatially compatible (Proctor, 2011). Based on the ideomotor assumption that suggests people anticipate action effects prior to action execution, a similar compatibility phenomenon should occur between anticipated effects and responses. Although the study mainly focused on the compatibility between stimulus and effect relationship, the first evidence related to this Simon-like influence of action-effects was reported by Hommel (1993). In this study, participants responded to the pitch of a laterally presented tone with left or right keys. After pressing the keys, participants lit a lamp on either the same or on the opposite side of the response key. Regardless of the compatibility between tone location (stimulus) and response keys, the results revealed that the compatibility between the location of the light (effects) and response keys made reaction times faster. This finding implies that the classical Simon effect (Simon, 1969) could be reversed when the location of the responses matched the location of the action effects they produce. The first systematic investigation of REC was conducted by Kunde (2001). During the experiments, the participants were instructed to press keys arranged horizontally in response to a neutral target stimulus in the center of the screen. Each keypress resulted in a visual action effect, and the spatial compatibility between these effects and the keys was changed across conditions. In the first condition, the key location and effect location were compatible, meaning that the right key presses produced action effects on the right side, and the left key presses produced action effects on the left side. In the second condition, the key location and effect location were incompatible, meaning that the right key presses produced action effects on the left side of the screen and vice versa. Although participants were not instructed to create or attend to any specific outcomes of their actions, their reaction

times were faster in the compatible condition compared to the incompatible condition. Kunde explained that this finding was due to the anticipation of action effects before the execution of actions, as both conditions utilized identical target stimuli that the participants responded to. Furthermore, in an aviation simulation setting, Janczyk et al. (2012) made use of two distinct display types that are used plane cockpits (Figure 1).

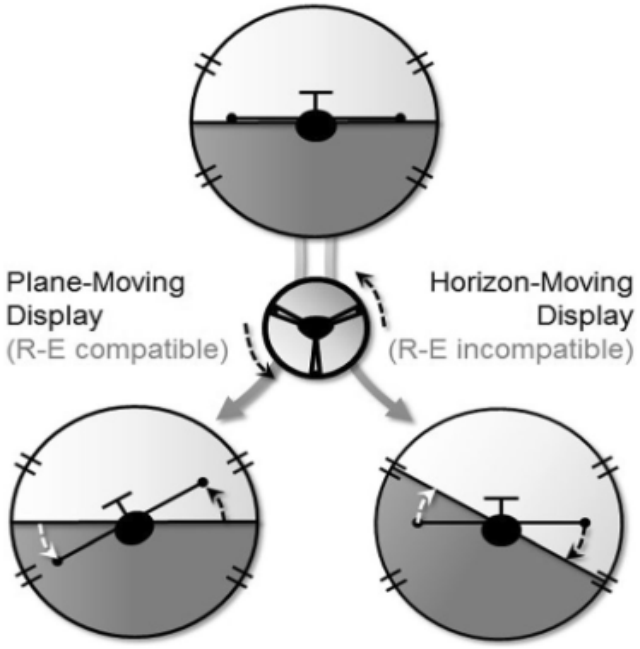


Figure 1. Depiction of experimental conditions in the study of Janczyk et al. (2015)

Reprinted from "Response-effect compatibility with complex actions: The case of wheel rotations." by Janczyk, M., Yamaguchi, M., Proctor, R. W. and Pfister, R. (2015). Attention, Perception, & Psychophysics, 77(3), 930–940

These displays have distinct ways of showing the tilt of the plane in response to the wheel rotations. In some displays, the wheel turns the image of the plane congruently to the turning direction, and in others, the horizon gets tilted incongruently to the wheel rotation while the plane image stays still. Consequently, plane-moving displays produce

compatible action-effects with the actions, while the horizon-moving displays produce incompatible action effects despite the matching implications of actions in both conditions. Researchers reported that mental rotations prior to actual actions facilitate manual wheel rotations in the plane-moving condition (when there are action-compatible visual effects) as opposed to the horizon-moving condition (when there are action-incompatible visual effects). In addition, Kunde et al. (2011) suggested that the REC phenomenon ensues in the control of facial expressions. They found that when participants were required to smile or frown, the expressions were generated quicker when they received compatible feedback from a virtual counterpart than when it was not. Furthermore, Pfister et al. (2014) have shown that the ideomotor effect can even arise in a REC paradigm which involves imaginary action effects that are believed to be produced by own actions but not physically experienced in person. Similar compatibility phenomena have been shown with many different domains of motor control and effect features. For example, Keller and Koch (2008) found that anticipations of upcoming notes contribute to the planning of note-compatible actions in musical performance.

In summary, there is sufficient evidence suggesting that anticipation of action consequences is indeed involved in generating motor responses. In line with the ideomotor theory, findings from REC studies show that a wide variety of features from consequences of actions, even when they are not yet perceptually present, can affect the actions that will produce them. It should be noted that the REC paradigm specifically relies on the use of predictable action effects that share physically compatible features vs. contrasting features with the actions that produce them, such as performing a left action and seeing a visual action-effect on the left side vs. right side. Considering the initial assumption of the ideomotor theory suggesting that the capability of performing

goal-directed actions arise from associating actions with their contingent effects, it is important to investigate the associative mechanism that created these response-effect compatibilities in the first place.

2.4 Acquiring novel action-effect associations: Ideomotor learning paradigms

Studies that employed REC paradigms clearly show that people exploit expected action-effect anticipations prior to the execution of actions. However, in order to control actions by anticipating their effects, first, the knowledge of what sort of actions reliably brings about what sort of effects needs to be acquired. Recalling the assumptions of the ideomotor theory, it was suggested that bidirectional action-effect associations are established by the mere experience of the contingent pairing of actions and their respective sensory outcomes. In this sense, another line of ideomotor research investigates the conditions in which action-effect learning takes place (Elsner & Hommel, 2001; Hommel et al., 2003; Pfister et al., 2011; Sun et al., 2020).

As summarized in the previous section, REC studies do not employ any prior learning stage to associate actions with their outcomes as they make use of natural compatibilities across action and perception dimensions. However, if people can readily anticipate the leftwards effect before making a leftwards action without an explicit learning process, such anticipations also should have been made possible by some sort of associative process that was forged by experiencing leftwards effects following leftwards actions throughout life. After all, people have observed that doing something with the left hand, for example, reliably results in leftward visual and proprioceptive perceptions ever since infancy. Correspondingly, in action-effect learning studies, people are exposed to novel sensory consequences following their actions and then tested to

determine whether this motor-sensory experience makes them acquire new action-effect associations. If experiencing the contingency between a particular action and a particular effect indeed creates a bidirectional association between the representation of the action and the representation of the effect, presenting the effect as an imperative stimulus should reactivate its representation and prime the associated action. Accordingly, the two-stage ideomotor learning (IML) paradigm that was initially proposed by Greenwald (1970) targets both the learning and the anticipation stages of effect-based action control (Figure 2).

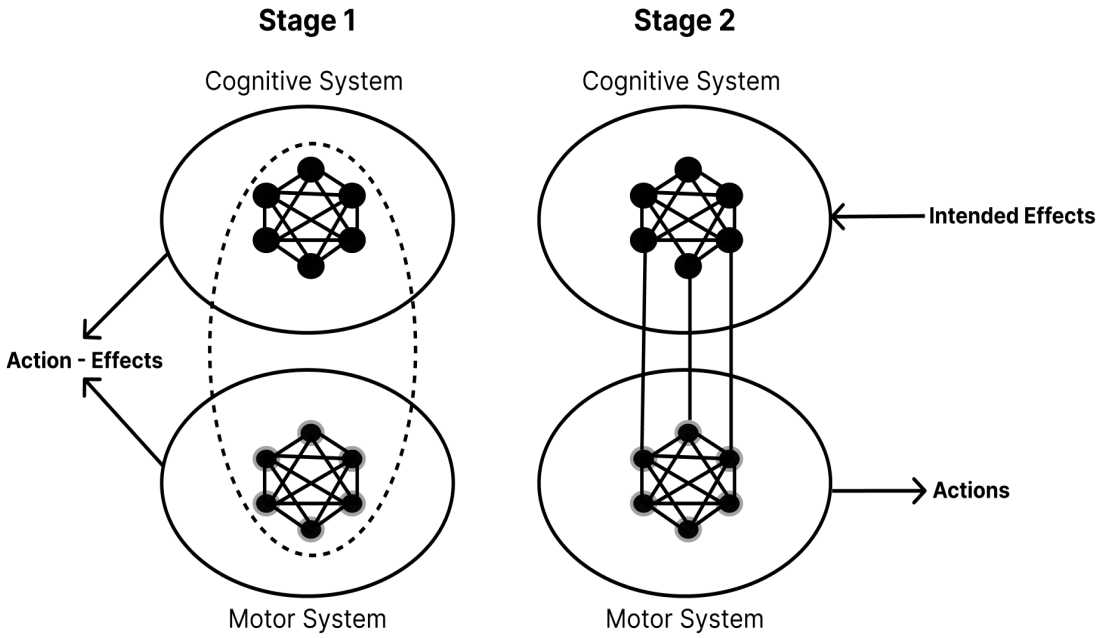


Figure 2. The two-stage model of action control

At stage one, motor codes producing a movement are integrated with perceptual codes of resulting effects. At stage two, actions are retrieved by accessing the motor codes through activating associated effect codes. Adapted from "Effect anticipation and action control." by Elsner, B., and Hommel, B. (2001). Journal of Experimental Psychology. Human

The central idea behind this paradigm is to simulate the natural occurrence of hardwired action-effect contingencies with novel action-effect pairings in the first stage (acquisition phase) and test whether experiencing these contingencies has really resulted in action-effect associations that can be anticipated during the selection of related actions in the second stage (test phase). In a seminal study, Elsner and Hommel (2001) first made subjects carry out free-choice left and right keypresses in response to a neutral stimulus in the initial acquisition phase. Here, each keypress action contingently produced an auditory effect with a particular feature (left key - low tone, right key - high tone). Although the effects were irrelevant to the task, the hypothesis was that the participants would spontaneously establish bidirectional action-effect associations between the motor codes of keypresses and the perceptions of the contingent tones. Two separate conditions employed forced-choice and free-choice designs in the test phase. In the forced-choice test phase, previous action-effects were presented as imperative stimuli in a choice reaction time task. One group of participants had to press keys in response to the tones that were compatible with earlier learned responses (low tone - left key, high tone - right key), while for the other group, the action-effect mapping was incompatible (low tone - right key, high tone - left key). Results showed that actions were performed significantly faster when they were compatible with the previously associated action-effects compared to when they were incompatible. In addition to this ideomotor effect observed in reaction times, researchers also observed that participants were more likely to choose the action that previously had produced the currently presented action-effect (e.g., they preferred pressing the left over pressing the right key when being presented with a low tone) when they were free to choose their responses in other experiments. These findings suggest that lateral key presses and low and high

tones indeed formed novel, arbitrary action-effect associations in a bidirectional fashion, as shown by the observation that these effects become primes of the associated actions. Similar findings have been reported for a wide range of actions and effects (Hommel & Elsner, 2009).

Although the IML paradigm has been investigated by pairing simple keypress actions with auditory effect features (Elsner & Hommel, 2001; Herwig & Waszak, 2012; Pfister et al., 2011; Sun et al., 2020), there is also evidence that suggests action - effect associations can be formed with arbitrary visual effects (Hommel et al., 2003; Wolfensteller & Ruge, 2011; Ziessler & Nattkemper, 2011). Moreover, Elsner et al. (2002) employed the IML paradigm and had participants undergo an acquisition phase in which they carried out free-choice key presses that contingently produced particular tones. In the following test phase, participants listened to a stream of sounds that contained various portions of previously acquired action-effect tones while their brain activity was measured by means of repeated PET scans. The analysis of the correlation between perceiving previously associated action-effects and activated brain areas revealed that the right posterior hippocampus and the supplementary motor area as the neural substrates of action-effect associations. In a subsequent fMRI study, Melcher et al. (2008) replicated this observation with a more sensitive design.

Taken together, a significant amount of evidence suggests that people can form novel action-effect associations with actions and effects that do not readily share a physical feature. Even though the ideomotor effect has shown to be robust in IML paradigms, previous research typically targeted the association of actions with momentary effect features that do not span out in time. Therefore, it is not known whether a temporal feature of an action effect, such as its duration, can be associated

with preceding actions and anticipated during action control (Janczyk et al., 2017). In the next section, we will finally review the current state of the literature on the effect of time perception on ideomotor actions.

2.5 Effect-based action control with temporal features

Optimal action control requires people to consider the time it will take until they reach their goals and select actions accordingly. Imagine a scenario where one wakes up later than usual in the morning and realizes that they have limited time to prepare and leave home to arrive at work on time. They usually achieve certain goals before leaving, such as dressing up, having breakfast, and brewing coffee. Given that the time is short, achieving all of these goals this morning is impossible. So, they sacrifice having breakfast, but some time might still be left for preparing the coffee. Suppose this person has bi-directional associations between actions needed to brew the coffee and the duration of their effects. In that case, they can anticipate the time until the coffee is prepared and decide based on this anticipation. People seem to be relatively capable of adjusting their actions based on the expected duration of their effects in such cases. Does this mean we also anticipate the temporal features of action-effects in action control?

The research suggests that the perception of duration is subject to changes around the time of actions (Ayhan & Ozbagci, 2020; Hughes et al., 2013). Despite this malleability of time perception during action control, there is evidence that the cognitive system trusts its perception of time just enough to exploit temporal information when performing actions. Indeed, Grosjean and Mordkoff (2001) provided the first evidence that suggests observing a dynamic stimulus with a specific duration can lead to the activation of temporal features of actions, thereby influencing the time it takes to

produce the action. In a stimulus-response compatibility paradigm, the participants were more accurate and faster when shorter-lasting stimuli required short keypresses and longer-lasting stimuli required long keypresses compared to the reverse of this mapping. In a subsequent study, Kunde and Stöcker (2002) showed that this S-R compatibility effect based on temporal features occurs even when the duration is a task-irrelevant stimulus feature. Here, the subjects pressed a single key for either short or long durations in response to the color of a visual stimulus presented for different durations. They reported a temporal variant of the Simon effect as short keypresses were initiated faster in response to a short as opposed to long stimulus duration and vice versa. As stimulus duration was not a task-relevant feature (color was), the researchers suggested that the duration of a stimulus automatically activates the responses of a corresponding duration, just as how stimuli perceived in a certain location activate responses of corresponding locations in classical Simon tasks.

Of particular importance to the topic of this thesis, the duration of action-effects was shown to influence the preceding actions as well. Using a REC paradigm (Kunde, 2003) has shown that the anticipation of how long the action-effects will last impacts the temporal features of actions. Here, the participants responded to two color stimuli with either short or long key presses. Critically, short or long tones were presented as action-effects after the responses had been made. The duration of the action-effect could be either compatible (short/long responses followed by short/long effects) or incompatible (short/long responses followed by long/short effects). Similar to the spatial response-effect compatibility effects as outlined in the previous section, the responses were performed faster when response and effect duration was compatible. In addition to this compatibility effect, Kunde found an overall influence of effect duration on reaction

times. Irrespective of the compatibility, actions that precede longer action-effects were performed slower, while actions that precede shorter action effects were performed faster and it has been argued that it takes longer to anticipate longer effects compared to shorter effects. Moreover, Kiesel and Hoffmann (2004) replicated these findings with an experimental design in which actions were not performed with regard to their temporal features. This time, the participants were instead simply instructed to press one of two response keys as quickly as possible while action-effects with either short or long durations followed their responses. Again, the overall influence of effect duration in previous responses was observed: Actions that were followed by longer effects took longer to initiate. In light of these findings, one can ask whether we can also form novel action-effect associations based on the temporal features of action effects. It would be adaptive to do so, especially for situations in which the agents are in a dynamic relationship with their surroundings. Imagine someone driving a car on a highway and intending to turn right at the next junction. The intended effect (perceiving the car as making a successful turn) must be achieved by retrieving a set of actions that are anticipated to produce both spatial and temporal effects. After all, not considering the duration of the consequences while adjusting the actions would most likely result in an accident, as anticipating the time it would take for the effects to occur - or how long they will last - matters for selecting suitable actions in such dynamic situations. Therefore, people should be able to acquire action-effect relationships to strategically select suitable actions for producing effects for the intended durations.

Regarding the role of time perception in the context of action-effect learning, temporal contiguity has been shown as an important criterion for acquiring action–effect associations (Elsner & Hommel, 2004). The authors of this study emphasized the role of

time as a connective element that influences the strength of the associative link between momentary actions and effects. Crucially, this perspective renders temporal information as a catalyst for establishing the action-effect association. However, it does not necessarily suggest that time can be the very essence of the association. The first evidence regarding the anticipation of temporal information in effect-based actions was reported by (Haering & Kiesel, 2012). Here, the participants first responded to imperative stimuli and observed action - effects in an acquisition phase. Importantly, each response triggered an effect after a specific delay. Contrary to the traditional ideomotor learning paradigms (Elsner & Hommel, 2001) that often asks participants to respond congruently or incongruently to the previously associated action - effects, the test phase in this study required participants to detect the onset of action effects that appear after a learned delay compared to earlier/later than expected. Results suggested that detections were made quicker when the effect appeared after a learned delay compared to the trials in which the effects were delayed incongruently. Even though this finding was suggestive in the sense that temporal regularities between actions and effects can be acquired, it provides no direct evidence for temporal information, specifically the delay between action effect, itself to be represented as an action-effect feature that can be selectively anticipated to bring associated actions.

Furthermore, Dignath et al. (2014) investigated whether delays between actions and effects can be integrated together to form a unified effect feature to be anticipated during action selection. In a series of experiments, they used the classical action-effect learning paradigm and tested participants in both free-choice and forced-choice test phases. In the acquisition phase, different keypress actions were followed by contingent auditory effects. Notably, there was a fixed 2000 ms of delay between the actions and

effects in the acquisition phase. Besides replicating the action-effect compatibility effect in free-choice conditions (compatible actions selected more frequently after perceiving their previously associated effects), the important finding was that only the compatible actions are initiated more slowly. Researchers argued that when participants performed compatible actions, seeing action-effect retrieves the compatible actions as well as the long time interval between these actions and the effects. In other words, the delay in between the action and effects was acquired as an Action - Delay - Effect sequence, and seeing the effect in the test phase activated the action codes through the delay in between, which manifests in longer reaction times for compatible actions. This effect was not due to the free-choice mode of action as the same effect ensued in the forced-choice condition as well: The reaction times were significantly longer in the blocks where stimulus-response mapping was compatible with the action-effect associations in the acquisition phase. In a subsequent study, Dignath and Janczyk (2017) further asked whether the delay between action - effects is represented and anticipated separately or integrated with the momentary effect identities. In three experiments, they manipulated the compatibility between actions and their auditory effects, while the delays between actions and effects were always contingent. The results showed that the retrieval of delay between actions and effects does not hinge on retrieving the momentary action effect identity, as delays in reaction times did not differ if action effects were also contingent or not. This observation fits well with the idea that temporal information can go beyond its associative role in action-effect associations and becomes the content of action-effect associations, albeit its influence on action-control seems independent from the influence of momentary effect identities.

2.6 Present research

There is ample evidence suggesting that the timing of action-effects is anticipated. In accordance with the ideomotor theory, people associate actions with the temporal information of their effects. Thus, when the effect is anticipated, its temporal features influence the temporal features of actions, which results in actions that take longer to produce if the associated timing is also longer (Dignath & Janczyk, 2017). What still remains unknown is whether the anticipation of different time intervals can be used to control actions rather than merely influence them. In this case, we can expect a facilitative role of temporal anticipation for compatible actions by means of quicker reaction times, regardless of whether the anticipated time is longer or shorter.

This facilitative role has been well documented in ideomotor learning studies that use momentary action-effects (Band et al., 2009; Elsner & Hommel, 2001; Greenwald, 1970; Herwig & Waszak, 2012; Hoffmann et al., 2009; Hommel et al., 2003; Pfister et al., 2011). In these studies, the perception of a momentary effect feature, such as a specific visual or a specific auditory tone, facilitates the specific actions that it had become associated with, such as left or right keypresses.

When it comes to studying the influence of perceiving temporal effect features, such as stimulus duration or the delay between action and effects, however, the focus is exclusively on the automatic manifestation of the temporal information on the related action codes. Since the reaction time itself is a temporal feature of action, it is considered that perceiving a temporal feature as an action-effect feature influences the reaction times to the direction of the observed time, as perceiving a longer delay is assumed to activate the action codes and lead to slower responses automatically. Even though this anticipation effect supports the claim that goal-directed actions are

influenced by their anticipated temporal effects, it misses out on the possibility that people can form novel associations between specific actions and specific temporal effects (i.e., action a - duration x, action b - duration y), so that actions can be controlled by anticipating their associated temporal effects (i.e., duration x - action a, duration y - action b).

Using an IML paradigm, the following study aims to uncover whether specific actions can be associated with specific durations and whether anticipating time can facilitate the associated actions. If a specific duration can be integrated together with the action that produces it in the acquisition stage, the presentation of that duration in the test stage should facilitate the associated action regardless of whether the time is short or long. More specifically, if actions are activated by anticipating the intended times of their outcomes, similar compatibility effects that were observed for momentary effects should also arise for the dynamic effects that differ in the temporal domain. To put our hypothesis to the test, we used dynamic stimuli that occur for long or short durations contingent on the left and right keypresses in the acquisition stage. We specified the short duration as 200 ms and the long duration as 400 ms. This difference between short and long durations was selected as more pronounced in previous ideomotor effect studies that also used duration as an action effect feature (Kunde 2003; Kiesel & Hoffmann 2004). However, these studies did not directly measure reaction times from responses made to different durations of stimuli. As per the IML paradigm, our study involves a test phase in which participants give speeded responses to different durations. Since responding to stimuli with a longer duration will be more advantageous because participants will have more time to select correct responses, it is likely that there will be an overall influence of stimulus duration apart from the hypothesized advantage of

responding with compatible keys, which makes up our main variable of interest. Therefore, we chose a more subtle difference between long and short durations to curb this advantage of responding to longer stimuli regardless of compatibility.

Furthermore, we created two different dynamic stimuli as action effects for our experiments. First, a flicker stimulus that oscillated for either short or long durations was used to establish the baseline condition of duration anticipation. Importantly, the only distinctive and contingent feature of this stimulus was its duration. The second stimulus was a vertically drifting Gabor patch. Again, the only contingent feature of drifting stimulus was its duration, but it also had a direction of movement as a distractor feature. This drift direction changed randomly from trial to trial and was not contingent on actions. Since duration is a part of the multidimensional features of dynamic events, we expected to see the compatibility effect for this compound stimulus as well. We designed three experiments to test whether the duration of an action effect is acquired after the repeated experience of action-effects with contingent durations and whether seeing the effect with a specific duration can retrieve the associated actions. All experiments used a free-choice acquisition phase, as previous research suggests that action-effect associations are more strongly acquired and subsequently used when participants perform free-choice responses during the acquisition phase instead of following a particular response rule (Herwig et al., 2007). Moreover, Pfister et al. (2011) suggested that ideomotor effects are most likely to be observed when participants are tested under the voluntary mode of action. Therefore, we used a free-choice test phase in Experiment 1 to capture any possible ideomotor effect in a most likely condition. Here, we used the Go-No-Go paradigm to prevent participants from making their decisions before the stimulus appears (Elsner & Hommel, 2001, Exp 3.) As the free-choice design is, by

definition, open to conscious deliberation and choice. Experiment 2 and 3 were conducted with a forced choice task using a 2-block design to rule out the possibility that the ideomotor effect can stem from these deliberative processes. Here, the participants received opposing instructions in each block, forcing them to respond to outcome stimuli either according to the learned action-outcome mapping (compatible condition) or the reverse mapping (incompatible condition). In Experiment 3, we reduced the contingency of omnipresent tactile action effects by simultaneously delivering vibrations to the left and right fingertips with each action. We reasoned that this manipulation would render the tactile effects less efficient for action control by reducing their contingency in the acquisition phase. Therefore, the contingent duration features will be rendered as more salient action contingent effects during the acquisition phase. The experimental data were analyzed using Jamovi for Windows (The jamovi project: Version 2.3, 2022). The reaction times were compared using repeated measures ANOVA. Greenhouse-Geisser (GG) correction was utilized when assumptions of sphericity were violated. Data points were visualized with the raincloud plots (Allen et al., 2019).

CHAPTER 3

EXPERIMENTS

3.1 Experiment 1: Free-Choice IML Paradigm

The ideomotor effect was found to be more pronounced when assessed with free-choice test stages (Pfister et al., 2011). Accordingly, in order to detect any evidence of the acquisition and anticipation of duration in effect-based action control and to partially control for deliberative response choices, this experiment used the Go-No-Go paradigm in a free-choice test stage. After the acquisition of action-effect pairs, participants were asked to choose their actions freely in response to the previously associated action-effects and omit responses when they saw a stimulus signaling No-Go trials. The proportion of compatible response choices to the action-effects measured the ideomotor effect. In addition, reaction times in the acquisition stage were analyzed as a factor of effect durations to see whether temporal features of action-effects directly influence temporal features of actions.

3.1.1 Participants

Nineteen undergraduate students (two left-handed; mean age = 20.47 years, ranging from 19 to 24) were recruited through Boğaziçi University Research Participation System and compensated with course credits for their participation. All participants had normal or corrected vision and reported no neurological disorder. They were naïve concerning the purpose of the experiment and were provided with written informed

consent before the experiment. The study was approved by the university ethics committee (see Appendix).

3.1.2 Stimulus and Apparatus

The participants were asked to place their heads on a headrest to ensure a stable viewing distance throughout the sessions. They had a viewing distance of about 60 centimeters from a CRT Monitor (Samsung Syncmaster 753 DF with a refresh rate of 100 Hz and pixel resolutions of 1024 × 768). The experimental procedure was programmed in MATLAB using Psychtoolbox (Brainard, 1997; Pelli, 1997; Kleiner et al., 2007). The actions were performed by pressing the left and right arrow keys on the keyboard with the index fingers of the right and left hands. All the experiments were conducted in a dark room without any light source other than the light emitted by the display that presents the stimuli (Figure 3).



Figure 3. A typical arrangement in experimental sessions

Two different dynamic stimuli were used in two counterbalanced within-subject conditions. In the Flicker condition, the stimulus was a circle that underwent periodic luminance changes (Relative luminance to background oscillated sinusoidally between 0% and 100%) at rates of 7 Hz. In the Drift condition, the stimulus was a Gaussian-windowed Gabor patch with a sinusoidal luminance pattern that drifts vertically at five cycles per second.

3.1.3 Procedure

The participants were given verbal instructions that they would be doing tasks on a computer and were advised to thoroughly read the instructions on the screen. Either flicker or drift stimuli that lasted for 200ms and 400ms were followed by responses in the acquisition phase, depending on the experimental condition. These stimuli were presented again in the test phase, and participants were instructed to freely choose between a left or right response. Action-effect mappings were counterbalanced among the participants. For half of the participants, the left key was followed by the short stimulus and the right key by the long stimulus, whereas for the other half, the opposite key-tone mappings were used. At the beginning of the acquisition phase, participants saw the instruction below (in Turkish) on display. The trials started upon pressing any key after reading the instruction:

> In this stage, you have to press the right or left arrow keys with your right and left index finger as soon as you see that the “+” turns into “x”. You are free in which keys you decide to press, but please be spontaneous in your decisions in each trial and do not follow a designated response sequence. Around halfway through the block, you will see the left/right ratio of your decisions. On average, try to press both keys about equally. After the keypress, you will see a brief dynamic image, and the new trial will start when the “+” figure appears on the screen again

The timeline of the acquisition phase is depicted in Figure 4. Each trial of the acquisition phase started with a fixation sign ("+") for 1500 ms in the middle of the screen.

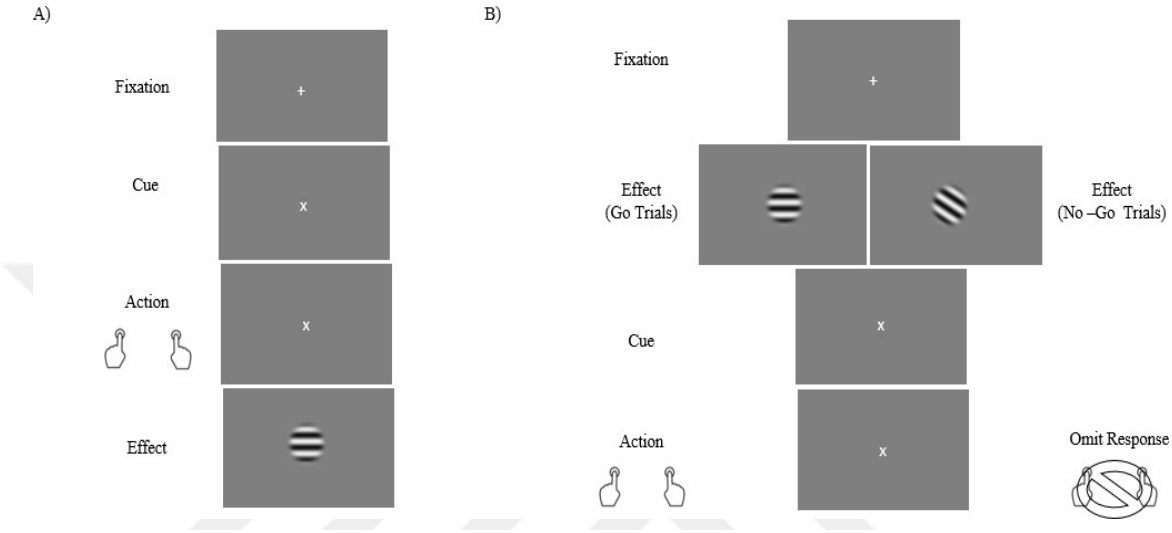


Figure 4. The experimental sequence for Drift condition

Section A demonstrates the acquisition phase for all experiments while Section B shows free-choice test phase of Experiment 1

Participants were asked to press the left or right key freely as soon as they saw the Go stimulus, which is signaled by the orientation change in the fixation sign ("x"). The program waited up to 1000 ms for a response; reaction times that were above 1000 ms were treated as omissions, and reaction times lower than 100 ms as anticipations. These trials were recorded and fed back to the participant by 3000 ms warning messages. The erroneous trials were repeated by the end of the block in a random order, and participants had to go through all the incorrect trials until 200 valid trials were done. There was a small break after the 50th, 100th, and 150th trials in which the participants were informed about the proportion of their decisions regarding choosing left and right keys. Lastly, when the reaction times were in the valid range, left and right key presses

triggered drifting action - effects or flicker action - effects depending on the condition. The action - effects lasted for either short (200 ms) or long (400 ms) durations.

After 200 valid acquisition trials, the test phase commenced. Here, a Go/No-go-task paradigm was used to minimize strategic response choices (Elsner & Hommel, 2001, Exp. 3), and this time the stimuli with different durations that previously served as action-effects in the acquisition phase were presented as imperative stimuli. Participants were instructed to press the left or right keys randomly in response to seeing the stimulus. After the offset of the stimulus (200 ms for short and 400 ms for long durations), the program waited for the response until 1000 ms elapsed. The participants were free to choose which key to respond with and were instructed to respond as quickly as possible with left or right keys without following a deliberate response strategy in their responses. 70 out of 210 trials were No-Go trials that required participants to withhold their responses. The No-Go trials were signaled by the orientation change in the Drift condition and the contrast change in the Flicker condition. The response omissions, anticipations, and failure to withhold responses in No-Go trials were recorded and repeated in random order at the end of the block as in the acquisition phase.

3.1.4 Results of Experiment 1: Acquisition stage

In order to ensure participants followed the instruction of performing left and right keypresses randomly but equally often, response proportions of left and right keypresses were calculated for each participant. One participant with response proportions outside the pre-set range of 40% to 60% was excluded from the further analyses. The mean left/right response proportions were 49.9% vs. 50.1% in the Flicker condition and 50% vs. 50% in the Drift condition. The average response proportions did not deviate from

equal left/right proportion (M = 49.9%, SD = 0.017) t (17) = 0.67, p = 0.5. The acquisition phase of this experiment resembles the design of previous studies that reported an elongation of reaction times for actions that produce longer effects (Kiesel & Hoffmann (2004). To see whether a similar pattern is present, the reaction times in the acquisition phase were analyzed with repeated-measures ANOVA. Consequently, no main effect of experimental condition F (1, 17) = 0.41, p = .53, as well as effect durations F (1,17) = 2.86, p = .11 was found. The interaction between the two factors was also non-significant F (1, 17) = 2.01, p = .11. When tested in a separate t-test, however, the responses that produce longer-lasting effects in the Drift condition took longer the produce (M = 350 ms, SD = 61.6 ms) than the responses that produce shorter effects (M = 336 ms, SD = 47.2 ms) t (17) = 2.09, p = 0.02 Cohen's d = .49.

To see whether the duration of action-effects exerted influence on yet another temporal aspect of actions, a separate ANOVA was conducted on keypress durations. Again, no main effect of experimental condition F (1, 17) = 0.19, p = .66, as well as effect durations F (1,17) = 0.33, p = .57 was found. The interaction between the two factors was also non-significant F (1,17) = 0.02, p = .87.

3.1.5 Results of Experiment 1: Test stage

The ideomotor effect is measured by the percentage of compatible responses in response to previously acquired action-effects for each participant. For instance, if participants experienced left actions followed by shorter-lasting stimuli in the acquisition phase, responding to shorter-lasting stimuli with left actions in the free-choice test phase was counted as a compatible response. Visualized in Figure 5, the mean proportion of compatible responses was significantly higher than the chance level in the Flicker

condition (50%), (M = 55.6%, SD = 5.3%) t (18) = 4.42, p < 0.001 Cohen's d = 1.04. However, in the Drift condition, participants' compatible response choices were not higher than chance. M = 49.9%, SD = 3%, t (18) = -.121, p = 0.90. The direct comparison between the two conditions revealed a significant difference t (17) = 3.60, p = 0.002 Cohen's d = .84.

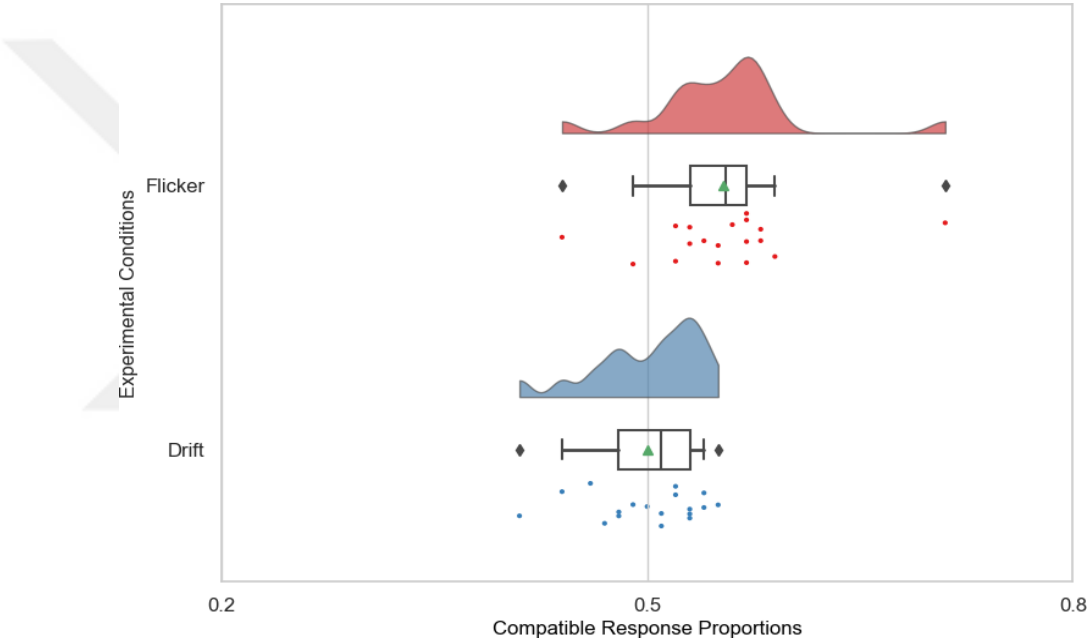


Figure 5. Distribution of individual data points in Experiment 1

Whiskers of boxplots represent the 95% confidence intervals. Triangles indicate the mean values of each condition. The range of box plots indicates .5 of data around the median.

Furthermore, the reaction times were subjected to an analysis of variance (ANOVA) with the within-subject variables, experimental condition (Flicker vs. Drift), compatibility (compatible vs. incompatible), and effect duration (short vs. long). The analysis yielded a significant effect of the experimental condition, F (1, 17) = 25.17, p < .001, ηp2 = 0.59; participants responded significantly slower in the Flicker condition

(480 ms) than in the Drift condition (419 ms). Moreover, there was a significant effect of effect duration, $F(1, 17) = 57.22$, $p < .001$, $\eta p2 = 0.77$; reaction times were slower when the action-effect duration was short (473 ms) than it was long (426 ms).

In sum, the ideomotor effect was observed for duration information in the Flicker condition. Participants responded according to associated action-effects even when they were free to choose which actions they would perform. This finding provides the first evidence that specific durations and actions can be associated with ideomotor learning. However, the effect occurred only when it was the only salient feature of a dynamic action effect in the Flicker condition but not when it was compounded with intramodal features in the Drift condition.

3.2 Experiment 2: Forced-choice IML paradigm

While the first experiment shows that an ideomotor effect for the duration can occur, the use of free-choice test phases in IML paradigms does not provide strong evidence for the mechanistic nature of the effect (i.e., seeing the effect automatically activates the codes of associated actions), as it is possible to understand the action-effect association in the acquisition stage and give deliberate responses accordingly in the test stage. To eliminate the possibility that the effect we observed stemmed from participants' conscious deliberations, a block-based choice reaction time task was used in Experiment 2. In the compatible block, participants received instructions to respond to effect durations that were compatible with the previously acquired mapping. In the incompatible block, these instructions were reversed. The order of the two test blocks was counterbalanced across participants. We hypothesized that the reaction times in the compatible condition would be significantly lower compared to the incompatible condition.

3.2.1 Participants

A total number of thirty-five undergraduate students from Boğaziçi University participated in this experiment (two left-handed; mean age = 21.27 years, ranging from 18 to 29) and were assigned randomly to the Flicker and Drift conditions. Data from two participants in the Drift condition and one participant from the Flicker condition were excluded from the analyses due to the unbalanced proportion of keypresses in the acquisition phase (outside of the range of a left/right proportion of 40% to 60%). Data from the remaining 32 participants (Drift condition: n = 17 vs. Instruction condition: n = 15) were considered in analyses. The students were recruited through Boğaziçi University Research Participation System and compensated with course credits in return. All participants had normal or corrected vision, and they did not disclose any neurological disorder. They were naïve concerning the purpose of the experiment and were provided with written informed consent before the experiment. The experiment was authorized by the university ethics committee.

3.2.2 Stimulus and Apparatus

The setup for this experiment was identical to that of the initial experiment (Figure 3).

3.2.3 Procedure

Participants were randomly assigned to Flicker and Drift conditions. After finishing the acquisition phase, which was identical to Experiment 1, the choice reaction time task commenced within the forced-choice test stage. In terms of the action-effect pairings in the acquisition, the response rule that the participants received on one block was compatible, whereas, on the other block, it was incompatible. For example, if the

participant experienced action effects with a short duration after pressing the left key and a long duration after pressing the right key, the compatible block meant that participants were asked to do a left keypress after seeing drifting Gabor patches (in Drift group) or flickers (in Flicker condition) with short duration, and they were asked to do right keypress following the stimulus with a long duration. In contrast, the mapping in the incompatible block was reversed with regard to the acquired action-effect pairs. Each trial began with a 1500 ms fixation ("+") centered in the screen, and then the effects with one of two durations (200ms for short, 400ms for long) were presented. The program waited up to 1000 ms until the response. Trials with reaction times quicker than 100ms were counted as anticipations and slower than 2000 ms as omissions. Performing the wrong keypress resulted in an error message that was displayed for 3000 ms. These trials were recorded and repeated at the end of the block until participants went through 100 valid trials for compatible and incompatible blocks.

3.2.4 Results of Experiment 2: Acquisition Stage

Response proportions between left and right keypresses were calculated for each participant. The mean left/right response proportions were 52.2% in the Flicker condition and 50.1% in the Drift condition. The average response proportions did not deviate from the equal amount of left/right responses $M = 51.1\%$ $SD = 0.10$ $t(30) = 0.60$, $p = 0.56$.

In the analysis of reaction times, there was no main effect of experimental group $F(1, 30) = 0.54$, $p = .46$, as well as the duration of produced action effects $F(1, 30) = 0.71$, $p = .40$. The interaction between effect duration and experimental condition was

significant F (1, 30) = 4.40, p = .044. However, post-hoc comparisons did not reveal any difference between conditions (all p > .1).

There was also no main-effect of produced effect duration F (1, 30) = 0.32, p = .57, and experimental condition F (1, 30) = 2.52, p = .12 on keypress durations. The interaction between the two factors was also non-significant F (1,30) = 0.02, p = .87.

3.2.5 Results of Experiment 2: Test Stage

Response omissions or anticipations, as well as data from two participants in the Drift condition, were excluded from the analyses. For the analysis of reaction time data in the test phase, reaction times were averaged within subjects only across correct trials. The averaging was separate for the five blocks consisting of 20 trials each, and for compatible and incompatible blocks. In addition, the percentage of response errors was calculated for each participant in compatible and incompatible trials.

The erroneous response proportions in compatible and incompatible trials were contrasted in both groups. In the Flicker condition, participants responded more inaccurately in incompatible trials (M = 0.36, SD = 0.03) than incompatible trials (M = 0.04, SD = 0.02) t (14) = -2.20, p = 0.04 Cohen's d = -0.56. In the Drift condition, the accuracy did not change between compatible (M = 0.14, SD = 0.14) and incompatible (M = 0.15, SD = 0.13) conditions t (16) = -0.32, p = .74.

Mean reaction times for correct trials were subjected to a 3-way mixed ANOVA with a between-subject variable Condition (Flicker vs. Drift) and with within-subject variables Compatibility (Compatible vs. Incompatible) and Blocks (1-20, 21-40, 41-60, 61-80, 81-100). No main effects of Compatibility, F (1,30) = 1.86, p = 0.18, Blocks, F (4,120) = 1.28, p = 0.28, and Condition F (1,30) = 0.39, p = 0.53, were found.

Furthermore, the Blocks ∗ Condition F (4,120) = 1.56, p = 0.18, Compatibility ∗ Condition, F (1,30) = 2.56, p = 1.12, and Blocks ∗ Compatibility, F (4,120) = 0.27, p = 0.89, interactions were not significant, as well as the 3-way interaction, F (4,120) = 0.00, p = 0.89.

The analysis was conducted separately for each experimental group to further evaluate this evidence suggesting no compatibility effect. The ANOVA between compatibility and blocks revealed a main effect of compatibility in Flicker condition F (1,14) = 8.70, p = .011, ηp2 = .38. Figure 6 shows the comparison of reaction times that revealed quicker reaction times when the mapping was compatible with acquired action effect associations (M = 410 ms, SD = 14ms) compared to when it was incompatible (M = 450 ms, SD = 20 ms).

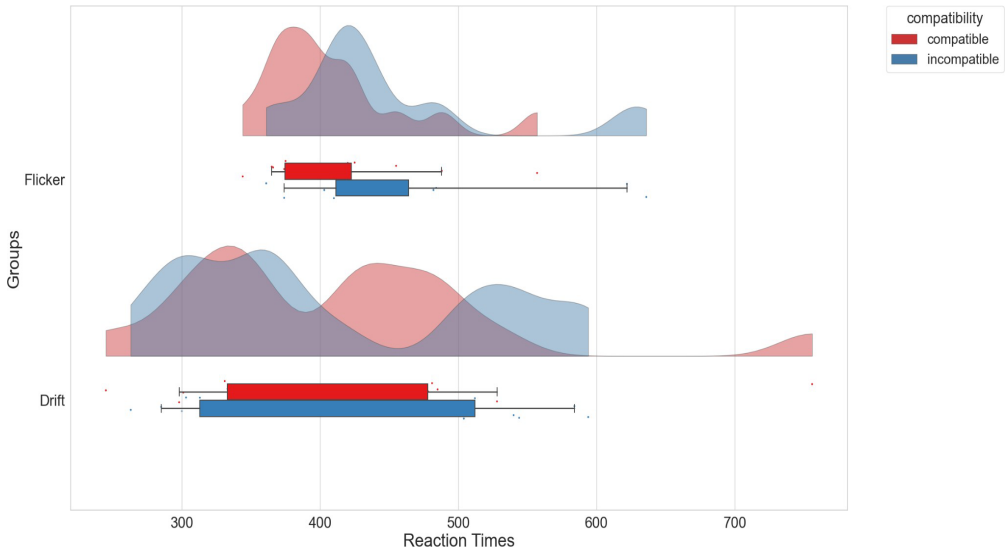


Figure 6. Distribution of individual data points in Experiment 2

Compatible and incompatible conditions were presented together for each experimental group. Whiskers of the boxplot represent the 95% confidence intervals. The range of box plots indicates .5 of data around the median.

Neither the effect of block F (4,56) = 1.43, p = .34 ηp2 = .075 nor the interaction between compatibility and blocks F (4,56) = .61, p = .64, ηp2 = .042 have reached significance. Meanwhile, In the Drift condition, there was no main effect of compatibility F (1,16) = 0.21, p = .88. The comparison of reaction times revealed that there was no difference in action selection performance between compatible (M = 412 ms, SD = 28 ms) and incompatible conditions (M = 409 ms, SD = 27 ms) Neither the effect of block F (4,64) = 1.68, p = .16 nor the interaction between compatibility and blocks F (4,64) =.11, p = .97 was significant (Figure 7).

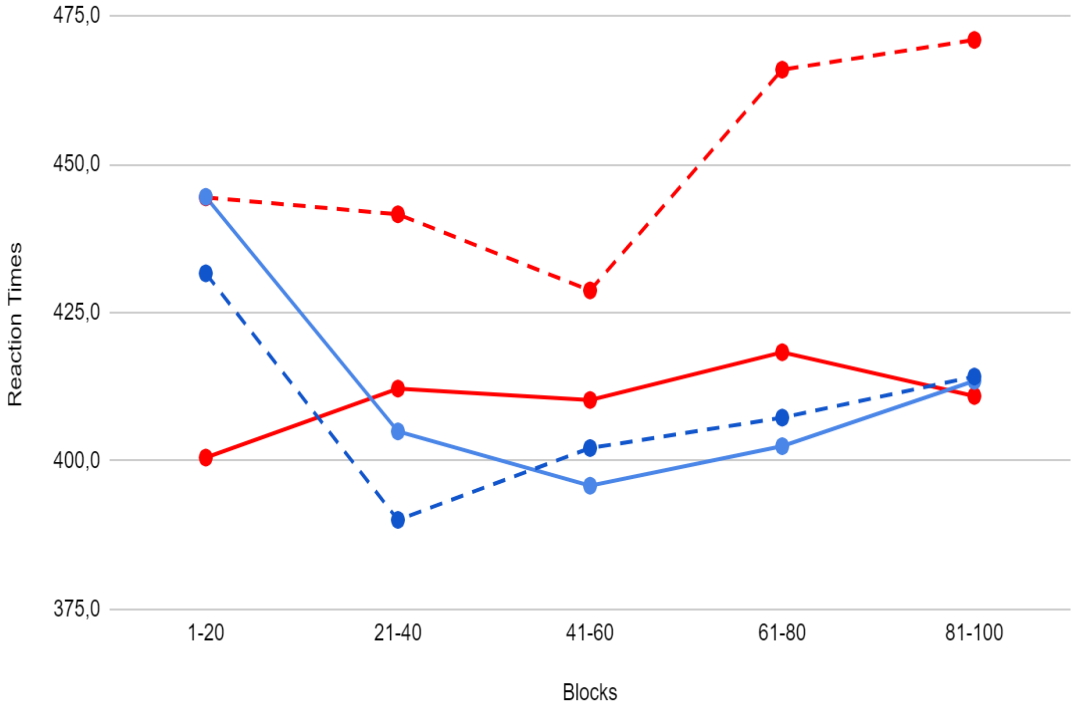


Figure 7. Distribution of mean reaction times across blocks in Experiment 2

Blue lines indicate Drift condition while red lines indicate Flicker condition. Solid lines indicate reaction times in the compatible trials, whereas dashed lines belong to the incompatible trials.

Furthermore, the impact of action-effect duration on responses was analyzed with between-subject variable Condition (Flicker vs. Drift) and with within-subject variables Duration (Long vs. Short) in a two-way mixed ANOVA. The analysis revealed the main effect of effect duration $F(1,30) = 13.0$, $p = .001$, $\eta p2 = .30$. A comparison of reaction times revealed that participants reacted more quickly to the effects with longer duration ($M = 403$ ms, $SD = 19$ ms) than when the effect was short ($M = 438$ ms, $SD = 14$ ms). The interaction between effect duration and conditions was significant, $F(1, 30) = 16.2$, $p < .001$, $\eta p2 = .35$; the difference between long and short durations was larger in the Drift condition (374 ms vs. 447 ms) compared to Flicker condition (429 ms vs. 433 ms). For keypress durations, neither the main effect of effect duration $F(1,30) = 1.11$, $p = .30$, nor the conditions $F(1,30) = 3.46$, $p = .073$ have reached significance. However, the interaction between the conditions and effect duration was significant $F(1,30) = 9.28$, $p = .005$. Post-hoc t-test revealed that only in the Flicker condition the participants responded with longer keypresses to shorter lasting action-effect ($M = 115$, $SD=8.89$) and with shorter keypresses to longer lasting action effects ($M = 106$, $SD=8.84$) $t(30) = -2.81$, $p = .041$.

For keypress durations, neither the main effect of effect duration $F(1,30) = 1.11$, $p = .30$, nor the conditions $F(1,30) = 3.46$, $p = .073$ have reached significance. However, the interaction between the conditions and effect duration was significant $F(1,30) = 9.28$, $p = .005$. Post-hoc t-test revealed that only in the Flicker condition participants responded with longer keypresses to shorter lasting action-effect ($M = 115$, $SD=8.89$) and with shorter keypresses to longer lasting action effects ($M = 106$, $SD=8.84$) $t(30) = -2.81$, $p = .041$.

3.3 Experiment 3: Forced-choice IML paradigm with body-related effects

In the previous experiments, the ideomotor effect was observed for the duration in Flicker conditions in which duration is the only salient action effect feature, but not in the Drift conditions in which duration is coupled with random upwards or downwards movements. These results suggest that contingent duration information of action effects can be acquired and anticipated during effect-based action control, but only when there is no other apparent feature embedded in the effect. The importance of saliency was discussed in a few previous studies that did not report ideomotor effects for visual stimuli (Dutzi & Hommel, 2009). Thus a simple explanation might be that the different durations of the visual stimulus in this condition were not salient enough to form action - effect associations. However, it is common sense that duration itself cannot be present in isolation in the real world as it is the factor that moderates the presence of constructs in the temporal domain. Therefore, the lack of evidence for the integration of duration in action - effects in the Drift condition may need some further exploration.

One explanation might stem from the fact that actions do not only produce distal or environment-related effects that are traditionally targeted in previous research, but actions also produce proximal or body-related effects such as different proprioceptive or tactile sensations emitted from performing a simple keypress with different effectors (Pfister, Janczyk, et al., 2014; Wirth et al., 2016). Therefore, the saliency of these omnipresently contingent action effects might have rendered the relatively noisy duration information of drifting stimulus useless to integrate with the acquisition phases (Pfister, 2019). To test this possibility, the anticipations of tactile action effects were controlled in Experiment 3. The keypress actions in the acquisition phase simultaneously produced tactile effects to the effector and idle finger alike. It is assumed that

experiencing tactile feedback to both fingertips while performing actions will render the proximal effects less contingent or discriminative, thus will increase the chances of integration of the contingent distal effect, represented by duration in our study.

3.3.1 Participants

A total number of thirty-two undergraduate students from Boğaziçi University participated in this experiment (two left-handed; mean age = 20.92 years, ranging from 18 to 24) and were assigned randomly to the Flicker and Drift conditions. The students were recruited through Boğaziçi University Research Participation System and compensated with course credits in return. All students had normal or corrected vision, and they did not report any neurological disorder. They were naïve concerning the purpose of the experiment and were provided with written informed consent prior to the experiment. The experiment was approved by the university ethics committee.

3.3.2 Stimulus and Apparatus

The experimental arrangement was identical to the first two experiments except for the addition of an electromagnetic solenoid-type vibrotactile device (Tactor, 2021) that was driven by a 4-channel amplifier. The device was attached to the left and right index fingertips with adhesive bands and produced sinusoidal vibrations at 100 hz simultaneously with keypresses (Figure 8).

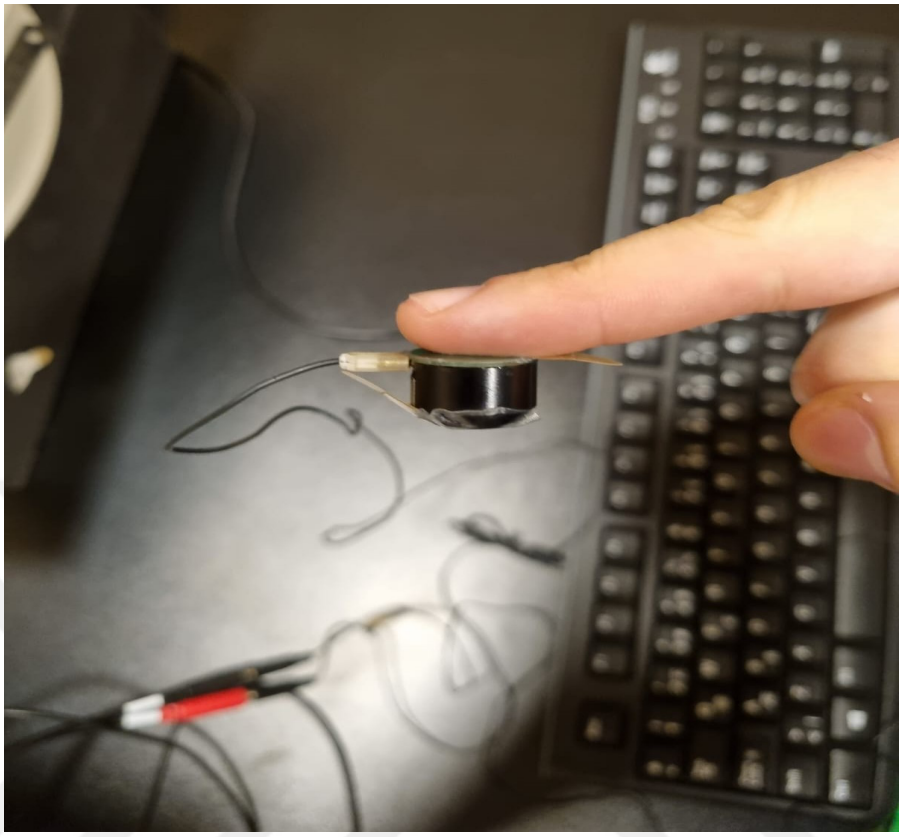


Figure 8. The tactor device was attached to the fingers during experiments

3.3.3 Procedure

In the acquisition stage, each left and right keypress simultaneously produced tactile effects on both the left and right fingertips. Besides this adjustment, the flow of the experiment was exactly the same as in Experiment 2. The response omissions, anticipations, and errors were treated as in Experiment 2.

3.3.4 Results of Experiment 3: Acquisition Stage

Response proportions between left and right keypresses were calculated for each participant. One participant was excluded because of the unbalanced response ratios. The mean left/right response proportions were 50.9% in the Flicker condition and 49.7%

in the Drift condition. The average response proportions did not deviate from the equal amount of left/right responses M = 50.3% SD = 0.433 t (31) = 0.668, p = 0.66.

The analysis of reaction times of actions as a factor of the duration of the produced effects and experimental conditions was conducted with mixed ANOVA. There were no main effects of between subject variable experimental condition F (1, 30) = 3.09, p = .09, and within subject variable duration of produced action effects F (1, 30) = 0.07, p = .783. The interaction between effect duration and experimental condition was non-significant F (1, 30) = 0.33, p = .57.

The same analysis was conducted for the keypress durations. There was a main effect of duration F (1, 30) = 6.08, p = .02. Post-hoc analysis of keypress durations between actions that produced long effects vs. short effects demonstrated that participants pressed the keys significantly longer when the upcoming effect had a shorter duration (M = 161 ms, SE = 26.7 ms) whereas they pressed the keys shorter when the upcoming effect was longer (M = 175 ms, SE = 27.4 ms) t (30) = -2.47, p = 0.02. There was no main effect of experimental condition F (1, 30) = 0.24, p = .62 and the interaction was non-significant F (1, 30) = 1.30, p = .26.

3.3.5 Results of Experiment 3: Test Stage

For the analysis of the ideomotor effect, the reaction times were averaged within subjects only across correct trials in the test phase. The averaging was again separate for the five blocks consisting of 20 trials each and for compatible and incompatible blocks. In addition, the percentage of response errors was calculated for each participant in the compatible and incompatible trials.

Neither the main effect of compatibility on participants' accuracy F (1,30) = 1.80, p = 0.18; nor the main effect of conditions F (1,30) = 0.73, p = 0.39 have reached significance; There was also no interaction between compatibility and condition F (1,30) = 0.45, p = 0.50.

Mean reaction times for correct trials were subjected to a 3-way mixed ANOVA with a between-subject variable Condition (Flicker vs. Drift) and with within-subject variables Compatibility (Compatible vs. Incompatible) and Blocks (1-20, 21-40, 41-60, 61-80, 81-100). There was a main effect of compatibility F (1,30) = 23.61, p < 0.001 ηp2 = 0.44. In the Flicker condition, participants responded to compatible trials faster (M= 424, SD=75.1) than the incompatible trials (M= 465, SD=96.3) t (15) = -3.43, p= 0.002 Cohen's d = -0.85. Likewise, the reaction times of the actions in the compatible trials were faster (M= 433, SD=85.1) than the incompatible trials (M= 462, SD=95.3) t (15) = -3.61, p= 0.001 Cohen's d = -0.90 in Drift condition. (Figure 9).

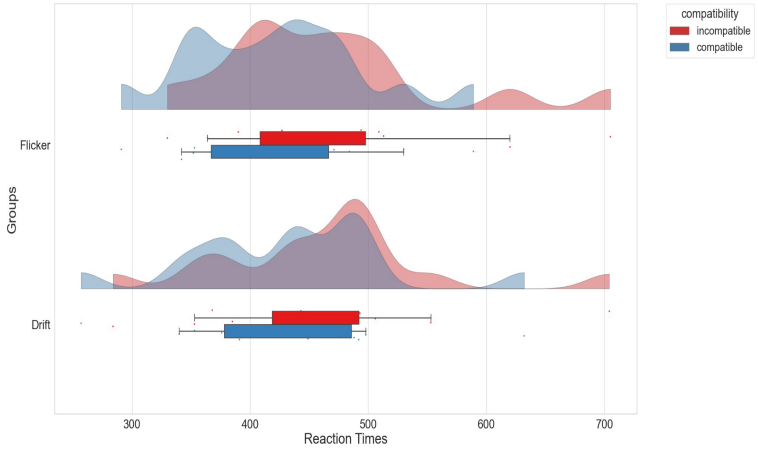


Figure 9. Distribution of individual data points in Experiment 3

Compatible and incompatible conditions were presented together for each experimental group. Whiskers of the boxplot represent the 95% confidence intervals. The range of boxplots indicates .5 of data around the median

No main effects of Blocks, F (4,120) = 1.35, p = 0.25, and Condition F (1,30) < 0.001, p = 0.92, were found. Blocks ∗ Condition, F (4,120) = 0.72, p = 0.57, Compatibility ∗ Condition, F (1,30) = 0.73, p = .39, and Blocks ∗ Compatibility, F (4,120) = 1.23, p = 0.29, interactions were not significant, as well as the 3-way interaction, F (4,120) = 1.23, p = 0.29 (Figure 10).

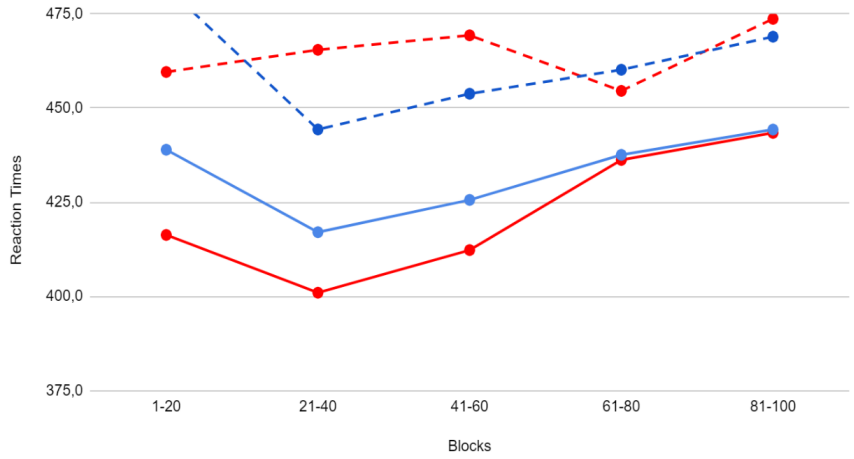


Figure 10. Distribution of mean reaction times across blocks in Experiment 3

Blocks consist of 20 trials. Blue lines indicate Drift condition while red lines indicate Flicker condition. Solid lines indicate reaction times in the compatible trials, whereas dashed lines belong to incompatible trials

Furthermore, the impact of action-effect duration on responses was analyzed with between-subject variable Condition (Flicker vs. Drift) and with within-subject variables Duration (Long vs. Short) in a two-way mixed ANOVA. The analysis revealed a main effect of effect duration F (1,30) = 6.86, p = 0.01, ηp2 = .18. Neither the main effect of condition F (1,30) < 0.001 p = 93, nor the interaction between effect duration and conditions was significant F (1,30)= 0.04, p = 0.93. A comparison of reaction times in the Flicker condition revealed that participants reacted more quickly to the effects

with longer duration (M = 433 ms, SD = 80.1 ms) compared to when the effect was short (M = 456 ms, SD = 93 ms), and this difference was significant t (15) = -1.80, p = 0.04 Cohen's d = -0.451. Likewise, reactions to the action-effects that lasted longer (M = 437 ms, SD = 82 ms) were faster compared to the reactions that lasted shorter (M = 457 ms, SD = 99 ms) t (15) -1.95, p = 0.03.

Analysis of keypress duration revealed no main effect of duration F (1,30) = .94, p = 0.33, and conditions F (1,30) = .207, p = 0.65. The interaction between the conditions and effect duration was also not significant F (1,30) = .99, p = .32.

CHAPTER 4

DISCUSSION AND CONCLUSION

Research on ideomotor action control has produced abundant information on how people control actions based on the anticipation of their effects. There has been a growing interest in examining the temporal mechanisms of ideomotor actions in recent years. However, it is not known whether temporal features can be the subjects of anticipation due to the lack of experimental work with dynamic action-effects in the field. This thesis addresses this gap by studying the acquisition and anticipation of duration in ideomotor action control with the IML paradigm.

The first experiment provided initial evidence for our hypothesis that suggests actions can be acquired with the temporal features of the effects they produce. In the Flicker condition, the participants observed dynamic flicker stimuli that oscillate for either short (200 ms) or long (400 ms) durations upon keypresses. When they were presented with these stimuli in a subsequent stage and asked to respond freely, the participants chose the actions that were compatible with the previously experienced action-duration pairs at a higher rate than would be expected by chance, even when there were no criteria that restricted their action decisions. To our knowledge, this was the first evidence of ideomotor action control based on dynamic action-effect features. In the Drift condition, the experimental procedure was exactly the same. This time, however, participants produced (acquisition stage) and responded to (test stage) a Gabor patch that drifted for either short or long durations. Importantly, this stimulus involved vertical movements that differed in upward and downward directions. This difference was randomized on a trial basis; hence it was not contingent on the keypresses that have

produced them. However, the randomized movements comprised an extra effect feature in addition to the contingent durations produced upon specific actions. Importantly, there was no evidence of duration anticipation in this condition. This finding implies that the saliency of contingent duration information might be important for its acquisition with actions.

In order to provide a stronger case for the findings of this experiment and rule out the possible deliberative sources of the ideomotor effects we observed in the Flicker condition of experiment one, we followed up with a second experiment and adopted a forced-choice test stage instead in an IML paradigm. Participants were randomly divided into two groups; one group experienced the occurrence of action-contingent durations with flicker stimulus, while the other experienced it with drift stimulus. The results of this experiment replicated the previous findings. In the test stage, the responses to the previously observed action effects were performed significantly faster when the actions were compatible with the mapping in the acquisition stage compared to when they were incompatible. However, this trend was significant only in the Flicker condition again. In the Drift condition, which included duration information compounded with other features, there was no indication of the ideomotor effect.

Dutzi and Hommel (2009) previously argued that visual action effects might be integrated only if a sufficient amount of attention is allocated to the visual modality or if they are salient enough to attract attention in a bottom-up fashion. Since contingent duration features were accompanied by arguably more salient random directions in the drift stimuli, the duration feature might have become overshadowed by direction features, thereby suspending the chances of action-effect acquisition based on duration (Flach et al., 2006). However, it should be noted that duration cannot be perceived

independently in the real world. Instead, its perception depends on the consistent changes in time of the otherwise complex stimuli, just as how the drifting stimulus was designed in our experiments. Therefore, our findings indicating people cannot acquire duration information in Drift conditions may require further exploration beyond what the saliency account proposes.

One possible explanation could be inferred from studies focusing on body-related action effects. Previous studies have found that body-related action-effects, such as the tactile and proprioceptive sensations that arise from keypress actions, impact action control as much as environment-related effects (Janczyk et al., 2014; Wirth et al., 2016). As the participants did not have a task demand other than responding freely but about as equal for each action in the acquisition phase, these ubiquitous and compatible action-effects might have become sufficient for successful action-control during acquisition (Pfister, 2019). Moreover, since the duration information of the drifting stimulus was relatively noisy in the Drift condition, it might have been rendered redundant to acquire with preceding actions in the presence of contingent tactile effects that can be reliably anticipated to perform left and right keypresses. We went after this possibility in the third experiment. In order to make the naturally compatible body-related effects of keypresses (left keypress - left tactile effect and vice versa) less reliable during the acquisition stage, we used a tactor device that can be attached to the fingertips and delivered vibrations during actions (Figure 5.). The vibrations were delivered to both fingertips at the onset of actions to make the anticipation of body-related effects in action control less efficient. Indeed, we observed the ideomotor effect in the Drift condition this time, as well as replicating the previous findings in the Flicker condition.

This finding implies that the duration feature of an action-effect can be acquired even when it is overshadowed by non-contingent distractors.

Furthermore, we assessed whether producing longer vs. shorter-lasting effects in acquisition stages exerts a direct influence on the reaction times, in addition to the observed overall facilitations that arise from responding congruently to the acquired key-duration mapping in the test stages. Previous studies have reported that when the produced effects last for a longer time, the reaction times become elongated compared to when the effect duration is shorter (Kiesel & Hoffmann, 2004; Kunde, 2003). In our data, we observed the reverse of this effect, but only in the Drift condition of the first experiment (Cohen's d = .493). In the Flicker condition of this experiment, as well as all conditions in the other experiments, the length of the produced effect's duration did not impact the reaction times of the preceding actions. This is clearly an incongruent finding with the literature that needs further clarification. One reason behind this finding might be due to the use of closer differences between short and long durations in our experiments compared to the previous studies that reported the effect. In the study of Kiesel and Hoffman (2004), for example, the short effects were 232 ms, and the long effects were 1160 ms. Also, the short effects were 80 ms, and the long effects were 240 ms in the other study (Kunde, 2003). Since our test phase required participants to respond to effects with different durations, we opted for a more subtle difference (200 ms for short, 400 ms for long effects) to forestall the advantage of responding to the longer-lasting effects while retaining the perception of the difference between long and short action-effects. Therefore, it is possible that we did not observe any influence of producing longer or shorter effects on reaction times in the acquisition stage because the effects did not differ in duration as much as in the previous studies.

Moreover, we returned to the data from the test stages and further assessed whether responding to longer vs. shorter stimuli still impacted the reaction times, independently from whether the response was compatible or incompatible. Despite our efforts to curb this advantage, in all experiments, the reaction times were significantly faster when the stimulus duration was long. Since participants essentially had to react upon a stimulus that starts at a fixed time but ends in a variable time (200ms vs. 400ms), the conditional probability of responding to the longer effect increased after 200ms elapsed. Therefore, the reason behind the faster responses to longer-lasting stimuli might be that the participants have an additional 200 ms to prepare their responses when they respond to the longer effects. This effect is usually attributed to the variable foreperiod effect in previous studies (Thomaschke et al., 2011).

Another temporal feature that action-effect duration could exert a direct influence on was the duration of the performed keypresses. In this sense, we assessed whether the duration of keypresses changed as a factor of the duration of the effects that the respective keypresses produced. We found two significant effects across all experiments and conditions. In the acquisition stage of the third experiment, participants performed longer keypresses when the produced effects' duration was shorter and performed shorter keypresses when it was longer. Moreover, in the Flicker condition of the second experiment's test stage, the participants responded to short-lasting effects with longer keypresses and long-lasting effects with shorter keypresses. This finding was also reported by Kunde (2003). In this study, the shorter lasting auditory action-effects increased the keypress durations relative to longer-lasting ones and vice versa. Kunde argued that this contrasting bias might arise due to the integration of different sources of action-effects into a sensorimotor ensemble. As a result, the process of controlling

actions based on their effects may be about achieving a specific duration for the entire ensemble set. However, a more detailed examination is necessary to test this claim.

To sum up, our results support the hypothesis that people control their actions based on the anticipation of how long the consequences of actions will last. In three experiments, we were able to show that specific actions can be associated with the duration of their effects. When participants experience that their actions contingently produce effects that last for a specific duration, performing the actions that once produced these effects is facilitated upon seeing similar stimuli that last for the same time. In addition to furthering the understanding of how temporal aspects of goals are represented and initiated, our results can inform practical applications, such as human-machine interface designs where discrete actions, such as keypresses in our experiment, are often followed by continuous outcomes that have distinct temporal properties.

APPENDIX

ETHICS COMMITTEE APPROVAL

Evrak Tarih ve Sayısı: 08.04.2021-11050

T.C.
BOĞAZİÇİ ÜNİVERSİTESİ REKTÖRLÜĞÜ
Sosyal ve Beşeri Bilimler İnsan Araştırmaları Etik Kurulu (SBİNAREK)

Sayı : E-84391427-050.01.04-11050
Konu : 2021-05 Kayıt Numaralı Başvurunuz Hakkında

Sayın Dr. Öğr. Üyesi İnci AYHAN
Psikoloji Bölüm Başkanlığı - Öğretim Üyesi

"Zamanın Hedef Odaklı Eylem Üzerindeki Rolü" başlıklı projeniz ile Boğaziçi Üniversitesi Sosyal ve Beşeri Bilimler İnsan Araştırmaları Etik Kurulu (SBİNAREK)'e yaptığınız 2021-05 kayıt numaralı başvurunuz 02.04.2021 tarih ve 2021/03 sayılı kurul toplantısında incelenmiş ve projenize etik onay verilmesi uygun bulunmuştur.

Bu karar tüm üyelerin toplantıya on-line olarak katılımıyla ve oybirliği ile alınmıştır. COVID-19 önlemleri nedeniyle üyelerden ıslak imza alınamadığından bu onam mektubu tüm üyeler adına Komisyon Başkanı tarafından e-imzalanmıştır.

Saygılarımızla, bilgilerinizi rica ederiz.

Doç. Dr. Osman Sabri KIRATLI
Başkan

Bu belge, güvenli elektronik imza ile imzalanmıştır.
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