THE EFFECT OF AFFORDANCES ON PERCEIVED INTERVAL DURATIONS DURING MOTOR ACTION

SUNNY JIN

BOĞAZİÇİ UNIVERSITY

2023

THE EFFECT OF AFFORDANCES ON PERCEIVED INTERVAL DURATIONS DURING MOTOR ACTION

Thesis submitted to the

Institute for Graduate Studies in Social Sciences

in partial fulfillment of the requirements for the degree of

Master of Arts

in

Psychology

by

Sunny Jin

Boğaziçi University

2023

The Effect of Affordances on Perceived Interval Durations

During Motor Action

The thesis of Sunny Jin

has been approved by:

Assoc. Prof. İnci Ayhan
(Thesis Advisor) _____

Assoc. Prof. Emre Uğur _____

Assoc. Prof. Argiro Vatakis
(External Member) _____

December 2023

DECLARATION OF ORIGINALITY

I, Sunny Jin, certify that

- I am the sole author of this thesis and that I have fully acknowledged and documented in my thesis all sources of ideas and words, including digital resources, which have been produced or published by another person or institution;
- this thesis contains no material that has been submitted or accepted for a degree or diploma in any other educational institution;
- this is a true copy of the thesis approved by my advisor and thesis committee at Boğaziçi University, including final revisions required by them.

Signature.....

Date.....

ABSTRACT

The Effect of Affordances on Perceived Interval Durations

During Motor Action

Affordances describe the possible actions that an agent can perform on an object, determined by the agent's morphology as well as the object's perceptual features. Using a stimulus-response compatibility (SRC) setup in virtual reality, this study aimed to investigate whether visual perception of affordances while performing motor actions could affect the perceived durations of these actions or the visual stimuli being acted upon. The reaching affordance was proposed to be present in congruent conditions, in which the handle of a pan stimulus was on the same side as the hand to respond. Subjects reported longer perceived durations in congruent conditions than in incongruent conditions, hinting at the possibility of affordance effects on perceived time. However, the control study suggests that these differences in perceived time may have been due to Vierordt's phenomenon. Additionally, subjects similarly reported longer perceived durations in congruent conditions when the pan stimulus was placed in extrapersonal space, where reaching was not afforded. While this thesis could not elucidate the relationship between affordance perception and time perception, the results suggest that the differences in response times to and perceived durations of graspable stimuli in SRC setups might be due to spatial compatibility, rather than affordance potentiation. Further research is still necessary to determine the effects of affordances on perceived time. Once these effects are determined, the exact details of the mechanism by which these effects are mediated can be investigated.

ÖZET

Sağlarlıkların Motor Hareket Sırasında Algılananan (Aralık) Süresine Etkisi

Sağlarlıklar bir aktörün bir nesne üzerinde uygulayabileceği, aktörün morfolojisi ve ve nesnenin algısal özelliklerine bağlı olan olası motor hareketlerdir. Bu çalışma sanal gerçeklikte uyaran-tepki uyumluluk (UTU) paradigmasını kullanarak motor hareket sırasındaki görsel sağlarlık algısının, yapılan hareketin veya tepki verilen uyaranın algılanan süresini etkileyip etkilemediğini incelemeyi amaçlamıştır. Uzanabilme sağlarlığının, tava uyaranının sapı ile tepki vermek için kullanılan elin aynı tarafta olduğu uyumlu koşullarda görüldüğü öne sürülmüştür. Katılımcılar uyumlu koşullarda, uyumsuz koşullara göre daha uzun algılanan süreler raporlamışlardır, bu sonuç algılanan zaman üzerinde bir sağlarlık etkisi olduğuna işaret etmektedir. Ancak, kontrol çalışması algılanan sürelerde görülen farkın Vierordt fenomeninden kaynaklandığını göstermektedir. Ek olarak, katılımcılar tava uyaranının ulaşılamayacak bir yere yerleştirildiği ve uzanabilme sağlarlığının ortadan kaldırıldığı durumlarda da benzer bir şekilde uyumlu koşullarda, uyumsuz koşullara göre daha uzun algılanan süreler raporlamıştır. Bu tez çalışması sağlarlık ve zaman algıları arasındaki ilişkiye açıklık getiremese de UTU paradigmasında uzanılabilir uyaranlara verilen tepki süreleri ve uyaranların algılanan sürelerinde görülen farkların sağlarlıkların aktifleşmesinden ziyade uzamsal uyumluluktan kaynaklandığını göstermektedir. Sağlarlıkların algılanan zamana etkisini incelemek için daha fazla çalışma gerekmektedir. Bu etki incelendikten sonra etkinin ortaya çıkmasına yarayan mekanizmalar da detaylı incelenebilir.

ACKNOWLEDGEMENTS

Firstly, I would like to thank my advisor Dr. Inci Ayhan for her academic and emotional support during my time at Boğaziçi. Her positivity and encouragement have motivated me to successfully complete this thesis.

I would also like to thank the members of the BUVIAR Lab and Vision Lab for their help and participation in my thesis project, as well as the community they provided along the way. Specifically, I would like to thank Batuhan Koçak for his input and participation in these studies as well as assisting with the Turkish translation of the abstract.

I would like to thank my undergraduate assistant Barış Karahan, who helped with subject recruitment, data collection, material translation, and any supporting tasks that needed to be done for these studies.

Lastly, I would like to thank my parents for their support for my academic and personal progress during these years abroad.

TABLE OF CONTENTS

CHAPTER 1: INTRODUCTION 1

1.1 Affordances 1

1.2 Select theories in time perception 7

1.3 Previous experimental work 10

1.4 The current study 12

CHAPTER 2: INITIAL REACHING EXPERIMENT 17

2.1 Participants 17

2.2 Methods 17

2.3 Results 24

CHAPTER 3: JOINT LIFT-OFF AND REACHING EXPERIMENT 31

3.1 Participants 31

3.2 Methods 32

3.3 Results 35

CHAPTER 4: VIERORDT'S LAW CONTROL EXPERIMENT 43

4.1 Participants 43

4.2 Methods 43

4.3 Results 46

CHAPTER 5: EXTRAPERSONAL SPACE EXPERIMENT 49

5.1 Participants 49

5.2 Methods 50

5.3 Results 52

CHAPTER 6: DISCUSSION AND CONCLUSION 59

6.1 Discussion 59

6.2 Limitations and future research 65
6.3 Concluding remarks 66
APPENDIX: ETHICS COMMITTEE APPROVAL 68
REFERENCES 69

LIST OF FIGURES

Figure 1. Experimental setup 18

Figure 2. Hand types and pan orientations 19

Figure 3. Sequence of events within a trial during the main portion of initial reaching study 23

Figure 4. Hand type and congruency on ratio value in initial study 25

Figure 5. Interaction between hand type and congruency on ratio value in initial study 25

Figure 6. Hand type and congruency on lift-off time (s) in initial study 26

Figure 7. Interaction between hand type and congruency on lift-off time (s) in initial study 26

Figure 8. Hand type and congruency on reaching time (s) in initial study 27

Figure 9. Interaction between hand type and congruency on reaching time (s) in initial study 27

Figure 10. Hand type and congruency on stimulus duration (s) in initial study 28

Figure 11. Interaction between hand type and congruency on stimulus duration (s) in initial study 29

Figure 12. Coefficient of variation results by condition 30

Figure 13. Headset placement used in the joint experiment 32

Figure 14. Hand type and congruency on ratio value in lift-off study 36

Figure 15. Interaction between hand type and congruency on ratio value in lift-off study 37

Figure 16. Hand type and congruency on ratio value in reaching study 38

Figure 17. Interaction between hand type and congruency on ratio value in reaching study 38
Figure 18. Hand type and congruency on lift-off time (s) in lift-off study 39
Figure 19. Interaction between hand type and congruency on lift-off time (s) in lift-off study 39
Figure 20. Hand type and congruency on reaching time (s) in reaching study 40
Figure 21. Interaction between hand type and congruency on reaching time (s) in reaching study 41
Figure 22. Hand type and congruency on stimulus duration (s) in reaching study ... 42
Figure 23. Interaction between hand type and congruency on stimulus duration (s) in reaching study 42
Figure 24. Hand type and congruency on ratio value in control study 46
Figure 25. Interaction between hand type and congruency on ratio value in control study 47
Figure 26. Hand type and congruency on stimulus duration (s) in control study 48
Figure 27. Interaction between hand type and congruency on stimulus duration (s) in control study 48
Figure 28. The pan in extrapersonal space 50
Figure 29. Hand type and congruency on ratio value in extrapersonal lift-off study 52
Figure 30. Interaction between hand type and congruency on ratio value in extrapersonal lift-off study 53
Figure 31. Hand type and congruency on ratio value in extrapersonal reaching study 54
Figure 32. Interaction between hand type and congruency on ratio value in extrapersonal reaching study 54

Figure 33. Hand type and congruency on lift-off time (s) in extrapersonal lift-off study 55
Figure 34. Interaction between hand type and congruency on lift-off time (s) in extrapersonal lift-off study 55
Figure 35. Hand type and congruency on reaching time (s) in extrapersonal reaching study 56
Figure 36. Interaction between hand type and congruency on extrapersonal reaching time (s) in reaching study 56
Figure 37. Hand type and congruency on stimulus duration (s) in extrapersonal reaching study 57
Figure 38. Interaction between hand type and congruency on stimulus duration (s) in extrapersonal reaching study 58

ABBREVIATIONS

ANOVA	Analysis of Variance
IQR	Interquartile Range
LGN	Lateral Geniculate Nucleus
LIP	Lateral Intraparietal Area
ms	Millisecond
Q1	First Quartile
Q3	Third Quartile
s	Second
SRC	Stimulus-Response Compatibility
VR	Virtual Reality

CHAPTER 1

INTRODUCTION

1.1 Affordances

Affordances are described as the possible actions that an agent can perform on an object, enabled by the agent's morphology as well as the object's structure (Gibson, 1979). For example, a small tree branch might afford the action of grasping to a human agent while affording perching to a bird. Coffee mugs, cooking pans, door handles, and countless other everyday objects afford grasping and many other action possibilities to human agents. Affordances are not only ubiquitous in our environment, but they also shape our perception of it— perception and action are inextricably intertwined in our experience of the natural world (Witt & Riley, 2014).

Gibson (1979), who coined the term "affordance" in his seminal work, proposed a theory of direct perception: the same visual information from the environment results in the same perceptual experience in different people. However, Witt and Riley (2014) assert in a recent review of perception-action literature that perception is more "action-specific" rather than direct, shaped by the individual's unique abilities to act, which give rise to a unique perception of the world at a given moment. For example, perceived height of or distance to an object is influenced by one's own eye height, perceived size of a nearby object by one's own body size, and perceived weight of an object by one's own lifting ability (Doerrfeld et al., 2012; Linkenauger et al., 2013; Sedgwick, 1986). Therefore, one's "effectivities" (i.e., abilities to act, determined by factors such as physique, fitness, fatigue, learned behaviors, and available tools), determine the available actions (i.e., affordances) and

shape one's perception of the surrounding environment, including its objects, as one interacts with the world (Witt & Riley, 2014).

While previous literature suggests that affordances impact the perceived dimensions of environmental objects during interaction, such as height, distance, and weight, whether affordances also impact the perceived time elapsed during interaction with objects has yet to be investigated. Utilizing virtual reality (VR), which effectively allows for the changing of an agent's body morphology in an immersive environment, this thesis aims to uncover how perceived affordances affect perceived time duration as one interacts with objects in a given space.

1.1.1 Affordance effect

While it is not yet known how affordance perception affects the perceived duration of a motor action performed on a target object, previous research claims that perceived affordances significantly impact motor response times to target objects (Tucker & Ellis, 1998). The affordance effect, usually associated with the work of Tucker and Ellis (1998), describes how perceived affordances significantly impact an agent's reaction times, through potentiating the motor representations of afforded actions. In their notable study, Tucker and Ellis (1998) employed a stimulus-response compatibility (SRC) paradigm, where the "reach-and-grasp" affordance was available in the compatible condition but unavailable in the incompatible. Subjects were shown images of various graspable objects and had to respond with a button press using either the left or right hand, depending on whether the object was upright or upside-down. In some trials, the graspable part of the object was on the same side as the correct hand to respond (i.e., the left hand is used to correctly respond to a cooking pan with the handle also on the left side); these trials were considered

compatible. In incompatible trials, the graspable part was on the opposite side as the correct hand to respond. Although the left-right orientation of the graspable portion was an irrelevant dimension for completing the task, it had a significant impact on subject response times. Subjects responded significantly faster and more accurately in compatible trials than in incompatible. The investigators attributed these results to the affordance effect: the internal motor codes (i.e., motor representations) of grasping with the specific hand were activated when viewing the compatible stimulus, resulting in faster reaction times and greater accuracy during action execution. In a follow-up study, they found that the reaction time differences were extinguished when subjects used two fingers of a single hand to respond. These results suggest that the findings obtained from the main experiment were not merely due to a general spatial compatibility or SRC effect (e.g., Simon effect) (Simon, 1969) but rather the activation of grasping with the hand on the same side as the object's graspable part.

Tucker and Ellis (1998) posit that viewing a stimulus that affords action, and thus perceiving its affordances as well, can elicit some level of activity in areas used for motor action. They describe this process as the potentiation (i.e., partial activation) of motor representations. The motor representation of an action refers to the unique pattern of neural activity in the specific cell populations and circuits involved in executing that action, constituting a neural code that is understood, employed, and communicated by the brain (Ellis & Tucker, 2000). The affordance effect is mediated by the partial activation of these internal motor representations when viewing a stimulus that affords the related action or actions (Tucker & Ellis, 1998). Partial activation refers to activity at a lower amplitude (i.e., below activation threshold) in the populations involved in action and the absence of an execution

command from the primary motor cortex (Cisek, 2007; Ellis & Tucker, 2000). A motor representation can be thought of as fully activated when it is selected and executed, with the speed and accuracy of this execution enhanced from the limited activation of its representations beforehand (Cisek, 2007; Tucker & Ellis, 1998).

The dorsal pathway, extending from the primary visual areas of the occipital cortex to the parietal cortex, is involved in executing motor actions in response to visual stimuli (Goodale & Milner, 1992; Ungerleider & Mishkin, 1982). Visual information is transformed into motor information for action execution as it travels up the pathway and beyond to the premotor and motor areas (Andersen, 1987; Andersen et al., 1998; Cisek, 2007). The vital role of the dorsal stream in responding to visual stimuli with appropriate actions is evidenced by optic ataxia, where lesions to the posterior parietal cortex resulted in subjects' inability to reach towards and properly grasp objects (Andersen et al., 2014; Jeannerod et al., 1994; Perenin & Vighetto, 1988). The parietal cortex contains cell populations necessary for coding the spatial location of objects and the formation of appropriate grasping shapes in response to different objects (Jakobson et al., 1991; Perenin & Vighetto, 1988), while both the parietal and motor cortices code for the direction of prospective movement (Alexander & Crutcher, 1990b; Georgopoulos, 1991; Georgopoulos et al., 1986). These areas in the dorsal stream and motor areas constitute the neurological basis of motor representations, which can be activated by stimulus viewing (Alexander & Crutcher, 1990a; Creem-Regehr & Lee, 2005; Lhermitte, 1983) under select conditions (e.g., when attention is given to the object's shape or texture, when the object's orientation aligns with its proper function) (Masson et al., 2011; Tipper et al., 2006; Vainio et al., 2007). The dorsal premotor cortex is suggested to be one such area with cells that can be activated by a visual stimulus, with or without subsequent

action execution, and whose activity, along with activity in other areas, forms the basis of affordance representation. For example, even when primates were restrained from reaching towards a visual target, dorsal premotor cells in both hemispheres were tuned to the direction of prospective reaching during motor planning (Cisek et al., 2003). Similarly, dorsal premotor cells were tuned to the direction of a prospective saccade and could be tuned to more than one direction in the presence of multiple saccade targets to choose from (Cisek & Kalaska, 2005). This evidence not only implicates that motor representations can be activated by viewing, even in the absence of executed action, but also that multiple representations can be activated simultaneously. The concurrent activation of multiple affordance representations before action selection and execution is further explained by the affordance competition hypothesis (Cisek, 2007).

1.1.2 Affordance competition hypothesis

To survive in the natural world, it is pragmatic for animals to partially specify how to execute possible actions before one or more are selected (Cisek, 2007). By activating at a subdued amplitude the neuronal populations and circuits involved in the possible actions (i.e., motor representations of possible actions), the specific mechanisms for action are already prepared, increasing the efficiency and speed of the actions once executed (Cisek, 2007; Tucker & Ellis, 1998). According to the affordance competition model proposed by Cisek (2007), currently available affordances are simultaneously represented in the brain, and the brain must select the action it wants to execute from these internal representations. The processes of internal representation and selection are continuous as the individual interacts with and

receives updates from the environment. These continuous processes are involved in making fine motor adjustments for object interaction.

As an individual perceives the environment, current affordances are encoded along with information for object identification (Cisek, 2007). According to the model (Cisek, 2007), visual information is sent to the visual cortex and further processed along the dorsal pathway, modulated by selective attention. To begin, information from attended visual targets for action is encoded in the striate cortex. As information travels upstream, selective attention continues to modulate visuomotor processing, enhancing information from visual targets of interest while suppressing other information. This filtering of visual information narrows down the number of actions that develop cortical representation in the parietal cortex. Representation in the parietal cortex involves the unique combination of activity of individual cells in a population involved in the action's execution. For example, possible saccades are represented by cellular activity in lateral intraparietal area (LIP), where different active sites in the LIP correspond to different saccade targets (Cisek & Kalaska, 2005). Similarly, activity in the medial intraparietal area represents possible reaching movements in specific directions (Ferraina & Bianchi, 1994). In Cisek's reaching model (2006, 2007), individual cells in populations found in the posterior parietal cortex and dorsal premotor cortex each code for a specific movement direction, and the cells with the highest activity determine the executed reaching direction. More than one cell cluster in the population can exhibit high activity, with each cluster's activity representing a reaching action in a specific direction. Thus, one or more reaching actions can be represented simultaneously (Grèzes et al., 2003). Competition between potential actions is exhibited when clusters of cells involved in one action inhibit the activity of clusters involved in other actions (Cisek, 2006,

2007). Biasing influences from subcortical and cortical regions, such as the basal ganglia and prefrontal cortex, which are involved in assessing decision value and predicted reward (Cisek & Pastor-Bernier, 2014, Padoa-Schioppa & Assad, 2006; Samejima et al., 2005), determine which action is ultimately executed from the pool of competing action possibilities (Cisek, 2006, 2007). These influences heighten the activity of a select peak until it reaches a threshold (i.e., an action is selected), resulting in the execution of the action represented by the peak, cued by the primary motor cortex (Cisek, 2006, 2007).

1.2 Select theories in time perception

1.2.1 Internal clock model

A classic paradigm for time perception is the internal clock model described by Treisman (1963). This model describes a mechanism for calculating time that is centralized in a particular area in the brain and is universally used for multiple sensory modalities (e.g., vision, audition) (Ayhan, 2010; Hodinott-Hill et al., 2002). In this model, a pacemaker produces ticks at a certain rate, and these ticks are counted by a counter (Treisman, 1963). Perceived interval duration is determined from counter output after ticks have been accumulated over the interval period (Ayhan, 2010; Treisman, 1963). Distortions in perceived interval duration from the actual duration could be due to the effects of arousal or attention on the pacemaker rate (e.g., speeding up, slowing down) or the number of clock ticks recorded versus missed (Burle & Casini, 2001; Tse et al., 2004; Wearden, 2008). While this paradigm is well-recognized in the field, alternative mechanisms have been proposed in response to findings that cannot be well-explained by the content-independent internal clock.

1.2.2 Attentional-gate model

During a task or event, attention may be divided between the processing of non-durational information and temporal information, and this division likely impacts the perceived duration of the interval (Thomas & Cantor, 1978; Tse et al., 2004). Specifically, the allocation of attention towards non-temporal information results in less capacity for temporal processing (Kahneman, 1973) and thus a shorter perceived duration (Brown, 1997). As a modification of Treisman's (1963) internal clock model, the attentional-gate model was proposed by Block and Zakay (1996), incorporating the role of attention in temporal processing. In this model, similarly to the internal clock, a pacemaker produces ticks at a specific rate, which is determined by the agent's internal state of arousal as well as the level of arousal induced by the external stimulus. These ticks flow to a gate, which opens each time the agent attends to information indicating or used for determining the passing of time (Tse et al., 2004), allowing some ticks to pass through to successive parts of the model. Meaningful information from the situation indicates the beginning and end of a specific interval, reflected in the opening and closing, respectively, of a switch (Block & Zakay, 2008). At the start of the interval, the switch opens, and ticks pass from the gate to an accumulator; when the interval ends, the switch closes, and ticks are no longer able to pass through to the accumulator (Block & Zakay, 1996). The number of ticks that reach the accumulator is counted by it, and this count determines the perceived interval duration. Thus, in this model, the perceived duration increases with the amount of attention given to temporal processing (Block & Zakay, 1996).

1.2.3 Content-dependent model

Rather than being independent of the visual content within an event (e.g., appearance and disappearance of a visual stimulus), time perception may be affected by the features of the visual image, such as its luminance and motion (Ayhan et al., 2011; Ayhan & Ozbagci, 2020; Kanai et al., 2006; Matthews, 2011), and it may be modality-specific (Grondin & McAuley, 2009; Walker & Scott, 1981; Wearden et al., 1998). Event-related timing proposes that the time during a visual stimulus (e.g., its duration) is another unique feature of the stimulus, arising under the influence of the stimulus's visual features (e.g., drift, flicker) (Ayhan, 2010; Johnston et al., 2006). The content-dependent clock model proposed by Johnston (2010) reflects the influence of visual stimulus features on perceived timing. In this model, a prediction of the visual image or scene after a certain period (e.g., 30 ms) is generated using information about changes in image brightness. The visual input at each moment in time is compared to this prediction, and a clock tick occurs when the system detects a match. Then, a new prediction is generated, and the comparison process begins again, ending with a clock tick. This prediction, compare, and tick method repeats over a meaningful time interval (e.g., the time between the appearance and disappearance of a visual stimulus), resulting in the accumulation of ticks over the interval. At the end of the interval, the number of accumulated ticks determines the perceived elapsed duration.

According to the model (Johnston, 2010), perceived time can deviate from actual time when the resetting of the prediction to a new forward model is delayed or hastened, resulting in fewer or more ticks, respectively. For example, one or more delays in prediction resetting would result in perceiving the interval as shorter than actual (i.e., time compression), as fewer ticks are counted over the interval. In the

context of previous research by Bruno and Johnston (2010), the resetting mechanism is postulated to be affected by the activity of magnocellular cells (M cells) in the magnocellular layers of the lateral geniculate nucleus (LGN), which receive input from the parasol ganglion cells in the retina (Callaway, 2005; Perry et al., 1984). M cell activity is used to determine the rate of change of image brightness, which is utilized in generating a forward prediction (Johnston, 2010). When M cells adapt to high-contrast images with high temporal frequencies (e.g., sinusoidal gratings with fast flicker or drift rates), their temporal response curve is sharpened and shows a phase advance (i.e., they respond faster to visual stimuli) (Benardete & Kaplan, 1999; Bruno & Johnston, 2010; Johnston et al., 2006; Stromeyer & Martini, 2003). This phase advance results in a prediction of the image after a longer period (e.g., the future image after 35 ms versus the future image after 30 ms in the case of no adaptation) (Johnston, 2010). More time must pass before the system detects a match, resulting in a delay in generating the next forward prediction (Johnston, 2010). During the overall interval, less ticks occur, and the interval seems shorter (Johnston, 2010). This model shows that the features of a local image, such as its rate of change in contrast, can affect its perceived duration. The "predict and compare" strategy utilized by the content-dependent clock may also be utilized by many other internal clocks for time perception (Johnston, 2010).

1.3 Previous experimental work

In a previous study conducted by the lab, Joy et al. (2021) investigated the effect of affordances on reaction times. The researchers utilized a similar experimental paradigm found in Tucker and Ellis's (1998) notable study on the affordance effect. However, in Joy et al.'s (2021) study, subjects were immersed in a virtual reality

environment and performed the experiment with virtual hands. The utilization of VR allowed for the manipulation of the perceived hand morphology of the subject. Subjects experienced two different types of virtual hands during the study: a normal hand that afforded grasping and a fingerless, pill-shaped (capsule) hand that did not. In the SRC setup, subjects had to reach and touch a virtual cooking pan stimulus with either their left or right hand, depending on whether the pan was upright or upside-down. The handle of the pan could either be compatible with the response hand or incompatible, like in Tucker and Ellis's (1998) study. Specifically, Joy et al. (2021) aimed to investigate whether hand type (normal versus capsule) or handle compatibility could significantly affect the reaction times of different action phases (e.g., action planning, action execution). They found that the reaction times during the periods of action planning (e.g., the time between the appearance of the target object and release of a keyboard key) and action execution (e.g., the time between release of the key and touching the target object) were differentially affected by the morphology of the avatar hand used as well as the handle orientation. Specifically, irrespective of hand type, planning time was faster when the handle was on the same side as the hand performing the action (compatible condition), rather than the opposite side (incompatible condition), but execution time was faster in the incompatible condition than compatible. Additionally, in the compatible condition, planning time was faster for fingerless (capsule) hands than with normal hands (Joy et al., 2021).

To explain their findings, Joy et al. (2021) employed the affordance effect proposed by Tucker and Ellis (1998) and the affordance competition hypothesis proposed by Cisek (2007). To begin, Joy et al. (2021) proposed that the general affordance effect may explain why planning times were shorter in compatible than

incompatible conditions, in both hand types, as reaching is potentiated when the handle is on the same side as the hand to respond (Joy et al., 2021; Tucker & Ellis, 1998). Additionally, they proposed that affordance competition may explain why the response time for planning was shorter for capsule hands than normal hands in the compatible condition: fewer actions are competing for selection with the restricted morphology, thus shortening planning time (Cisek, 2007; Joy et al., 2021). Furthermore, the response time for execution was longer in the compatible condition than incompatible, in both hand types (Joy et al., 2021). Joy et al. (2021) suggested that in the compatible condition, more fine motor adjustments must occur during execution, resulting in longer execution times (Cisek, 2007; Joy et al., 2021). Using a similar paradigm in VR, this thesis investigates how affordances may impact the perceived interval durations of action. In the experimental setup, the actual duration of the visual stimulus equates to the duration of subject action (e.g., the stimulus appears when subjects initiate the trial and disappears only after they complete the response).

1.4 The current study

An object's structure determines its visual features and its affordances to human agents (Gibson, 1979). The perception of an object's affordances is represented by (i.e., encoded by) the activation of these affordances' motor representations when the object is in view (Cisek, 2007; Tucker & Ellis, 1998). Temporal processing during object viewing and interaction may be impacted by affordance perception (i.e., the activation of affordance representations) or attentional effects (i.e., different distribution of attentional resources between compatible and incompatible conditions), or a combination of the two (Garrido-Vásquez & Schubö, 2014; Riggio

et al., 2008; Tucker & Ellis, 1998; Xiong et al., 2019). Thus, as proposed in the content-dependent clock, the visual features of a stimulus may influence its perceived duration (Johnston, 2010). Previous research shows that motor action can influence the perceived durations of visual stimuli (Ayhan & Ozbagci, 2020; Morrone et al., 2005). For example, simultaneous, continuous keypress during the period of stimulus display (i.e., an array of moving dots) resulted in the stimulus duration being perceived as shorter than in reality (Ayhan & Ozbagci, 2020). Similarly, Morrone et al. (2005) showed that the duration between the appearance of one visual stimulus (a horizontal bar) and the second (another horizontal bar) was perceived as compressed when the pair was shown near the onset of a saccade (less than 200 ms before). These results suggest that the visuomotor pathway, extending from as early as the LGN to the parietal cortex and beyond to motor areas, is involved in temporal processing (Ayhan & Ozbagci, 2020; Bueti et al., 2008; Leon & Shadlen, 2003); thus, motor action during or around visual stimulus presentation may affect perceived stimulus duration (Ayhan & Ozbagci, 2020; Morrone et al., 2005). This thesis proposes that visual affordances may affect temporal processing by activating corresponding motor representations along the visuomotor pathway, such that the possible effects of motor action on perceived duration are similarly induced from affordance perception. Alternatively, object affordances or visual features may influence perceived duration via other mechanisms (e.g., attentional effects).

1.4.1 Experimental paradigms

The experiments in this thesis employed the SRC setup in virtual reality found in Joy et al.'s (2021) study. The hand type (normal hands versus capsule hands) and handle compatibility (compatible versus incompatible) differed between experimental

conditions. For reporting duration judgments, the method of stimulus reproduction was employed: subjects pressed and held the spacebar to indicate their perceived durations.

When using the method of reproduction, short durations are usually overproduced and long durations underproduced, following Vierordt's law (Vierordt, 1868). Because subject reaction times and thus pan durations differed between different conditions (i.e., unique combinations of hand type and handle compatibility), the durations to be reproduced were variable. A follow-up study was conducted to confirm that the effects on perceived duration were not merely due to the Vierordt's law phenomenon. In this control study, subjects did not perform motor responses but merely observed pan stimuli that appeared and automatically disappeared after specific durations (determined by the combination of hand type and handle compatibility) preset by the computer. After stimuli disappearance, subjects similarly indicated the pan durations using reproduction. This setup aimed to elucidate the possible effects of stimulus duration on reproduced duration while minimizing the possible affordance effects, which may be strengthened when subjects are anticipating or engaged in action planning and execution during stimulus viewing.

Furthermore, there exists debate about whether the differences in reaction times found in SRC setups were due to the affordance effect (via motor potentiation) or another mechanism, such as a general SRC effect (e.g., mere effect of spatial compatibility between stimulus feature and response) (Cho & Proctor, 2010). To clarify whether the effects on perceived duration are due to affordances, a second follow-up study placed the pan stimuli in extrapersonal space, where subjects could

not reach (i.e., reach-and-grasp affordance is unavailable). Subjects completed motor responses with the pan stimuli in the new location.

1.4.2 Aims and significance

This thesis aims to uncover how affordance effects might distort perceived time during motor actions. Although affordance effects are suggested to exist with stimulus viewing in the absence of action, this project investigates affordance perception with motor action (i.e., action planning and execution). In each trial of the main studies, the pan stimulus appeared at the start of the trial and only disappeared after subjects completed an action response. In this case, the actual duration of the stimulus equals the duration of the response. Therefore, subjects' reported duration of the pan stimulus is used to represent the time that they perceive to have passed during motor action (i.e., their perceived duration of their motor action), separated into the phases of action planning and action execution. Furthermore, it can be said that this thesis investigates the impact of affordance perception on both the perceived duration of the visual stimulus and on the perceived duration of motor action, as they are considered equal in this context.

The significance of the work in this thesis is found in its utilization of virtual reality and its aim to connect affordances to time perception. VR expands the possibilities for psychological research by improving ecological validity and allowing for embodiment to be modified in ways not feasible in real life, such as altering avatar bodies to change subjects' action possibilities and perception. This thesis utilizes VR in an endeavor to promote its usage in future psychological research. Additionally, the relationship between affordances and time intervals had not been extensively studied before. This thesis endeavors to link affordance

perception to time perception and utilize its findings to refine and develop time perception theories.

CHAPTER 2

INITIAL REACHING EXPERIMENT

The initial reaching study was conducted to formulate plausible hypotheses from collected data as well as finalize details of the experimental design.

2.1 Participants

Twenty-two Boğaziçi University students (12 female, mean age 23.86, ranging from 18 to 36), either undergraduate or graduate, participated in the initial study. Subjects were right-handed and had normal or corrected-to-normal vision. They gave informed consent to participate, either as a volunteer or for course credits. The study was approved by the institutional ethics committee (see Appendix) and followed the standards of the Declaration of Helsinki (World Medical Association, 2013).

Half of the subjects completed the first three blocks of the study with normal hands and the second three with capsule hands. The other half completed the first three blocks with capsule hands and second three with normal hands.

2.2 Methods

The initial study followed a similar method as the previous study conducted by Joy et al. (2021), which investigated the affordance effect on reaction time during phases of action.

2.2.1 Experimental setup

The virtual reality environment was developed using Unity (Version 2020.3.23f1) in C# programming language. Virtual objects (e.g., cooking pan, white table) were

downloaded from the Unity Asset Store, and hand models were developed using the Ultraleap package for Leap Motion in Unity. The subjects were fully immersed in this online environment through a virtual reality headset with audio headphones (HTC Vive Pro). Their hand movements were tracked by a hand-tracking device (Leap Motion) that allowed them to move their hands naturally without holding VR controllers.

In the lab room (Figure 1), the subject sat in front of a desk, which had a keyboard and a computer monitor. The subject wore the VR headset with headphones while sitting. The hand-tracking device was placed on the desk to track hand movements. Foam pieces were placed on top of the S, L, and spacebar keys on the keyboard. The resting position consisted of placing the left hand on the S key foam and the right hand on the L key foam. Subjects pressed the spacebar foam to indicate their duration judgment during the experiment.



Figure 1. Experimental setup. The subject sits in front of a desk wearing the VR headset with audio headphones. Each hand was placed on the respective keyboard foam during resting position and lifted to perform a response. The hand tracker was placed either on the table or fixed to the front of the headset.

In the VR display (Figure 2), participants saw their virtual hands, either normally shaped (i.e., able hand) or as capsules without fingers (i.e., restricted hand). In each experimental trial, there was a pan with the handle oriented either to the left or right, and the pan was upright or upside down. Subjects had to reach and touch the pan with their right hand if the pan was upright and left hand if it was upside down. Subjects completed congruent (i.e., compatible) trials, in which the handle was on the same side as the hand to respond (e.g., handle on the right side of an upright pan), and incongruent (i.e., incompatible) trials, in which the handle was on the opposite side. They used normal hands in one portion of the study and capsule hands in the other portion, so that both hand types were tested within subjects.

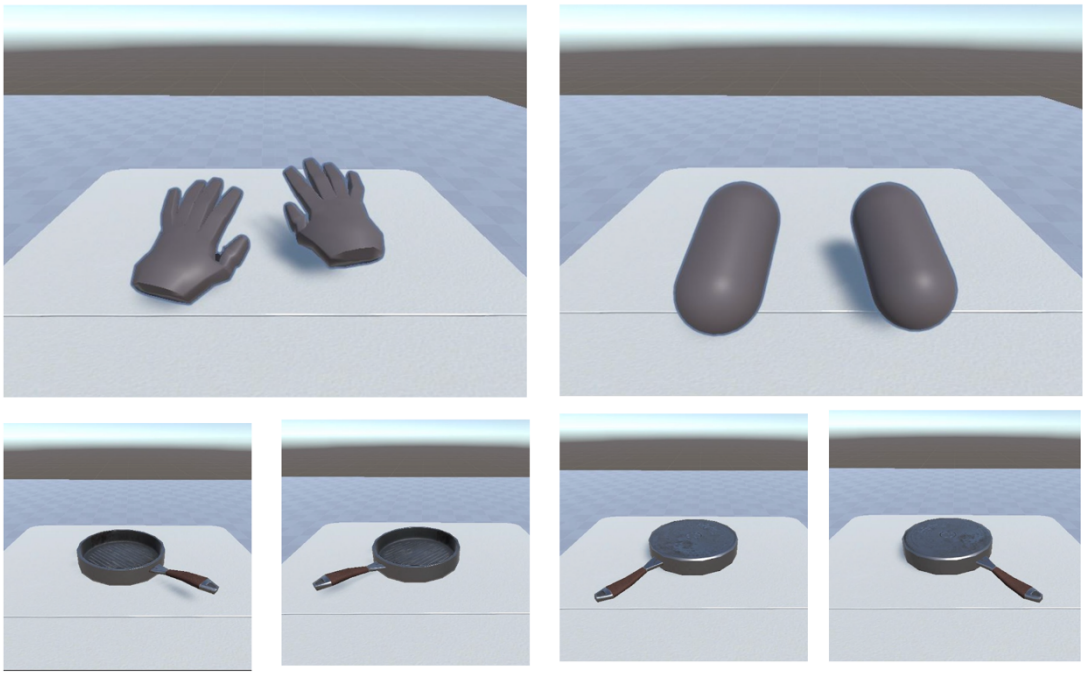


Figure 2. Hand types and pan orientations. The different hand types are displayed on the top row (from left to right): Normal hands, Capsule hands. The bottom row displays the pan orientations (from left to right): Upright, right-side handle (congruent); Upright, left-side handle (incongruent); Upside-down, left-side handle (congruent); Upside-down, right-side handle (incongruent)

2.2.2 Design

This study utilized a 2 x 2 within-subjects factorial design. The within-subjects factors were the avatar hand type (normal or capsule) and the handle congruency (congruent or incongruent). The dependent variable was the perceived interval durations (i.e., durations reproduced using keypress) during action planning and execution combined. The action planning phase was defined as the period between when the pan-with-handle stimulus appeared and when subjects lifted their hand off the rest key on the keyboard after deciding which hand to use. The action execution phase was defined as the period between when subjects lifted their hands off the rest key on the keyboard and when they touched the pan virtually with their avatar hand. The normal hand in VR had the appearance of a real hand with fingers, and the capsule hand had a pill-shaped appearance with no fingers. While the normal hand allowed for the grasping affordance with the pan handle, the capsule hand did not. The "grasp-the-handle" affordance (i.e., grasping affordance) was considered to be available in congruent trials with the normal hand, while the "reach-for-handle" affordance (i.e. reaching affordance) was considered to be available in congruent trials with either hand type. All subjects completed trials with congruent and incongruent handle orientations as well as using each type of hand. The method of reproduction was used to indicate duration judgments: subjects had to press and hold the spacebar to indicate their perceived durations.

2.2.3 Procedure

The study consisted of a training phase and a main portion. The main portion consisted of six blocks with 24 trials in each block; three blocks were performed with one hand type and another three with the other. In each block, four different pan

orientations (upright pan with handle on right, upright pan with handle on left, upside-down pan with handle on right, and upside-down pan with handle on left) were each presented in six trials per block, in a randomized order. Thus, 12 trials were congruent and 12 were incongruent in each block. If the subject made an error (i.e., used the wrong hand to respond), an additional trial was given, in which the pan orientation matched that of the error trial. Additional trials were given to ensure that the total number of accurate trials was consistent across subjects (24 trials per block), although the actual number of trials completed by subjects varied.

Subjects completed a training phase before moving on to the main portion of the initial reaching study. All subjects completed the training with normal hands first, then completed the training again with capsule hands immediately after. The training consisted of six parts (video of procedure: https://youtu.be/1cXFNAALudg), with subjects completing a different task in each part:

i. With palms facing up, subjects had to open and close both hands simultaneously 16 times, counting aloud. They repeated this process with palms facing down.

ii. Red blocks were generated one at a time, either on the left or right side of the virtual table, for a total of 16 blocks. Using the hand on the same side as the red block, subjects had to reach and touch the block, which disappeared upon contact. The next block appeared on the opposing side.

iii. Red blocks were generated one at a time, either on the left or right side of the virtual table, for a total of 16 blocks. Using the hand on the same side as the red block, subjects had to push the block forward on the table by using the back of their hand and flicking their wrist forward on the block, which

disappeared after passing the table edge. The next block appeared on the opposing side.

iv. Pairs of red and grey blocks were generated one at a time, either on the left or right side of the virtual table, for a total of 16 pairs. Using the hand on the same side as the blocks, the subjects had to grab the red block and place it on top of the gray block. The pair of blocks disappeared after correct placement or automatically after ten seconds, and the next pair appeared on the opposing side.

v. After interacting with blocks, subjects were trained to reproduce stimulus durations using the spacebar for 24 trials. In each trial, a pan stimulus appeared on the screen and automatically disappeared after 0.75 to 2 seconds. Afterward, subjects had to press and hold the spacebar for the duration that the pan stayed on the screen. Every pan had a different duration, and subjects received feedback on the difference between the actual pan duration and their reproduced duration. Subjects were told to minimize the difference.

vi. Finally, subjects completed a practice of the main portion of the study. They received audio feedback in the form of a balloon pop when they responded with the wrong hand.

After completing the training, subjects moved on to the main portion of the study. To cue a new trial (Figure 3), subjects placed their hands in resting position, with their left hand on the S key foam and right hand on the L key foam. Then, after a 500-ms fixation cube, a pan-with-a-handle stimulus was generated directly in front of them, either upright or upside down, and with the handle oriented towards either their left- or right-hand side. The subject had to reach and touch the pan with their

right hand if the pan was upright and left hand if it was upside down. The pan disappeared upon contact, and subjects then reproduced the pan time by pressing and holding the spacebar. In this case, the pan duration was equal to the subject's action planning time (i.e., time to lift off one hand from the keyboard) plus action execution time (i.e., time from lifting off to making contact with the pan). The total pan stimulus duration, action planning duration, action execution duration, and reproduced duration were recorded from each trial for further analysis.

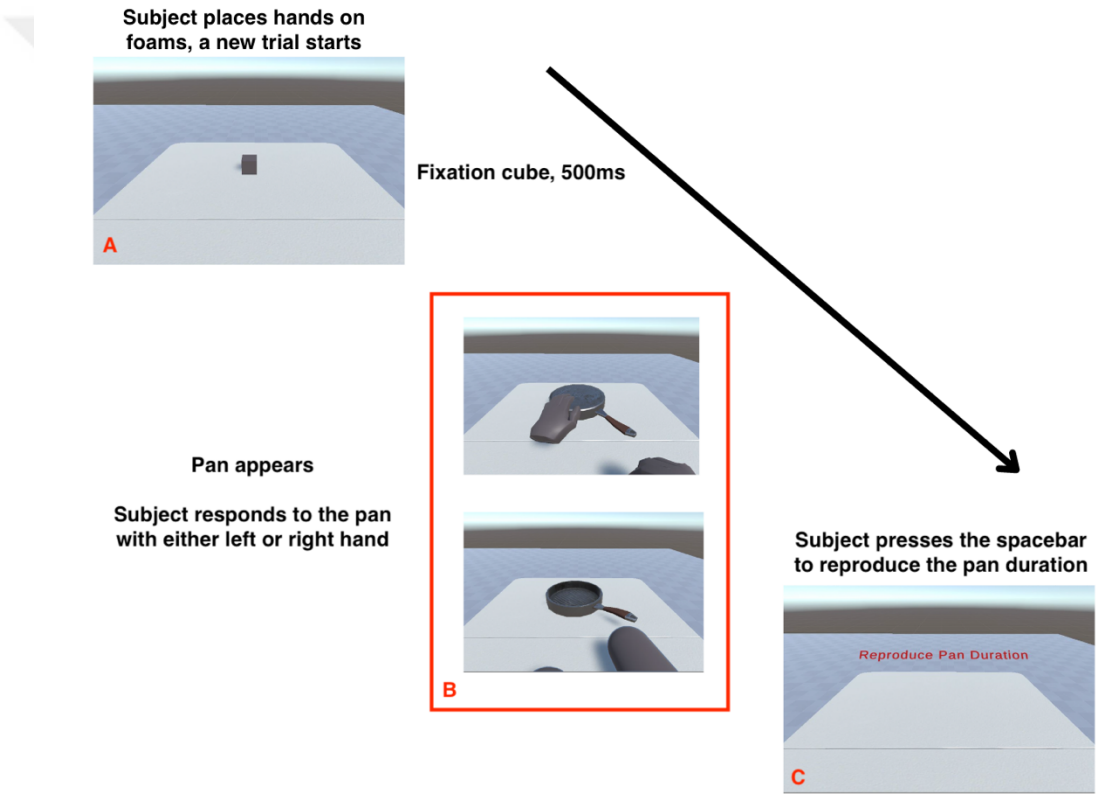


Figure 3. Sequence of events within a trial during the main portion of initial reaching study. (A) A new trial is initiated when subjects place both hands on the resting foams. (B) Once the pan appears, subjects must respond using the correct hand, depending on pan orientation. Examples of both hand types are shown. (C) Once the pan disappears, subjects must press the spacebar to match the pan duration on the screen.

2.3 Results

For data preprocessing, error trials (i.e., subjects responded with the incorrect hand) were excluded from data analysis. For each of the remaining trials, a decimal value (referred to as the ratio) was calculated by dividing the reproduced duration (i.e., duration of spacebar press) by the actual pan duration. Trials from all subjects were pooled and then grouped by hand type and congruency into four categories (normal [hand] and congruent [handle], capsule & congruent, normal & incongruent, capsule & incongruent). Outliers in each category were identified as values outside of the range [Q1 - 1.5(IQR), Q3 + 1.5(IQR)], where Q1 is the first quartile, Q3 is the third quartile, and IQR is the interquartile range. Trials that contained outlier values in total pan stimulus time were excluded. After this, the remaining trials that contained outlier values in the calculated ratio were also excluded. Jamovi for Mac (Version 2.3.26.0) and R (Version 4.1.3) in RStudio (Version 2022.02.1) were utilized for data analysis.

2.3.1 Reproduced duration

A 2 x 2 within-subjects ANOVA (Figure 4) indicated a significant effect of congruency ($F(1, 725) = 65.084$, $p < .001$, $\eta^2p = .082$) on reproduced duration, with longer perceived durations for congruent ($M = .989$, $SD = .357$) than incongruent ($M = .918$, $SD = .325$) trials. However, the effect of hand type was non-significant ($F(1, 725) = 0.335$, $p = 0.563$, $\eta^2p = .000$), with similar perceived durations for capsule ($M = .946$, $SD = .340$) and normal hands ($M = .961$, $SD = .346$). The interaction effect between hand type and congruency was also non-significant ($F(1, 725) = 0.025$, $p = 0.876$, $\eta^2p = .000$) (Figure 5).

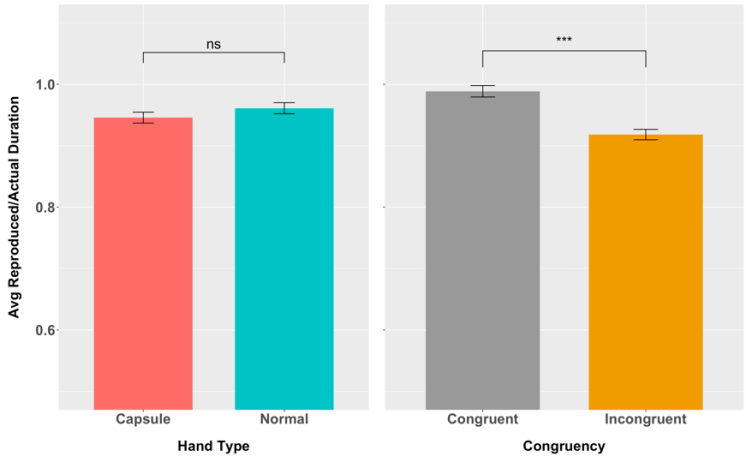


Figure 4. Hand type and congruency on ratio value in initial study

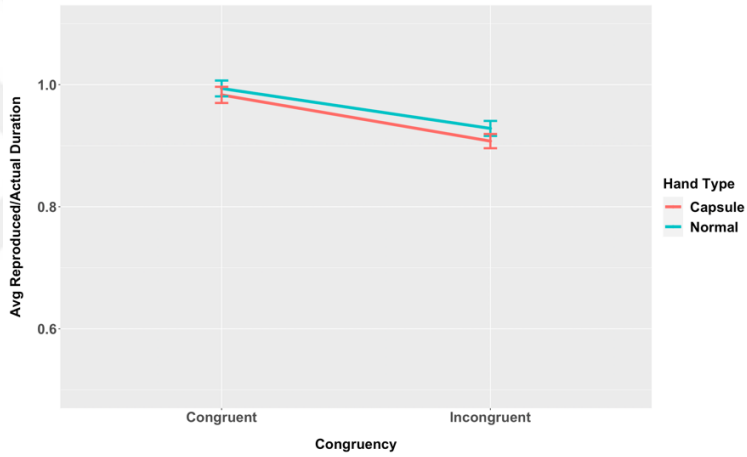


Figure 5. Interaction between hand type and congruency on ratio value in initial study

2.3.2 Lift-off time

A 2 x 2 within-subjects ANOVA (Figure 6) indicated a significant effect of congruency ($F(1, 725) = 124.775$, $p < .001$, $\eta^2p = .147$) on lift-off time, with faster lift-off times in congruent ($M = .588$, $SD = .136$) than incongruent ($M = .636$, $SD = .146$) trials. However, the effect of hand type was non-significant ($F(1, 725) = 0.283$, $p = 0.595$, $\eta^2p = .000$), with similar lift-off times for capsule ($M = .609$, $SD = .137$) and normal hands ($M = .615$, $SD = .149$). The interaction effect between hand type

and congruency was also found to be non-significant ($F(1, 725) = 2.434$, $p = 0.119$, $\eta^2p = .003$) (Figure 7).

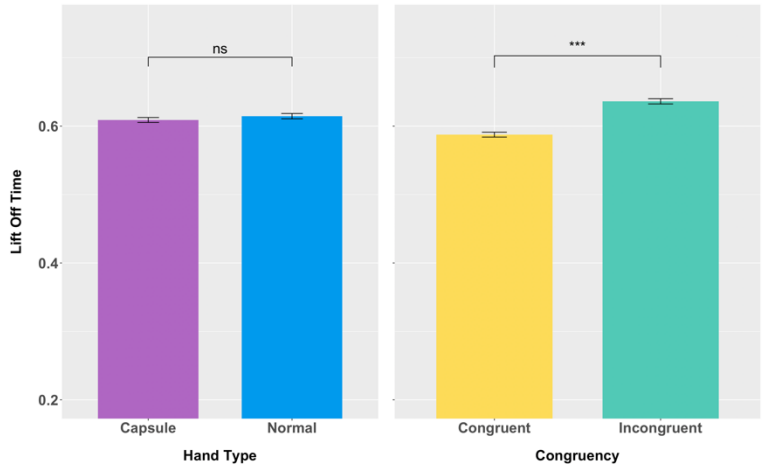


Figure 6. Hand type and congruency on lift-off time (s) in initial study

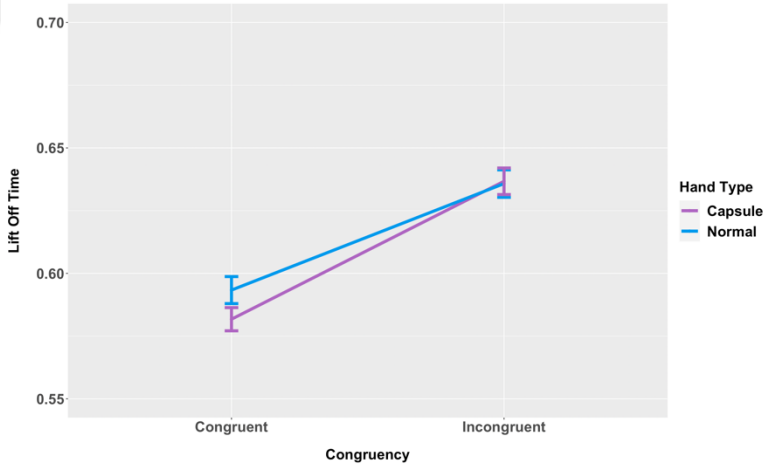


Figure 7. Interaction between hand type and congruency on lift-off time (s) in initial study

2.3.3 Reaching time

A 2 x 2 within-subjects ANOVA (Figure 8) indicated a significant effect of congruency ($F(1, 725) = 175.37$, $p < .001$, $\eta^2p = .195$) on reaching time, with faster reaching times in congruent ($M = .348$, $SD = .135$) than incongruent ($M = .396$, SD

= .121) trials. However, the effect of hand type was non-significant (F(1, 725) = 3.21, p = 0.074, η^2p = .004), with similar reaching times for capsule (M = .368, SD = .124) and normal hands (M = .375, SD = .137). The interaction effect between hand type and congruency was also non-significant (F(1, 725) = 1.31, p = 0.253, η^2p = .002) (Figure 9).

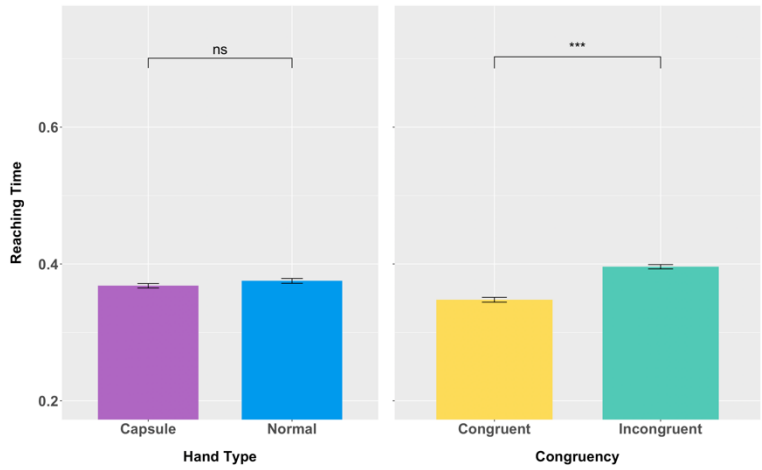


Figure 8. Hand type and congruency on reaching time (s) in initial study

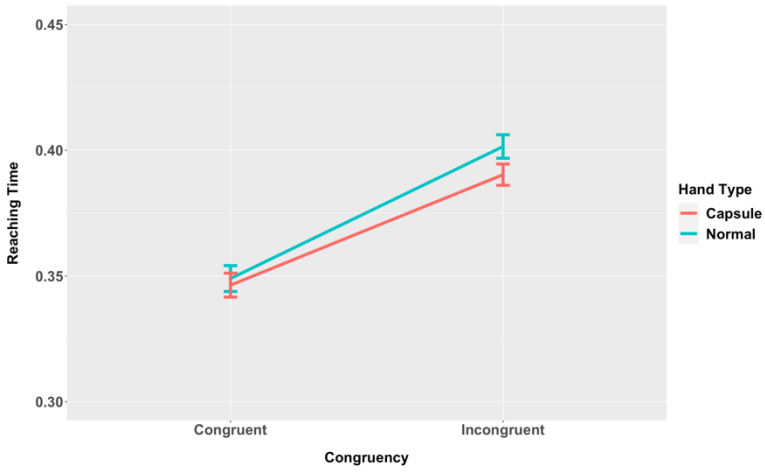


Figure 9. Interaction between hand type and congruency on reaching time (s) in initial study

2.3.4 Stimulus duration

A 2 x 2 within-subjects ANOVA (Figure 10) indicated a significant effect of congruency ($F(1, 725) = 309.043$, $p < .001$, $\eta^2p = .299$) on stimulus duration, with shorter stimulus durations in congruent ($M = .935$, $SD = .201$) than incongruent ($M = 1.032$, $SD = .192$) trials. However, the effect of hand type was non-significant ($F(1, 725) = 2.583$, $p = 0.108$, $\eta^2p = .004$), with similar stimulus durations for capsule ($M = .977$, $SD = .195$) and normal hands ($M = .990$, $SD = .210$). The interaction effect between hand type and congruency was also non-significant ($F(1, 725) = 0.328$, $p = 0.567$, $\eta^2p = .000$) (Figure 11).

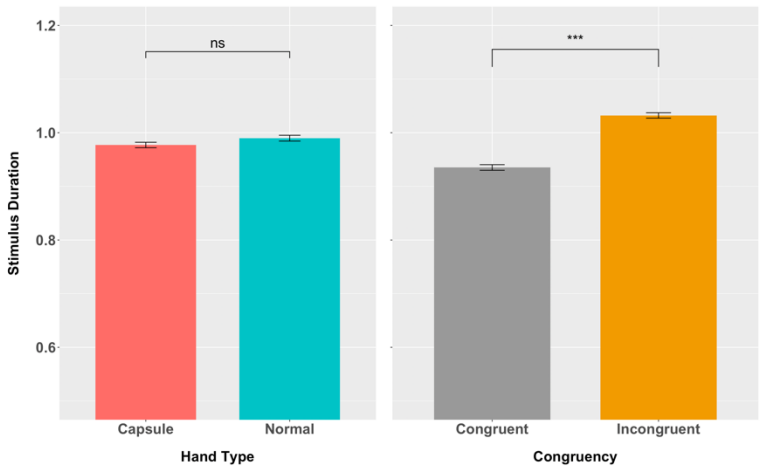


Figure 10. Hand type and congruency on stimulus duration (s) in initial study

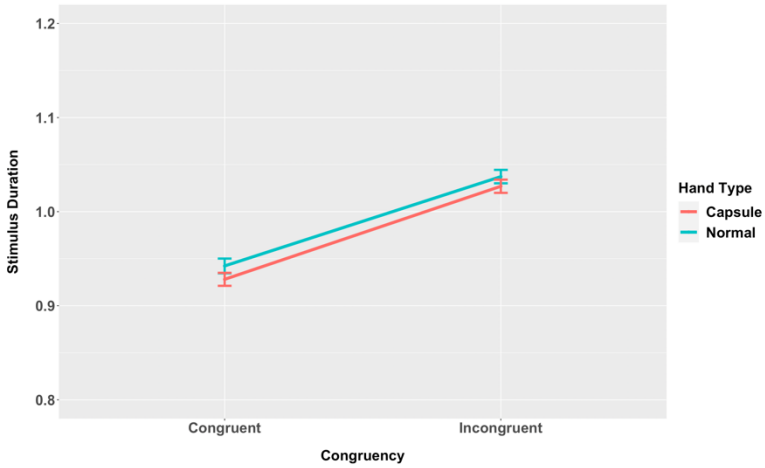


Figure 11. Interaction between hand type and congruency on stimulus duration (s) in initial study

2.3.5 Variation

The coefficients of variation of the ratios between reproduced duration and actual duration were calculated, four per subject (one coefficient per condition). A 2 x 2 within-subjects ANOVA (Figure 12) indicated that hand type ($F(1, 21) = 0.794$, $p = 0.383$, $\eta^2p = .036$), congruency ($F(1, 21) = 3.082$, $p = 0.094$, $\eta^2p = .128$), and their interaction ($F(1, 21) = 0.092$, $p = 0.764$, $\eta^2p = .004$) had no significant effects on the coefficient of variation. Subject responses showed similar levels of variation between categories.

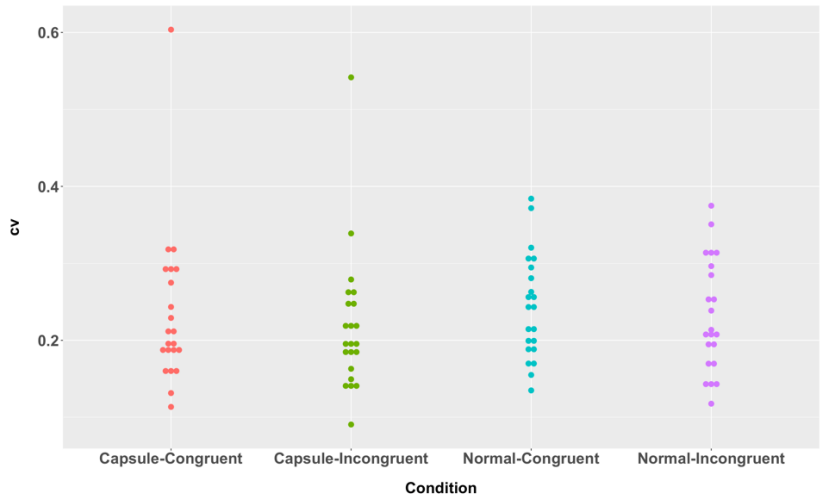


Figure 12. Coefficient of variation results by condition

CHAPTER 3

JOINT LIFT-OFF AND REACHING EXPERIMENT

This experiment consisted of two parts: a lift-off study and a reaching study. The purpose of the lift-off study was to investigate the effect of affordances on the perceived duration of action planning only. The reaching study was similar to the initial reaching experiment, and its purpose was to investigate the effect of affordances on perceived duration of action planning and execution combined. Subjects completed both parts.

3.1 Participants

Twenty-five Boğaziçi University students (10 female, mean age 21.76, ranging from 19 to 28), either undergraduate or graduate, participated in the joint experiment. Subjects were right-handed and had normal or corrected-to-normal vision. Twenty subjects performed both parts in one sitting, while five completed each on different days. Two subjects previously participated in the initial reaching experiment. They gave informed consent to participate, either as a volunteer or for course credits. The study was approved by the institutional ethics committee (see Appendix) and followed the standards of the Declaration of Helsinki (World Medical Association, 2013).

Twelve subjects completed the lift-off study first, then the reaching study. Six of these subjects began each study using capsule hands first, then normal. The other six began each study using normal hands first, then capsule. Thirteen subjects completed the reaching study first, then the lift-off study. Six of these subjects began

each study using capsule hands first, then normal. The other seven began each study using normal hands first, then capsule.

3.2 Methods

The joint experiment followed similar methods to the initial reaching experiment, with a few changes.

3.2.1 Experimental setup

The joint experiment shared the same experimental setup as the initial reaching experiment, with one change. While the hand tracker was placed facing up on the table in the initial experiment, in the joint experiment the hand tracker was fixed to the front of the headset, facing forward (Figure 13). This improvement allowed for the avatar hands to be visible in VR when the subjects rested their hands on the keyboard.

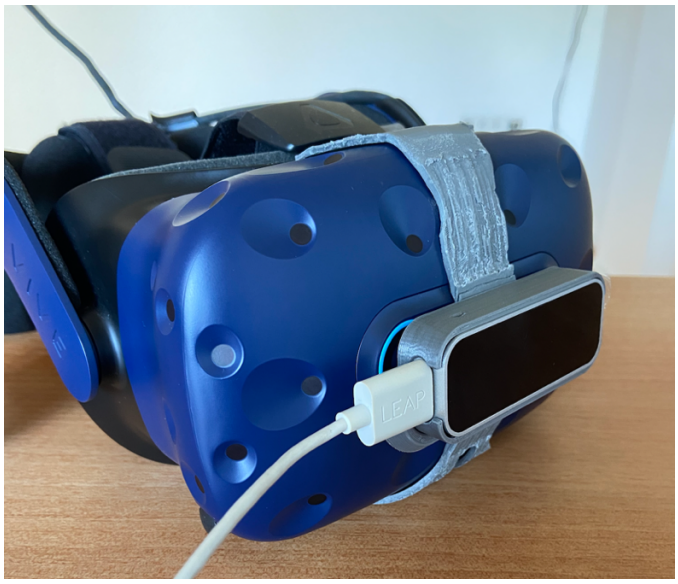


Figure 13. Headset placement used in the joint experiment. The headset was fixed to the front of the headset with the hand-tracking camera facing forward.

3.2.2 Design

The design of the joint experiment was similar to the design of the initial experiment. However, in the lift-off study, the dependent variable was the perceived duration of action planning. In the reaching study, the dependent variable was the perceived duration of action planning plus action execution.

3.2.3 Procedure

Similar to the initial experiment, each study in the joint experiment consisted of training as well as a main test portion. The main portion consisted of six blocks with 24 trials in each block; three blocks were performed with one hand type and another three with the other. In each block, four different pan orientations (upright pan with handle on right, upright pan with handle on left, upside-down pan with handle on right, and upside-down pan with handle on left) were each presented in six trials per block, in a randomized order. Thus, 12 trials were congruent and 12 were incongruent in each block. If the subject made an error (i.e., used the wrong hand to respond), an additional trial was given, in which the pan orientation was the same as in the error trial. Additional trials were given to ensure that the total number of accurate trials was consistent across subjects (24 trials per block), although the actual number of trials completed by subjects varied.

Unlike the initial experiment, training was not given all at once using one hand type and then the other before moving on to the main six testing blocks. In these studies, training for one hand type was given, and then the subjects completed the first three blocks of the main portion using that hand type. Afterward, training for the second hand type was given, followed by the last three blocks. The training in the joint experiment was similar to the training in the initial reaching experiment, with a

few changes. In part five, in which subjects learned how to accurately reproduce stimulus durations using the spacebar, they completed 36 trials, instead of 24. Training also differed somewhat between the lift-off and reaching studies, depending on which study the subject was being trained for (lift-off study versus reaching study). The pan stimulus automatically disappeared after 0.5 to 1.75 seconds in part five if subjects were being trained for the lift-off study and after 0.75 to 2 seconds for the reaching study. In part six, in which subjects completed a practice of the main portion, the practice portion matched one block of the lift-off study if subjects were being trained for the lift-off study and one block of the reaching study if subjects were being trained for the reaching study.

An example training and test sequence for the joint study is given below, for a subject assigned to complete the lift-off study first (then reaching study) and utilize the normal hands first (then capsule hands) within each study:

i. Subject completes training for lift-off study using normal hands.
ii. Subject completes the first three blocks of the lift-off study using normal hands.
iii. Subject completes training for lift-off study again, now using capsule hands.
iv. Subject completes the last three blocks of the lift-off study using capsule hands.
v. Subject completes training for reaching study using normal hands.
vi. Subject completes the first three blocks of the reaching study using normal hands.
vii. Subject completes training for reaching study again, now using capsule hands.

viii. Subject completes the last three blocks of the reaching study using capsule hands. The experiment is completed.

3.2.3.1 Lift-off study main portion

The procedure for the main test portion of the lift-off study was similar to that of the initial reaching experiment, with a few changes. Subjects had to merely lift the correct hand off the keyboard in response to the pan stimulus, rather than reaching and touching the pan. Instead of disappearing upon contact, the pan in each trial disappeared when the subject lifted one hand off the keyboard. Then, the subjects reproduced the pan stimulus duration by pressing the spacebar, with the stimulus duration equal to the action planning time. In this case, the total pan duration was equal to the subject's action planning time, while action execution time was always recorded as zero.

3.2.3.2 Reaching study main portion

The procedure for the main test portion of the reaching study was the same as the one used in the initial reaching experiment.

3.3 Results

The data were preprocessed in the same way as in the initial reaching experiment before being analyzed using the same programs.

3.3.1 Reproduced duration

For the lift-off study, a 2 x 2 within-subjects ANOVA (Figure 14) indicated a significant effect of congruency ($F(1, 813) = 31.806$, $p < .001$, $\eta^2p = .038$) on

reproduced duration, with longer perceived durations for congruent (M = 1.350, SD = .403) than incongruent (M = 1.286, SD = .391) trials. However, the effect of hand type was non-significant ($F(1, 813) = 0.448$, $p = 0.504$, $\eta^2p = .001$), with similar perceived durations for capsule (M = 1.313, SD = .385) and normal hands (M = 1.323, SD = .411). The interaction effect between hand type and congruency was significant ($F(1, 813) = 6.191$, $p = 0.013$, $\eta^2p = .008$). Subjects perceived pan durations to be longer in congruent conditions with capsule hand (M = 1.36, SD = .395) than normal hand (M = 1.34, SD = .410), but with normal hand (M = 1.30, SD = .412) than with capsule hand (M = 1.27, SD = .369) in incongruent conditions (Figure 15).

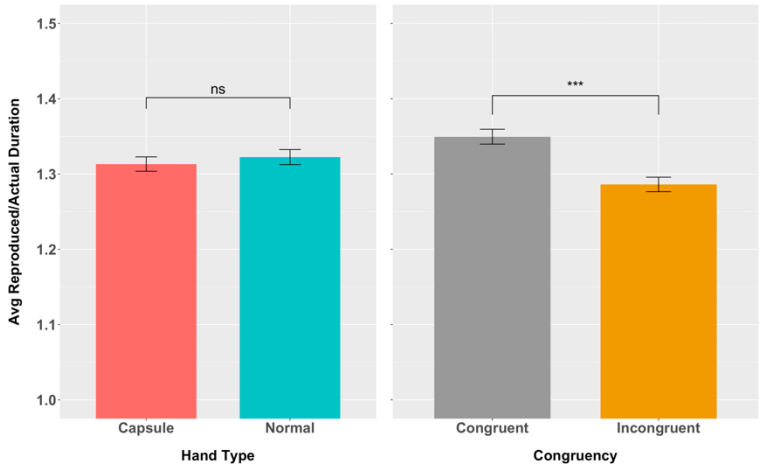


Figure 14. Hand type and congruency on ratio value in lift-off study

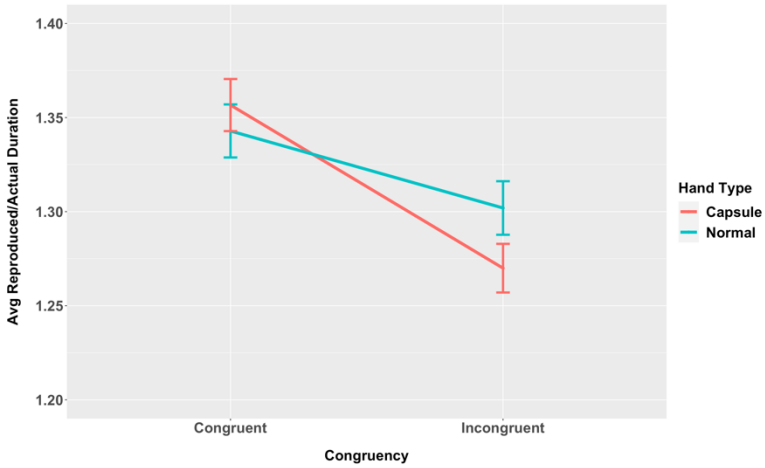


Figure 15. Interaction between hand type and congruency on ratio value in lift-off study

For the reaching study, a 2 x 2 within-subjects ANOVA (Figure 16) indicated a significant effect of congruency ($F(1, 831) = 36.012$, $p < .001$, $\eta^2p = .042$) on reproduced duration, with longer perceived durations for congruent ($M = 1.123$, $SD = .346$) than incongruent ($M = 1.062$, $SD = .333$) trials. However, the effect of hand type was non-significant ($F(1, 831) = 0.000$, $p = 0.995$, $\eta^2p = .000$), with similar perceived durations for capsule ($M = 1.096$, $SD = .336$) and normal hands ($M = 1.089$, $SD = .345$). The interaction effect between hand type and congruency was also non-significant ($F(1, 831) = 0.220$, $p = 0.639$, $\eta^2p = .000$) (Figure 17).

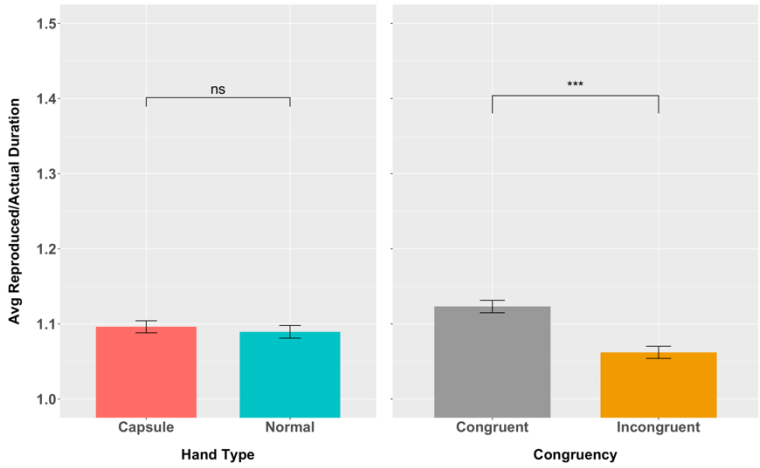


Figure 16. Hand type and congruency on ratio value in reaching study

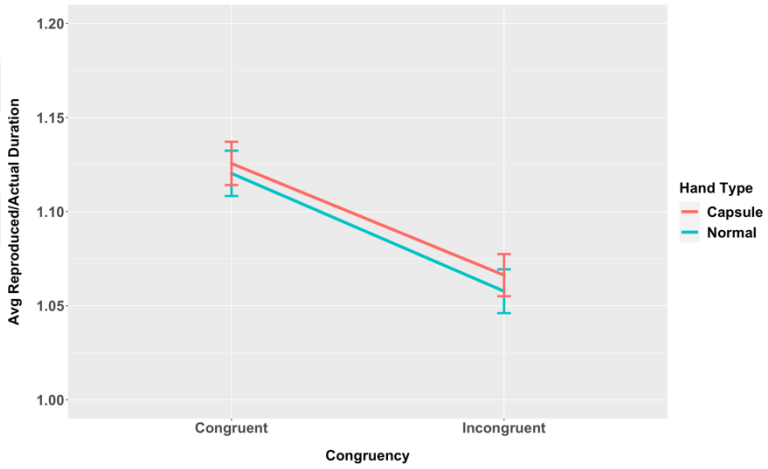


Figure 17. Interaction between hand type and congruency on ratio value in reaching study

3.3.2 Lift-off time

Subject lift-off times were analyzed from data taken from the lift-off study. A 2 x 2 within-subjects ANOVA (Figure 18) indicated a significant effect of congruency ($F(1, 813) = 89.928$, $p < .001$, $\eta^2p = .1$) on lift-off time, with faster lift-off times in congruent ($M = .598$, $SD = .135$) than incongruent ($M = .637$, $SD = .151$) trials. However, the effect of hand type was non-significant ($F(1, 813) = 0.984$, $p = 0.321$, $\eta^2p = .001$), with similar lift-off times for capsule ($M = .618$, $SD = .152$) and normal

hands (M = .617, SD = .138). The interaction effect between hand type and congruency was significant ($F(1, 813) = 14.324$, $p < 0.001$, $\eta^2p = .017$). Subjects lifted off faster in congruent conditions with capsule hand (M = .590, SD = .137) than normal hand (M = .605, SD = .134), but with normal hand (M = .630, SD = .142) than with capsule hand (M = .645, SD = .160) in incongruent conditions (Figure 19).

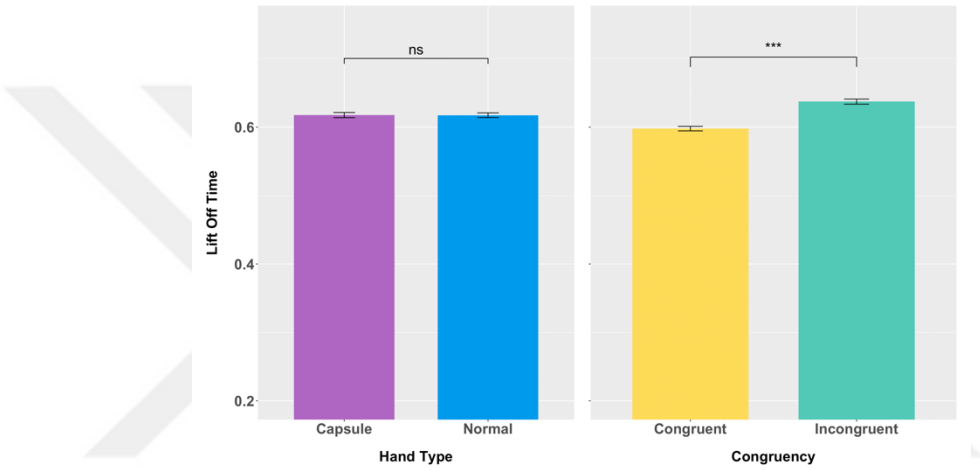


Figure 18. Hand type and congruency on lift-off time (s) in lift-off study

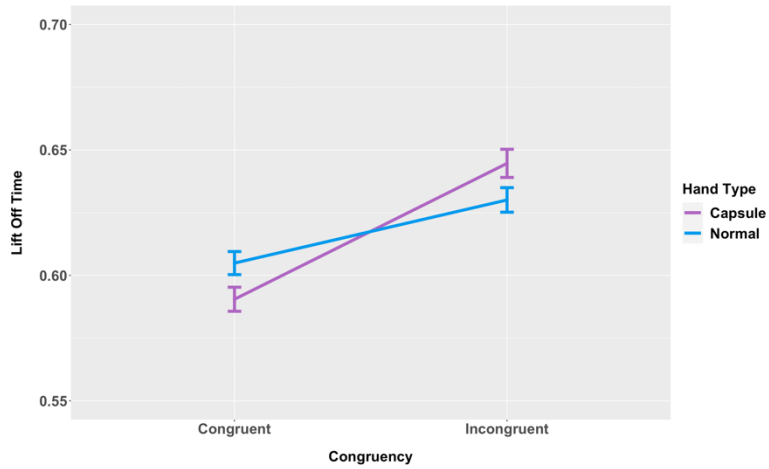


Figure 19. Interaction between hand type and congruency on lift-off time (s) in lift-off study

3.3.3 Reaching time

Subject reaching times were analyzed from data taken from the reaching study. A 2 x 2 within-subjects ANOVA (Figure 20) indicated a significant effect of congruency ($F(1, 831) = 75.178$, $p < .001$, $\eta^2p = .083$) on reaching time, with faster reaching times in congruent ($M = .371$, $SD = .135$) than incongruent ($M = .404$, $SD = .161$) trials. However, the effect of hand type was non-significant ($F(1, 831) = 0.354$, $p = 0.552$, $\eta^2p = .000$), with similar reaching times for capsule ($M = .392$, $SD = .158$) and normal hands ($M = .383$, $SD = .139$). The interaction effect between hand type and congruency was also non-significant ($F(1, 831) = 0.196$, $p = 0.658$, $\eta^2p = .000$) (Figure 21).

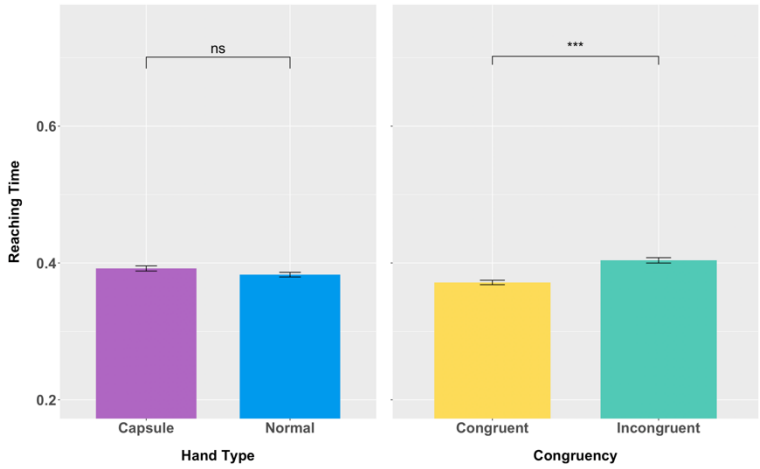


Figure 20. Hand type and congruency on reaching time (s) in reaching study

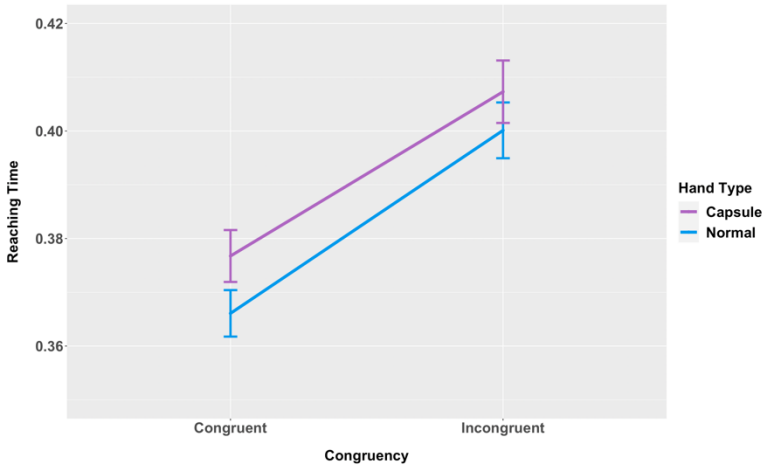


Figure 21. Interaction between hand type and congruency on reaching time (s) in reaching study

3.3.4 Stimulus duration

For the lift-off study, the analysis of hand type and congruency effects on stimulus duration is the same as the analysis on lift-off time (i.e., stimulus duration is equal to lift-off time).

For the reaching study, a 2 x 2 within-subjects ANOVA (Figure 22) indicated a significant effect of congruency ($F(1, 831) = 174.011$, $p < .001$, $\eta^2p = .173$) on stimulus duration, with shorter stimulus durations in congruent ($M = .937$, $SD = .200$) than incongruent ($M = 1.012$, $SD = .228$) trials. The effect of hand type was also significant ($F(1, 831) = 8.281$, $p = 0.004$, $\eta^2p = .010$), with longer stimulus durations for capsule ($M = .985$, $SD = .225$) than normal hands ($M = .964$, $SD = .210$). The interaction effect between hand type and congruency was non-significant ($F(1, 831) = 0.107$, $p = 0.744$, $\eta^2p = .000$) (Figure 23).

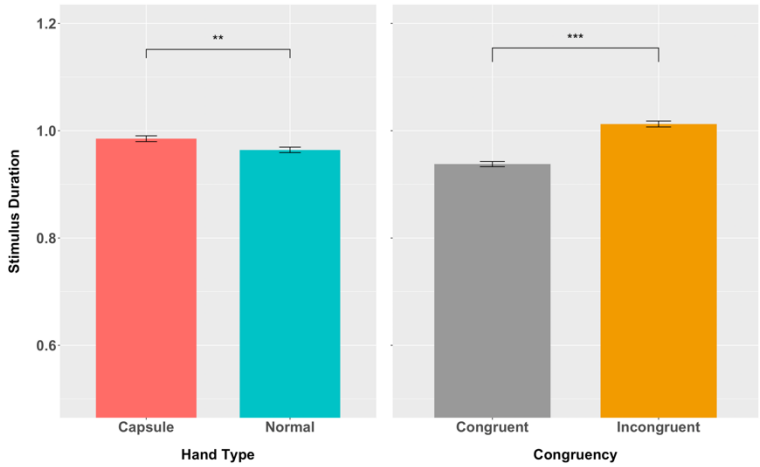


Figure 22. Hand type and congruency on stimulus duration (s) in reaching study

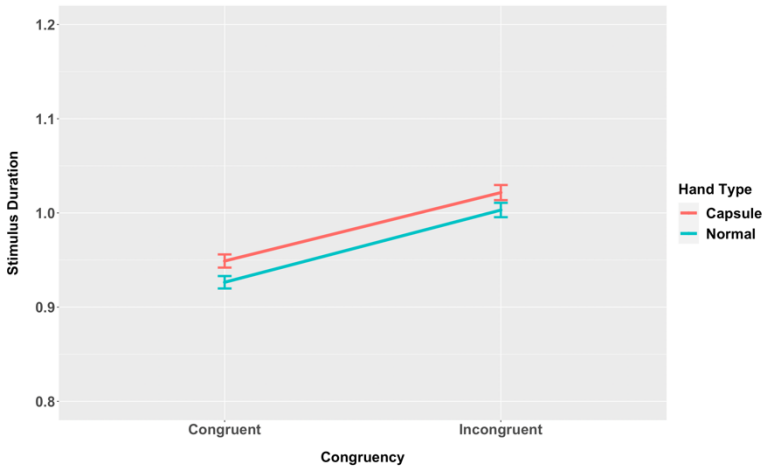


Figure 23. Interaction between hand type and congruency on stimulus duration (s) in reaching study

CHAPTER 4

VIERORDT'S LAW CONTROL EXPERIMENT

4.1 Participants

Fourteen Boğaziçi University students (10 female, mean age 25, ranging from 19 to 44), either undergraduate or graduate, participated in the control study. Subjects were right-handed and had normal or corrected-to-normal vision. One subject previously participated in both the initial reaching and joint experiments, and one subject previously participated in the joint experiment. They gave informed consent to participate, either as a volunteer or for course credits. The study was approved by the institutional ethics committee (see Appendix) and followed the standards of the Declaration of Helsinki (World Medical Association, 2013).

Half of the subjects completed the first three blocks of the study with normal hands and the second three with capsule hands. The other half completed the first three blocks with capsule hands and second three with normal hands.

4.2 Methods

4.2.1 Experimental setup

The control experiment shared the same experimental setup as the joint experiment.

4.2.2 Design

The design of the control experiment was similar to the design of the initial reaching experiment. However, the perceived durations reported by spacebar reproduction did not represent subjects' perceived durations of action planning and execution, since subjects did not perform action responses to the pan stimuli. The reproduced

spacebar durations merely represented subjects' perceived durations of the pan on the screen. The interquartile ranges of actual pan duration for each category (combination of hand type and handle congruency) from the joint experiment's reaching study were used to determine the actual pan durations. For the category of normal hand with congruent handle, the IQR was from 0.789 s to 1.055 s. For normal hand with incongruent handle, the IQR was from 0.844 s to 1.135 s. For capsule hand and congruent handle, the IQR was from 0.801 s to 1.077 s. For capsule hand with incongruent handle, the IQR was from 0.844 s to 1.166 s. For each trial in this study, Unity selected a random value within the IQR of the category that the trial belonged to. This value was used as the actual pan duration in the trial.

4.2.3 Procedure

Similar to the initial experiment, each study in the control experiment consisted of training as well as a main test portion. The main portion consisted of six blocks with 24 trials in each block; three blocks were performed with one hand type and another three with the other. In each block, four different pan orientations (upright pan with handle on right, upright pan with handle on left, upside-down pan with handle on right, and upside-down pan with handle on left) were each presented in six trials per block, in a randomized order. Thus, 12 trials were congruent and 12 were incongruent in each block. If the subject made an error (i.e., used the wrong hand to respond), an additional trial was given, in which the pan orientation was the same as in the error trial. Additional trials were given to ensure that the total number of accurate trials was consistent across subjects (24 trials per block), although the actual number of trials completed by subjects varied.

Similar to the joint experiment, training was not given all at once using one hand type and then the other before moving on to the main six testing blocks. In these studies, training for one hand type was given, and then the subjects completed the first three blocks of the main portion using that hand type. Afterwards, training for the second hand type was given, followed by the last three blocks. The training in the control experiment was similar to the training in the initial reaching experiment, with a few changes. In part five, in which subjects learned how to accurately reproduce stimulus durations using the spacebar, they completed 36 trials, instead of 24. In part six, in which subjects completed a practice of the main portion, the practice portion matched one block of the control study, in which subjects merely viewed the stimulus and reproduced the stimulus duration after its disappearance.

The procedure for the main test portion of the control study was similar to that of the initial reaching study, with a change. Subjects cued a new trial by placing their hands in resting position, with their left hand on the S key foam and right hand on the L key foam. After a 500-ms fixation, the pan appeared on the screen and automatically disappeared after the preset duration. Rather than performing any motor responses, subjects were asked to keep their hands in resting position until the pan disappeared. After the pan disappeared, subjects then reproduced the pan stimulus duration by pressing the spacebar. If the pan was upright, subjects used their right hand to press the spacebar. If the pan was upside-down, they used their left hand. The actual pan duration and reproduced duration were recorded from each trial for further analysis.

4.3 Results

The data were preprocessed in a similar way as in the initial reaching study, with one change, before being analyzed using the same programs. Trials in which subjects responded before the pan disappeared were excluded from analysis.

4.3.1 Reproduced duration

A 2 x 2 within-subjects ANOVA (Figure 24) indicated a significant effect of congruency ($F(1, 471) = 17.415$, $p < .001$, $\eta^2p = .036$) on reproduced duration, with longer perceived durations for congruent ($M = 1.130$, $SD = .288$) than incongruent ($M = 1.083$, $SD = .268$) trials. The effect of hand type was also significant ($F(1, 471) = 11.559$, $p < .001$, $\eta^2p = .024$), with longer perceived durations for capsule ($M = 1.128$, $SD = .275$) than normal hands ($M = 1.085$, $SD = .282$). The interaction effect between hand type and congruency was non-significant ($F(1, 471) = 0.054$, $p = 0.816$, $\eta^2p = .000$) (Figure 25).

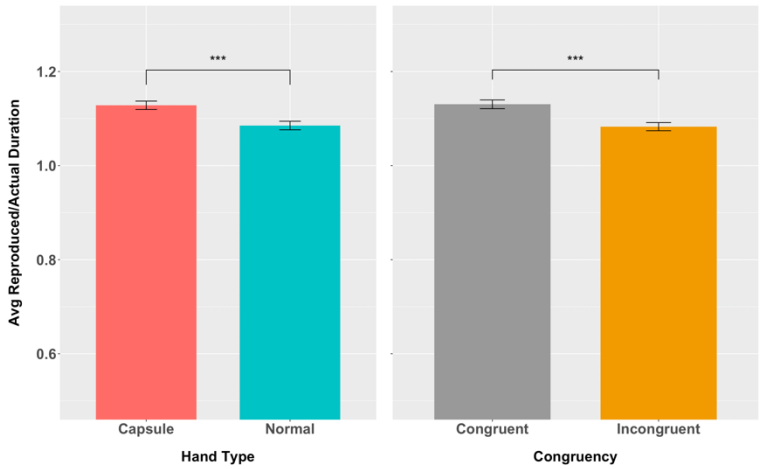


Figure 24. Hand type and congruency on ratio value in control study

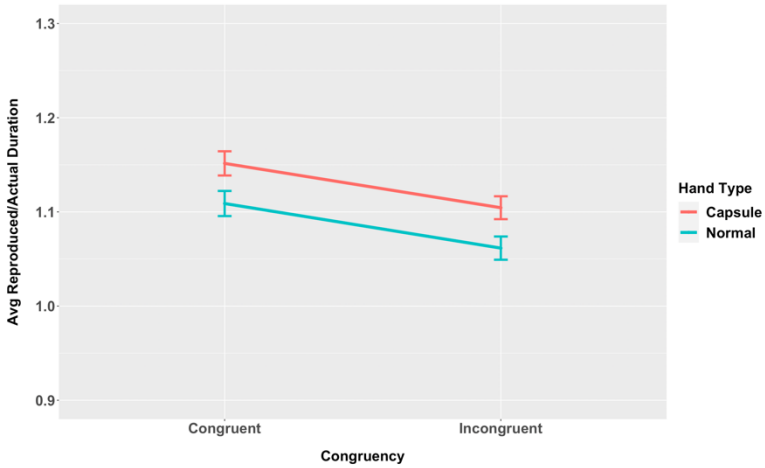


Figure 25. Interaction between hand type and congruency on ratio value in control study

4.3.2 Stimulus duration

A 2 x 2 within-subjects ANOVA (Figure 26) indicated a significant effect of congruency ($F(1, 471) = 365.949$, $p < .001$, $\eta^2p = .437$) on stimulus duration, with shorter stimulus durations in congruent ($M = .925$, $SD = .077$) than incongruent ($M = .992$, $SD = .086$) trials. The effect of hand type was also significant ($F(1, 471) = 18.25$, $p < .001$, $\eta^2p = .037$), with longer stimulus durations for capsule ($M = .966$, $SD = .090$) than normal hands ($M = .950$, $SD = .085$). The interaction effect between hand type and congruency was non-significant ($F(1, 471) = 0.073$, $p = 0.788$, $\eta^2p = .000$) (Figure 27).

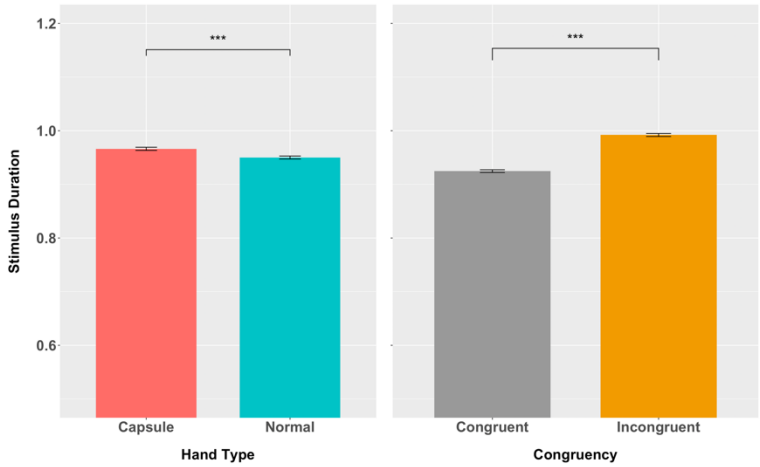


Figure 26. Hand type and congruency on stimulus duration (s) in control study

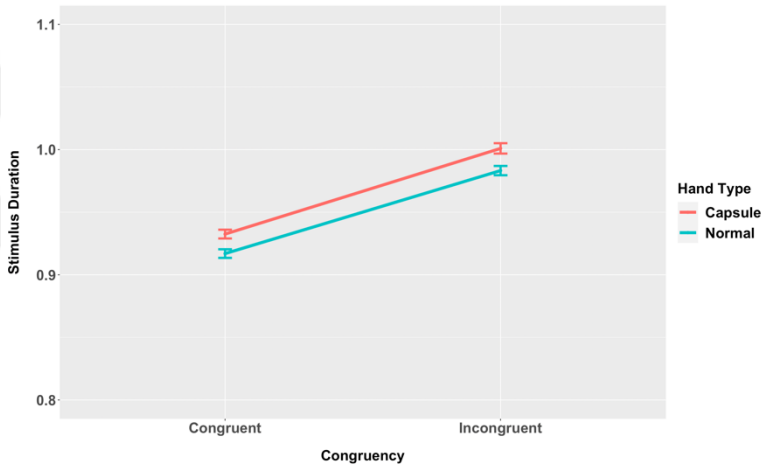


Figure 27. Interaction between hand type and congruency on stimulus duration (s) in control study

CHAPTER 5

EXTRAPERSONAL SPACE EXPERIMENT

The extrapersonal space experiment was a replica of the joint experiment, consisting of a lift-off study and a reaching study. The only difference was that the pan was placed in extrapersonal rather than peripersonal space.

5.1 Participants

Fifteen Boğaziçi University students (11 female, mean age 21.6, ranging from 19 to 24), either undergraduate or graduate, participated in the joint experiment. Subjects were right-handed and had normal or corrected-to-normal vision. All subjects performed both parts in one sitting. One subject previously participated in the initial reaching, joint, and control studies. One subject previously participated in the joint study, and three subjects previously participated in the control study. They gave informed consent to participate, either as a volunteer or for course credits. The study was approved by the institutional ethics committee (see Appendix) and followed the standards of the Declaration of Helsinki (World Medical Association, 2013).

Eight subjects completed the lift-off study first, then the reaching study. Three of these subjects began each study using capsule hands first, then normal. The other five began each study using normal hands first, then capsule. Seven subjects completed the reaching study first, then the lift-off study. Four of these subjects began each study using capsule hands first, then normal. The other three began each study using normal hands first, then capsule.

5.2 Methods

5.2.1 Experimental setup

The experimental setup was the same as in the joint experiment.

5.2.2 Design

The design was similar to that of the joint experiment. However, the pan was placed in extrapersonal space (i.e., outside of arm's reach) (Figure 28), where subjects could not reach with their arms fully extended while sitting at the lab desk. Therefore, the grasping and reaching affordances were unavailable, regardless of hand type and handle orientation.

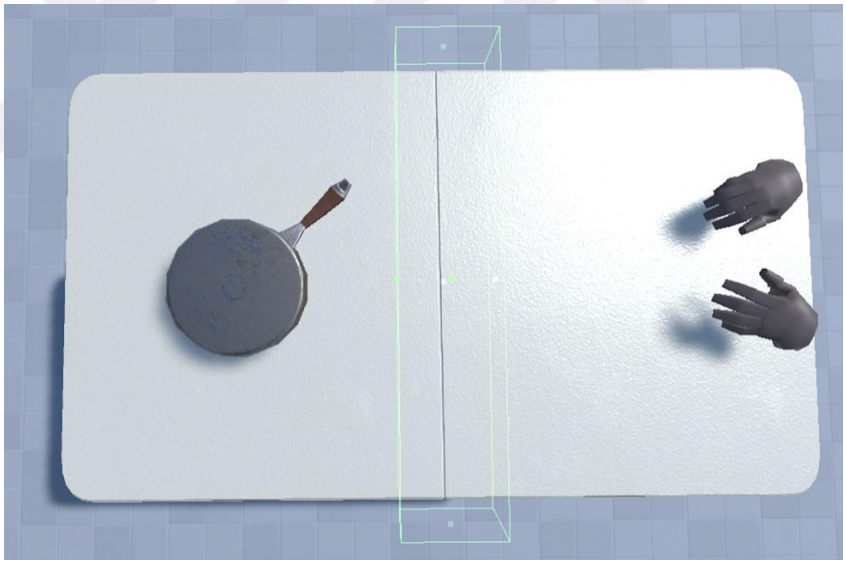


Figure 28. The pan in extrapersonal space. It could not be touched when subjects were sitting at the lab desk with arms fully extended.

5.2.3 Procedure

Similar to the joint experiment, each study in the extrapersonal experiment consisted of training as well as a main test portion. The main portion consisted of six blocks with 24 trials in each block; three blocks were performed with one hand type and

another three with the other. In each block, four different pan orientations (upright pan with handle on right, upright pan with handle on left, upside-down pan with handle on right, and upside-down pan with handle on left) were each presented in six trials per block, in a randomized order. Thus, 12 trials were congruent and 12 were incongruent in each block. If the subject made an error (i.e., used the wrong hand to respond), an additional trial was given, in which the pan orientation was the same as in the error trial. Additional trials were given to ensure that the total number of accurate trials was consistent across subjects (24 trials per block), although the actual number of trials completed by subjects varied. Training was not given all at once using one hand type and then the other before moving on to the main six testing blocks. In these studies, training for one hand type was given, and then the subjects completed the first three blocks of the main portion using that hand type. Afterwards, training for the second hand type was given, followed by the last three blocks.

The procedure for the extrapersonal lift-off study matched that of the joint experiment's lift-off study. The procedure for the extrapersonal reaching study was similar to that of the joint experiment's reaching study. However, since the pan was not in reachable distance, subjects merely had to reach towards the pan. In the virtual environment, an invisible sensor (shown in green outline in Figure 28) was placed on the virtual table, between the subject avatar and the pan stimulus. When subjects made contact with the sensor while reaching, the pan stimulus disappeared. Then, subjects again reproduced the pan stimulus duration using the spacebar.

5.3 Results

The data were preprocessed in the same way as in the initial reaching study before being analyzed using the same programs.

5.3.1 Reproduced duration

For the lift-off study, a 2 x 2 within-subjects ANOVA (Figure 29) indicated a significant effect of congruency ($F(1, 483) = 9.01$, $p = 0.003$, $\eta^2p = .018$) on reproduced duration, with longer perceived durations for congruent ($M = 1.281$, $SD = .406$) than incongruent ($M = 1.245$, $SD = 0.398$) trials. The effect of hand type was also significant ($F(1, 483) = 14.03$, $p < .001$, $\eta^2p = .028$), with longer perceived durations for capsule ($M = 1.291$, $SD = .415$) than normal hands ($M = 1.236$, $SD = .388$). The interaction effect between hand type and congruency was non-significant ($F(1, 483) = 1.52$, $p = 0.219$, $\eta^2p = .003$) (Figure 30).

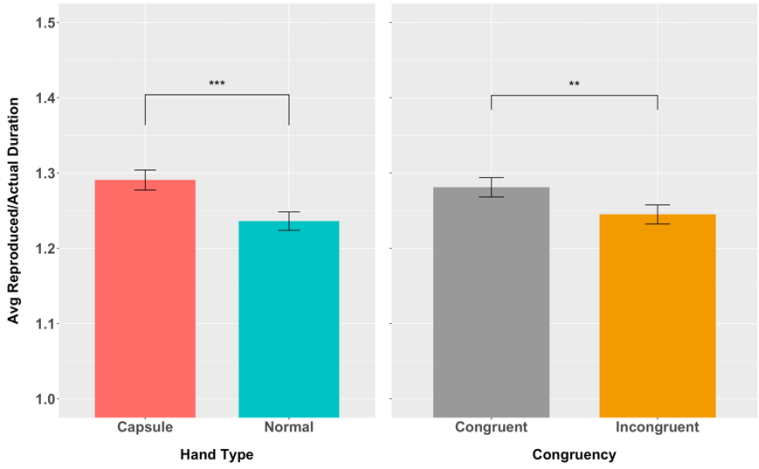


Figure 29. Hand type and congruency on ratio value in extrapersonal lift-off study

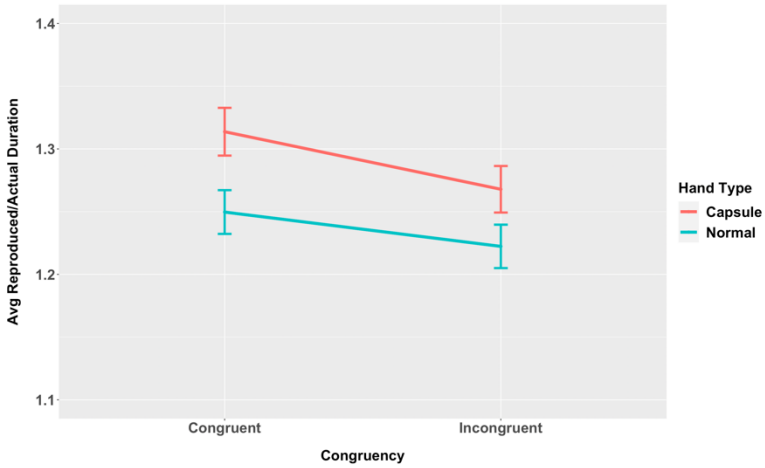


Figure 30. Interaction between hand type and congruency on ratio value in extrapersonal lift-off study

For the reaching study, a 2 x 2 within-subjects ANOVA (Figure 31) indicated a significant effect of congruency ($F(1, 465) = 6.181$, $p = 0.013$, $\eta^2p = .013$) on reproduced duration, with longer perceived durations for congruent ($M = 1.058$, $SD = .317$) than incongruent ($M = 1.031$, $SD = .298$) trials. The effect of hand type was also significant ($F(1, 465) = 48.714$, $p < .001$, $\eta^2p = .095$), with longer perceived durations for capsule ($M = 1.090$, $SD = .307$) than normal hands ($M = 1.00$, $SD = .302$). The interaction effect between hand type and congruency was non-significant ($F(1, 465) = 0.043$, $p = 0.836$, $\eta^2p = .000$) (Figure 32).

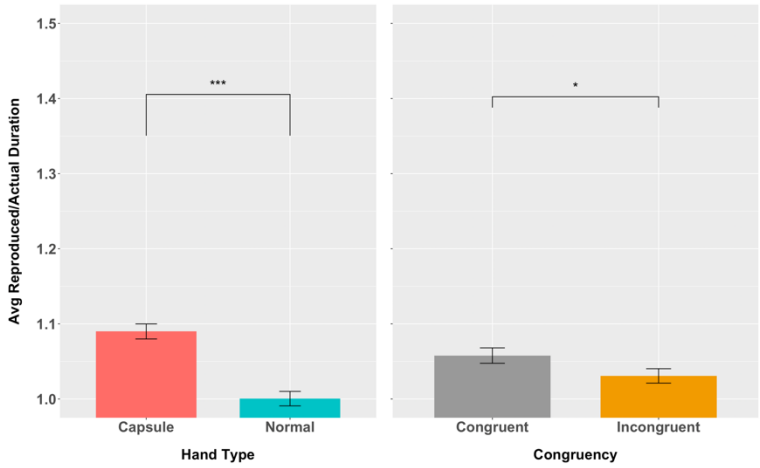


Figure 31. Hand type and congruency on ratio value in extrapersonal reaching study

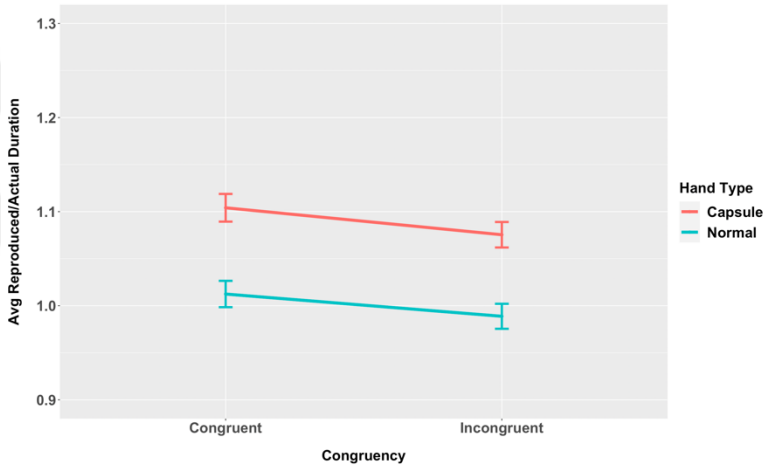


Figure 32. Interaction between hand type and congruency on ratio value in extrapersonal reaching study

5.3.2 Lift-off time

Subject lift-off times were analyzed from data taken from the extrapersonal lift-off study. A 2 x 2 within-subjects ANOVA (Figure 33) indicated a significant effect of congruency ($F(1, 483) = 25.25$, $p < .001$, $\eta^2p = .050$) on lift-off time, with faster lift-off times in congruent ($M = .625$, $SD = .156$) than incongruent ($M = .652$, $SD = .167$) trials. The effect of hand type was also significant ($F(1, 483) = 4.28$, $p = 0.039$, $\eta^2p = .009$), with faster lift-off times for capsule ($M = .629$, $SD = .157$) than normal

hands (M = .649, SD = .167). The interaction effect between hand type and congruency was non-significant ($F(1, 483) = 0.001$, $p = 0.976$, $\eta^2p = .000$) (Figure 34).

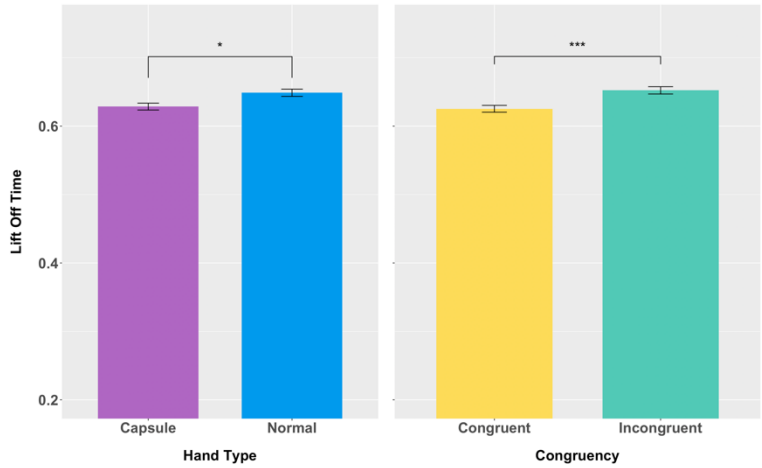


Figure 33. Hand type and congruency on lift-off time (s) in extrapersonal lift-off study

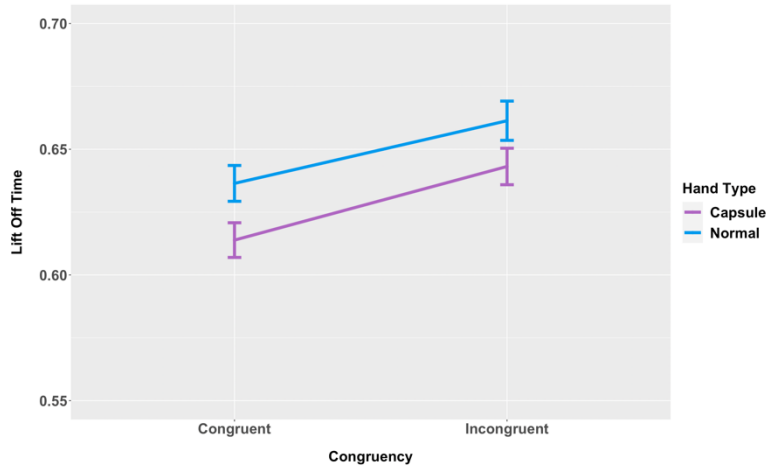


Figure 34. Interaction between hand type and congruency on lift-off time (s) in extrapersonal lift-off study

5.3.3 Reaching time

Subject reaching times were analyzed from data taken from the extrapersonal reaching study. A 2 x 2 within-subjects ANOVA (Figure 35) indicated a non-

significant effect of congruency ($F(1, 465) = 2.13$, $p = 0.145$, $\eta^2p = .005$) on reaching time, with similar reaching times in congruent ($M = .416$, $SD = .106$) and incongruent ($M = .422$, $SD = .130$) trials. However, the effect of hand type was significant ($F(1, 465) = 6.35$, $p = 0.012$, $\eta^2p = .013$), with faster reaching times for capsule ($M = .412$, $SD = .114$) than normal hands ($M = .425$, $SD = .123$). The interaction effect between hand type and congruency was also non-significant ($F(1, 465) = 2.57$, $p = 0.109$, $\eta^2p = .006$) (Figure 36).

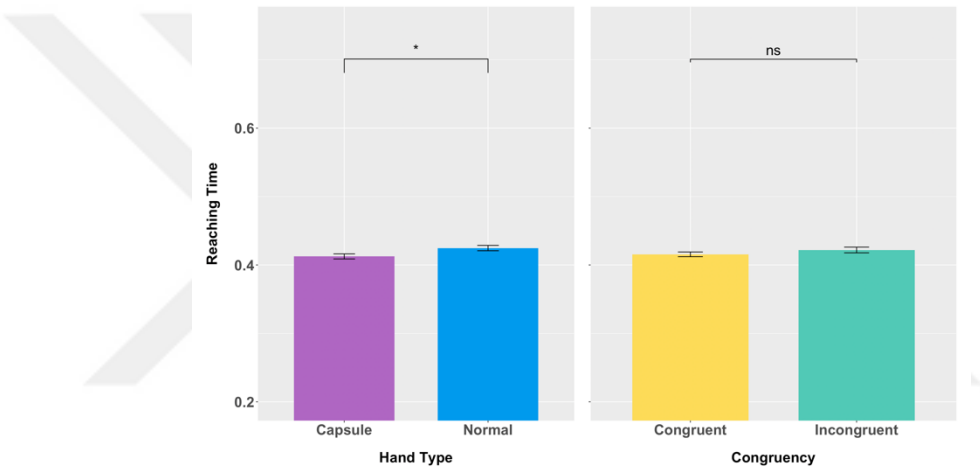


Figure 35. Hand type and congruency on reaching time (s) in extrapersonal reaching study

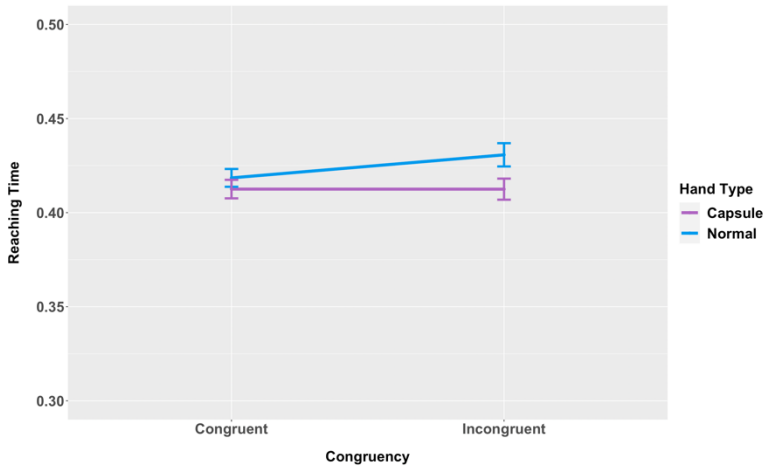


Figure 36. Interaction between hand type and congruency on extrapersonal reaching time (s) in reaching study

5.3.4 Stimulus duration

For the extrapersonal lift-off study, the analysis of hand type and congruency effects on stimulus duration is the same as the analysis on lift-off time (i.e., stimulus duration is equal to lift-off time).

For the extrapersonal reaching study, a 2 x 2 within-subjects ANOVA (Figure 37) indicated a significant effect of congruency ($F(1, 465) = 59.66$, $p < .001$, $\eta^2p = .114$) on stimulus duration, with shorter stimulus durations in congruent ($M = 1.024$, $SD = .194$) than incongruent ($M = 1.091$, $SD = .242$) trials. The effect of hand type was also significant ($F(1, 465) = 12.43$, $p < .001$, $\eta^2p = .026$), with shorter stimulus durations for capsule ($M = 1.034$, $SD = .193$) than normal hands ($M = 1.081$, $SD = .244$). The interaction effect between hand type and congruency was non-significant ($F(1, 465) = 3.26$, $p = 0.072$, $\eta^2p = .007$) (Figure 38).

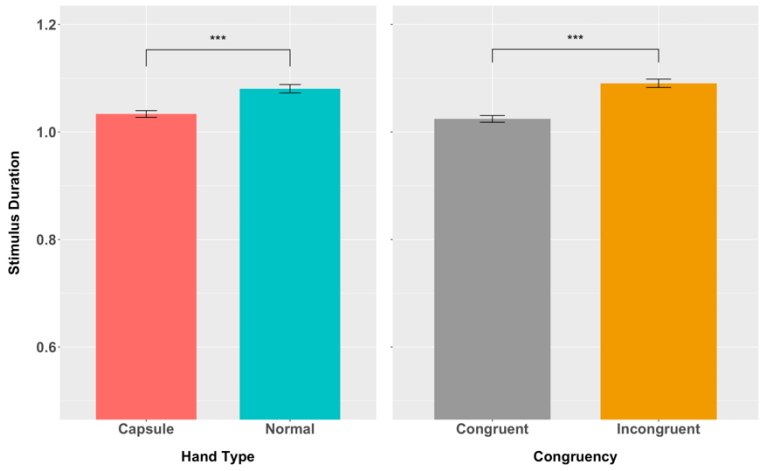


Figure 37. Hand type and congruency on stimulus duration (s) in extrapersonal reaching study

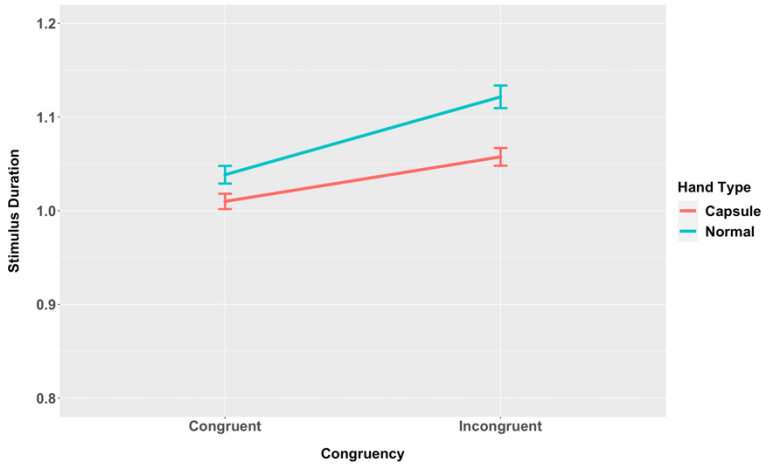


Figure 38. Interaction between hand type and congruency on stimulus duration (s) in extrapersonal reaching study

CHAPTER 6

DISCUSSION AND CONCLUSION

6.1 Discussion

This thesis aimed to investigate the possible effects that perceived affordances could have on perceived time during motor action. Although the results from the studies were conflicting, some conclusions are suggested from the trends that were consistent across studies.

6.1.1 Stimulus duration effects on perceived duration

To begin, the results from the initial reaching and joint experiments suggested that congruency might have a significant effect on subjects' perceived temporal durations, due to the affordance effect or another mechanism. In these studies, subjects' reproduced durations were significantly longer for congruent than incongruent trials. However, it is known from Vierordt's law that subjects usually overproduce shorter durations and underproduce longer durations when using the method of reproduction (Vierordt, 1868). In the initial reaching and joint experiments, the stimulus durations in congruent trials were significantly shorter than in incongruent trials. Thus, the control study was conducted to confirm that the results of congruency affecting perceived time were not merely due to Vierordt's phenomenon. In the control study, the stimulus durations of congruent trials were significantly shorter than in incongruent trials, reflecting the pattern shown in the previous two experiments. Subjects merely had to reproduce the stimulus duration after the pan automatically disappeared from the screen, rather than giving a motor response to the pan while it was on the screen. This procedure was used to study the

effects of stimulus duration on reproduced duration, after reducing or eliminating the possible affordance effect activated by action anticipation or execution during stimulus viewing. The control study results show that subjects' reproduced durations in congruent trials were still significantly longer than in incongruent trials, suggesting that the significant differences in perceived or reproduced time in the initial reaching and joint experiments may have been merely due to the effect of stimulus duration. The effect of stimulus duration may also explain the significant interaction effect in the joint experiment's lift-off study. In the congruent condition, lift-off times, equal to the stimulus durations, were significantly faster using capsule hand than normal hand; in the incongruent condition, lift-off times were significantly faster using normal than capsule hand. Following Vierordt's phenomenon, in the congruent condition, reproduced duration was longer for capsule hand trials than normal hand trials, and in the incongruent condition, reproduced duration was longer for normal hand trials than capsule hand trials. Furthermore, in the lift-off and reaching extrapersonal studies, the reproduced durations in congruent trials were significantly longer than in incongruent trials, probably due to stimulus durations being significantly shorter in congruent than incongruent trials. Additionally, in both extrapersonal studies, the reproduced durations in trials with capsule hands were significantly longer than with normal hands, also probably due to stimulus durations being shorter with capsule hands than normal hands. From the results of the studies in this thesis, the possible effects of affordances on perceived time remain unclear, as the obtained results may more likely reflect the effect of stimulus durations and Vierordt's phenomenon.

6.1.2 Possible mechanisms behind response time differences

Since Tucker and Ellis's (1998) notable study proposing the affordance effect on reaction times, there has been considerable debate about whether the significant differences in reaction times between compatible and incompatible conditions are due to the affordance effect or other mechanisms. A plausible alternative explanation is the effect of the spatial compatibility of the most visually salient stimulus feature with the response (Cho & Proctor, 2010; Matheson & Thompson-Schill, 2019; Xiong et al. 2019). Salient stimulus features may activate the instructed motor response on the corresponding side, contributing to faster and more accurate responses in congruent conditions (Andersen et al., 2002; Kornblum et al., 1990; Phillips & Ward, 2002). While the results in this thesis could not clearly elucidate the effect of affordances on perceived time, they provide useful evidence in this debate about whether the observed results on reaction times (and possibly on perceived duration) can be attributed to the potentiation of specific affordance representations or perhaps to the activation of the instructed motor response on the congruent side. In the extrapersonal study, the pan stimulus was placed outside of reachable space, where the subjects could not touch with their arms fully extended. Thus, the reaching and grasping affordances were supposedly absent, as well as the potentiation of their corresponding motor representations in the brain. However, although the pan was unreachable, the instructed response of reaching towards it may still have been activated via compatibility effects. The lift-off times in the extrapersonal lift-off study show significantly faster responses in congruent trials than in incongruent. Although Tucker and Ellis (1998) proposed that the affordance effect is responsible for quickening responses to graspable stimuli in compatible conditions, it was found in this thesis that lift-off response times were still faster in the congruent conditions

when the stimuli were out of grasp. It is perhaps the spatial compatibility effect that is responsible for the differences in lift-off times.

In a previous study by Joy et al. (2021), it was also found that subjects had faster responses when the handle of a mug was congruent with the response hand, regardless of whether the mug was placed at a reachable or unreachable distance. However, while the interaction between congruency and distance was insignificant, the difference in response times between compatible and incompatible trials was smaller (although not completely absent) when the mug was placed in extrapersonal rather than peripersonal space. In this thesis, the effect size of congruency on lift-off time was smaller when the pan was in extrapersonal rather than peripersonal space. The diminished effects of congruency when stimuli are in extrapersonal space hints at the possibility that affordance effects may have some contribution to response times and, in this thesis, perceived duration. Therefore, if congruency could elicit significant effects on response times and perceived duration, these effects can be induced purely by spatial compatibility, or in combination with affordance effects (when grasping or reaching are available) (Buccino et al., 2009; Kostov & Janyan, 2015; Pappas, 2014; Pellicano & Binkofski, 2021).

Previous literature suggests that compatibility effects are sufficient to induce significant response time differences (Cho & Proctor, 2010; Matheson & Thompson-Schill, 2019; Pellicano & Binkofski, 2021; Xiong et al., 2019). In a study by Cho and Proctor (2010), subjects had to respond to an image of a pan based on its vertical orientation (upright or upside down) by making a keypress with either their left and right index fingers or the index and middle fingers of their right hand. The handle side also varied (left or right side) and could thus be congruent or incongruent with the spatial location of the hand or finger to respond. When the pan stimuli had intact

handles, they found that the differences in response times between congruent and incongruent trials were similar in size between using two hands to respond and using one hand to respond. When the pan stimuli had disembodied, ungraspable handles, the differences in response times were still similar between using a between-hands method and a within-hands method. Using these results, Cho and Proctor (2010) suggest that these differences are due to a spatial Simon effect (Simon, 1969), which activates responses on the same side as the visually salient stimulus feature (Kornblum et al., 1990), rather than the potentiation of grasping with the relevant hand. Furthermore, Xiong et al. (2019) found that subjects responded to a horizontal spoon stimulus significantly faster when asked to respond to the salient head than to the graspable handle, using the hand on the same side as the relevant part. Matheson and Thompson-Schill (2019) similarly suggest that the faster response times of their subjects to novel tools are due to compatibility between the spatial location of the most attention-drawing visual features on tools and the hand to respond, even if the most salient feature did not offer the affordance. The spatial compatibility of the protruding pan handle in the current studies may exert a greater effect than affordances on responses.

6.1.3 Possible compatibility effects on perceived duration

Spatial compatibility may also influence perceived durations. However, this thesis could not clearly ascertain this effect, as the differences in perceived duration could be merely due to the effect of stimulus duration on reproduced time. Although the pan could not be touched or grasped in the extrapersonal studies, the reproduced durations in congruent trials were still significantly longer. The stimulus durations for congruent trials were also significantly shorter, which may serve as the reason for

the differences in reproduced time. However, spatial compatibility could still have exerted an effect on perceived time in these studies, possibly due to motor activation, similar to the activation which Tucker and Ellis (1998) claimed to occur during affordance perception. In the context of the SRC paradigm, congruency occurs when the spatial location of the most salient, attention-drawing visual feature (in this case, pan handle) (Cho & Proctor, 2011) and spatial location of the response correspond. Kornblum et al. (1990) propose in the dimensional overlap model that the stimulus feature of interest prompts automatic motor activation of the instructed response (e.g., button press, reaching, depending on task instructions) in the corresponding spatial location. For example, in response to a pan with handle on the left, the response for a button press using left index finger is activated when using a between-hands method (using left and right hand index fingers) and the right index finger when using a within-hands method (using right hand index and middle fingers). This motor activation of the response on the corresponding side may impact perceived duration during motor action, leading to different results between congruent and incongruent trials. According to this model (Kornblum et al., 1990), in congruent trials, automatic activation of the correct response is present, facilitating motor responses. However, in incongruent trials, activation of the correct response is absent, as the incorrect response is activated (corresponding to the same side as the stimulus feature). As motor action is known to affect perceived time (Ayhan & Ozbagci, 2020; Hagura et al., 2012; Morrone et al., 2005), the presence or absence of initial motor activation of the hand used to respond may contribute to the differences in perceived time between these conditions. Additionally, in incongruent trials, the activated response with the incorrect hand must be inhibited (Andersen et al., 2002), which may not only slow down responses but also distort perceived durations. This

motor inhibition may require attentional resources and thus detract attention from temporal processing, leading to shorter perceived durations in incongruent trials (Brown, 1997; Fraisse, 1984; Kahneman, 1973). The motor response task may also be more difficult for subjects in incongruent trials; with greater task difficulty, more attention must be given to non-temporal processing (Fraisse, 1984; Tse et al., 2004). Perhaps, attention is differentially distributed for responding accurately as well as keeping track of passing time in congruent versus incongruent trials, contributing to the differences in perceived duration. The motor activation of spatially compatible responses and attentional modulation during task completion may involve activity along the dorsal pathway (Boussaoud, 2001; Dassonville et al., 2001; Koski et al., 2005; Praamstra et al., 1999), which was proposed to be involved in affordance potentiation (Tucker & Ellis, 1998). This concurrent activity along the pathway may interfere with the temporal processing that utilizes the same brain areas.

6.2 Limitations and future research

From the feedback about these studies, subjects found it difficult to keep track of the passing time while having to determine the hand to respond. Subjects may have given arbitrary responses when they were focused on responding with the correct hand and neglected thinking about the interval duration.

The hand tracking camera also experienced technical issues in some trials, causing the virtual hands to briefly disappear and reappear when subjects were reaching, more often for the left hand and when using the normal hand. This glitch distracted subjects during their motor responses and may have affected their perceived time. Additionally, the virtual hand disappearance also affected the recorded action execution interval, which did not end until the hand reappeared and

touched either the pan or invisible sensor. In the extrapersonal experiment, the invisible sensor appeared to be more sensitive to contact with the capsule hands than normal hands and with slower than faster reaching speeds. Consequently, the hand type effects, action execution times, and perceived durations found in these studies cannot provide highly credible evidence for affordance effect claims.

In future studies, rather than using the method of reproduction, another method could be used to report perceived time, such as comparing the pan's stimulus duration from the trial to another pan with a standard duration. Rather than conducting a joint experiment in which subjects completed both the lift-off and reaching studies, these studies could be conducted separately and completed by different subjects. This will allow particularly for the analysis of congruency effects on perceived action planning time in the lift-off study, without any confounding effects of action anticipation or inhibition. Lastly, better VR tools should be developed for scientific research in VR, and once available, utilized in future research to improve the validity of results obtained from VR.

Further research is still necessary to determine the effects of affordances on perceived time. Once these effects are determined, the exact details of the mechanism by which these effects are mediated can be investigated.

6.3 Concluding remarks

While this thesis could not elucidate the relationship between affordance perception and time perception, the results suggest that the differences in response times to graspable stimuli in SRC setups might be due to spatial compatibility, rather than affordance potentiation. Additionally, although more technical challenges may be

incurred by utilizing VR, it is a step forward in achieving more immersive environments with greater ecological validity.

APPENDIX

ETHICS COMMITTEE APPROVAL

Evrak Tarih ve Sayısı: 26.03.2022-59471

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

Toplantı Sayısı	:	29
Toplantı Tarihi	:	24.03.2022
Toplantı Saati	:	10:00
Toplantı Yeri	:	Zoom Sanal Toplantı
Bulunanlar	:	Prof. Dr. Ebru Kaya, Dr. Öğr. Üyesi Yasemin Sohtorik İlkmen
Bulunmayanlar	:	

Sunny Jin
Psikoloji

Sayın Araştırmacı,
"The effect of affordances on the perceived durations of visual stimuli during action" başlıklı projeniz ile ilgili olarak yaptığınız SBB-EAK 2022/22 sayılı başvuru komisyonumuz tarafından 24 Mart 2022 tarihli toplantıda incelenmiş ve uygun bulunmuştur.

Bu karar tüm üyelerin toplantıya çevrimiçi olarak katılımı ve oybirliği ile alınmıştır. COVID-19 önlemleri kapsamında kurul üyelerinden ıslak imza alınamadığı için bu onay mektubu üye ve raportör olarak Yasemin Sohtorik İlkmen tarafından bütün üyeler adına e-imzalanmıştır.

Saygılarımızla, bilgilerinizi rica ederiz.

Dr. Öğr. Üyesi Yasemin
SOHTORİK İLKMEN
ÜYE

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

SOBETİK 29 24.03.2022

Bu belge, güvenli elektronik imza ile imzalanmıştır.

REFERENCES

Alexander, G. E., & Crutcher, M. D. (1990a). Neural representations of the target (goal) of visually guided arm movements in three motor areas of the monkey. *Journal of Neurophysiology*, *64*(1), 164–178. https://doi.org/10.1152/jn.1990.64.1.164

Alexander, G. E., & Crutcher, M. D. (1990b). Preparation for movement: Neural representations of intended direction in three motor areas of the monkey. *Journal of Neurophysiology*, *64*(1), 133–150. https://doi.org/10.1152/jn.1990.64.1.133

Andersen, R. A. (1987). Inferior parietal lobule function in spatial perception and visuomotor integration. In F. Plum, V. B. Mountcastle, & S. R. Geiger (Eds.), *The handbook of sensory physiology: Section I. The nervous system* (pp. 483-518). American Physiological Society.

Andersen, R. A., Andersen, K. N., Hwang, E. J., & Hauschild, M. (2014). Optic ataxia: From Balint's syndrome to the parietal reach region. *Neuron*, *81*(5), 967–983. https://doi.org/10.1016/j.neuron.2014.02.025

Andersen, R.A., Snyder, L.H., Batista, A.P., Buneo, C.A. and Cohen, Y.E. (1998). Posterior parietal areas specialized for eye movements (LIP) and reach (PRR) using a common coordinate frame. In G.R. Bock & J.A. Goode (Eds.), *Sensory guidance of movement (Novartis Foundation Symposium 218)* (pp. 109-128). Wiley. https://doi.org/10.1002/9780470515563.ch7

Anderson, S. J., Yamagishi, N., & Karavia, V. (2002). Attentional processes link perception and action. *Proceedings Biological Sciences*, *269*(1497), 1225–1232. https://doi.org/10.1098/rspb.2002.1998

Ayhan, I. (2010). *Vision-based mechanisms of time perception* [Doctoral thesis, University College London]. UCL Discovery. https://discovery.ucl.ac.uk/id/eprint/623426/

Ayhan, I., Bruno, A., Nishida, S. Y., & Johnston, A. (2011). Effect of the luminance signal on adaptation-based time compression. *Journal of Vision*, *11*(7), 1–17. https://doi.org/10.1167/11.7.22

Ayhan, I., & Ozbagci, D. (2020). Action-induced changes in the perceived temporal features of visual events. *Vision Research*, *175*, 1–13. https://doi.org/10.1016/j.visres.2020.05.008

Benardete, E. A., & Kaplan, E. (1999). The dynamics of primate M retinal ganglion cells. *Visual Neuroscience*, *16*(2), 355–368. https://doi.org/10.1017/s0952523899162151

Block, R. A., & Zakay, D. (1996). Models of psychological time revisited. In Helfrich, H. (Ed.), *Time and mind* (pp. 171-195). Hogrefe & Huber.

Block, R. A., & Zakay, D. (2008). Timing and remembering the past, the present, and the future. In S. Grondin (Ed.), *Psychology of time* (pp. 367–394). Emerald Group.

Boussaoud, D. (2001). Attention versus intention in the primate premotor cortex. *Neuroimage*, *14*(1), S40-S45. https://doi.org/10.1006/nimg.2001.0816

Brown, S.W. (1997). Attentional resources in timing: Interference effects in concurrent temporal and nontemporal working memory tasks. *Perception & Psychophysics*, *59*, 1118–1140. https://doi.org/10.3758/bf03205526

Bruno, A., & Johnston, A. (2010). Contrast gain shapes visual time. *Frontiers in Psychology*, *1*, 1–8. https://doi.org/10.3389/fpsyg.2010.00170

Buccino, G., Sato, M., Cattaneo, L., Rodà, F., & Riggio, L. (2009). Broken affordances, broken objects: A TMS study. *Neuropsychologia*, *47*(14), 3074–3078. https://doi.org/10.1016/j.neuropsychologia.2009.07.003

Bueti, D., Bahrami, B., & Walsh, V. (2008). Sensory and association cortex in time perception. *Journal of Cognitive Neuroscience*, *20*(6), 1054-1062. https://doi.org/10.1162/jocn.2008.20060

Burle, B., & Casini, L. (2001). Dissociation between activation and attention effects in time estimation: Implications for internal clock models. *Journal of Experimental Psychology: Human Perception and Performance*, *27*(1), 195–205. https://doi.org/10.1037/0096-1523.27.1.195

Callaway, E. M. (2005). Structure and function of parallel pathways in the primate early visual system. *Journal of Physiology*, *566*, 13–19. https://doi.org/10.1113/jphysiol.2005.088047

Cho, D. T., & Proctor, R. W. (2010). The object-based Simon effect: Grasping affordance or relative location of the graspable part?. *Journal of Experimental Psychology: Human Perception and Performance*, *36*(4), 853–861. https://doi.org/10.1037/a0019328

Cho, D. T., & Proctor, R. W. (2011). Correspondence effects for objects with opposing left and right protrusions. *Journal of Experimental Psychology: Human Perception and Performance*, *37*(3), 737–749. https://doi.org/10.1037/a0021934

Cisek P. (2006). Integrated neural processes for defining potential actions and deciding between them: A computational model. *Journal of Neuroscience*, *26*(38), 9761–9770. https://doi.org/10.1523/JNEUROSCI.5605-05.2006

Cisek, P. (2007). Cortical mechanisms of action selection: The affordance competition hypothesis. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *362*(1485), 1585-1599. https://doi.org/10.1098/rstb.2007.2054

Cisek, P., Crammond, D. J., & Kalaska, J. F. (2003). Neural activity in primary motor and dorsal premotor cortex in reaching tasks with the contralateral versus ipsilateral arm. *Journal of Neurophysiology*, *89*(2), 922–942. https://doi.org/10.1152/jn.00607.2002

Cisek, P., & Kalaska, J. F. (2005). Neural correlates of reaching decisions in dorsal premotor cortex: Specification of multiple direction choices and final selection of action. *Neuron*, *45*(5), 801–814. https://doi.org/10.1016/j.neuron.2005.01.027

Cisek, P., & Pastor-Bernier, A. (2014). On the challenges and mechanisms of embodied decisions. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *369*(1655), 1–14. https://doi.org/10.1098/rstb.2013.0479

Creem-Regehr, S. H., & Lee, J. N. (2005). Neural representations of graspable objects: Are tools special?. *Cognitive Brain Research*, *22*(3), 457–469. https://doi.org/10.1016/j.cogbrainres.2004.10.006

Dassonville, P., Lewis, S. M., Zhu, X. H., Ugurbil, K., Kim, S. G., & Ashe, J. (2001). The effect of stimulus–response compatibility on cortical motor activation. *Neuroimage*, *13*(1), 1-14. https://doi.org/10.1006/nimg.2000.0671

Doerrfeld, A., Sebanz, N., & Shiffrar, M. (2012). Expecting to lift a box together makes the load look lighter. *Psychological Research*, *76*(4), 467–475. https://doi.org/10.1007/s00426-011-0398-4

Ellis, R., & Tucker, M. (2000). Micro-affordance: The potentiation of components of action by seen objects. *British Journal of Psychology*, *91*(4), 451–471. https://doi.org/10.1348/000712600161934

Ferraina, S., & Bianchi, L. (1994). Posterior parietal cortex: Functional properties of neurons in area 5 during an instructed-delay reaching task within different parts of space. *Experimental Brain Research*, *99*(1), 175–178. https://doi.org/10.1007/BF00241423

Fraisse, P. (1984). Perception and estimation of time. *Annual Review of Psychology*, *35*, 1-37. https://doi.org/10.1146/annurev.ps.35.020184.000245

Garrido-Vásquez, P., & Schubö, A. (2014). Modulation of visual attention by object affordance. *Frontiers in Psychology*, *5*, 1–11. https://doi.org/10.3389/fpsyg.2014.00059

Georgopoulos A. P. (1991). Higher order motor control. *Annual Review of Neuroscience*, *14*, 361–377. https://doi.org/10.1146/annurev.ne.14.030191.002045

Georgopoulos, A. P., Schwartz, A. B., & Kettner, R. E. (1986). Neuronal population coding of movement direction. *Science*, *233*(4771), 1416–1419. https://doi.org/10.1126/science.3749885

Gibson, J. J. (1979). *The ecological approach to visual perception*. Houghton-Mifflin.

Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in Neurosciences*, *15*(1), 20–25. https://doi.org/10.1016/0166-2236(92)90344-8

Grèzes, J., Tucker, M., Armony, J., Ellis, R., & Passingham, R. E. (2003). Objects automatically potentiate action: An fMRI study of implicit processing. *The European Journal of Neuroscience*, *17*(12), 2735–2740. https://doi.org/10.1046/j.1460-9568.2003.02695.x

Grondin, S., & McAuley, J. D. (2009). Duration discrimination in crossmodal sequences. *Perception*, *38*(10), 1542–1559. https://doi.org/10.1068/p6359

Hagura, N., Kanai, R., Orgs, G., & Haggard, P. (2012). Ready steady slow: Action preparation slows the subjective passage of time. *Proceedings of the Royal Society B: Biological Sciences*, *279*(1746), 4399-4406. https://doi.org/10.1098/rspb.2012.1339

Hodinott-Hill, I., Thilo, K. V., Cowey, A., & Walsh, V. (2002). Auditory chronostasis: Hanging on the telephone. *Current Biology*, *12*(20), 1779–1781. https://doi.org/10.1016/s0960-9822(02)01219-8

Jakobson, L. S., Archibald, Y. M., Carey, D. P., & Goodale, M. A. (1991). A kinematic analysis of reaching and grasping movements in a patient recovering from optic ataxia. *Neuropsychologia*, *29*(8), 803–809. https://doi.org/10.1016/0028-3932(91)90073-h

Jeannerod, M., Decety, J., & Michel, F. (1994). Impairment of grasping movements following a bilateral posterior parietal lesion. *Neuropsychologia*, *32*(4), 369–380. https://doi.org/10.1016/0028-3932(94)90084-1

Johnston, A. (2010). Modulation of time perception by visual adaptation. In A. C. Nobre & J. T. Coull (Eds.), *Attention and time* (pp. 187-200). Oxford University Press.

Johnston, A., Arnold, D. H., & Nishida, S. (2006). Spatially localized distortions of event time. *Current Biology*, *16*(5), 472–479. https://doi.org/10.1016/j.cub.2006.01.032

Joy, T., Ugur, E., & Ayhan, I. (2021). Trick the body trick the mind: Avatar representation affects the perception of available action possibilities in virtual reality. *Virtual Reality*, *26*, 615–629. https://doi.org/10.1007/s10055-021-00511-8

Kahneman, D. (1973). *Attention and effort.* Prentice-Hall.

Kanai, R., Paffen, C. L., Hogendoorn, H., & Verstraten, F. A. (2006). Time dilation in dynamic visual display. *Journal of Vision*, *6*(12), 1421–1430. https://doi.org/10.1167/6.12.8

Kornblum, S., Hasbroucq, T., & Osman, A. (1990). Dimensional overlap: Cognitive basis for stimulus-response compatibility--A model and taxonomy. *Psychological Review*, *97*(2), 253–270. https://doi.org/10.1037/0033-295x.97.2.253

Koski, L., Molnar-Szakacs, I., & Iacoboni, M. (2005). Exploring the contributions of premotor and parietal cortex to spatial compatibility using image-guided TMS. *Neuroimage*, *24*(2), 296-305. https://doi.org/10.1016/j.neuroimage.2004.09.027

Kostov, K., & Janyan, A. (2015). Reversing the affordance effect: negative stimulus-response compatibility observed with images of graspable objects. *Cognitive Processing*, *16*, 287–291. https://doi.org/10.1007/s10339-015-0708-7

Leon, M. I., & Shadlen, M. N. (2003). Representation of time by neurons in the posterior parietal cortex of the macaque. *Neuron*, *38*(2), 317-327. https://doi.org/10.1016/s0896-6273(03)00185-5

Lhermitte, F. (1983). 'Utilization behaviour' and its relation to lesions of the frontal lobes. *Brain*, *106*, 237–255. https://doi.org/10.1093/brain/106.2.237

Linkenauger, S. A., Leyrer, M., Bülthoff, H. H., & Mohler, B. J. (2013). Welcome to wonderland: The influence of the size and shape of a virtual hand on the perceived size and shape of virtual objects. *PloS ONE*, *8*(7), e68594. https://doi.org/10.1371/journal.pone.0068594

Masson, M. E., Bub, D. N., & Breuer, A. T. (2011). Priming of reach and grasp actions by handled objects. *Journal of Experimental Psychology: Human Perception and Performance*, *37*(5), 1470–1484. https://doi.org/10.1037/a0023509

Matheson, H. E., & Thompson-Schill, S. L. (2019). Investigating grounded conceptualization: Stimulus-response compatibility for tool handles is due to spatial attention. *Journal of Experimental Psychology: Human Perception and Performance, 45*(4), 441–457. https://doi.org/10.1037/xhp0000616

Matthews, W. J. (2011). How do changes in speed affect the perception of duration? *Journal of Experimental Psychology: Human Perception and Performance*, *37*(5), 1617–1627. https://doi.org/10.1037/a0022193

Morrone, M. C., Ross, J., & Burr, D. (2005). Saccadic eye movements cause compression of time as well as space. *Nature Neuroscience*, *8*(7), 950–954. https://doi.org/10.1038/nn1488

Padoa-Schioppa, C., & Assad, J. A. (2006). Neurons in the orbitofrontal cortex encode economic value. *Nature*, *441*(7090), 223–226. https://doi.org/10.1038/nature04676

Pappas, Z. (2014). Dissociating Simon and affordance compatibility effects: Silhouettes and photographs. *Cognition*, *133*(3), 716-728. https://doi.org/10.1016/j.cognition.2014.08.018

Pellicano, A., & Binkofski, F. (2021). The prominent role of perceptual salience in object discrimination: Overt discrimination of graspable side does not activate grasping affordances. *Psychological Research*, *85*(3), 1234-1247. https://doi.org/10.1007/s00426-020-01296-2

Perenin, M. T., & Vighetto, A. (1988). Optic ataxia: A specific disruption in visuomotor mechanisms. I. Different aspects of the deficit in reaching for objects. *Brain*, *111*, 643–674. https://doi.org/10.1093/brain/111.3.643

Perry, V. H., Oehler, R., & Cowey, A. (1984). Retinal ganglion cells that project to the dorsal lateral geniculate nucleus in the macaque monkey. *Neuroscience*, *12*(4), 1101–1123. https://doi.org/10.1016/0306-4522(84)90006-x

Phillips, J. C., & Ward, R. (2002). S-R correspondence effects of irrelevant visual affordance: Time course and specificity of response activation. *Visual Cognition*, *9*(4-5), 540–558. https://doi.org/10.1080/13506280143000575

Praamstra, P., Kleine, B. U., & Schnitzler, A. (1999). Magnetic stimulation of the dorsal premotor cortex modulates the Simon effect. *NeuroReport*, *10*(17), 3671-3674. https://doi.org/10.1097/00001756-199911260-00038

Riggio, L., Iani, C., Gherri, E., Benatti, F., Rubichi, S., & Nicoletti, R. (2008). The role of attention in the occurrence of the affordance effect. *Acta Psychologica*, *127*(2), 449-458. https://doi.org/10.1016/j.actpsy.2007.08.008

Samejima, K., Ueda, Y., Doya, K., & Kimura, M. (2005). Representation of action-specific reward values in the striatum. *Science*, *310*(5752), 1337–1340. https://doi.org/10.1126/science.1115270

Sedgwick, H. (1986). Space perception. In K. R. Boff, L. Kaufman, & J. P. Thomas (Eds.), *Handbook of perception and human performance* (Vol. 1, pp. 1–57). Wiley.

Simon J. R. (1969). Reactions toward the source of stimulation. *Journal of Experimental Psychology*, *81*(1), 174–176. https://doi.org/10.1037/h0027448

Stromeyer, C. F., 3rd, & Martini, P. (2003). Human temporal impulse response speeds up with increased stimulus contrast. *Vision Research*, *43*(3), 285–298. https://doi.org/10.1016/s0042-6989(02)00412-1

Thomas, E. A. C., & Cantor, N. E. (1978). Interdependence between the processing of temporal and non-temporal information. In J. Requin (Ed.), *Attention and performance VII* (pp. 43-62). Erlbaum.

Tipper, S. P., Paul, M. A., & Hayes, A. E. (2006). Vision-for-action: The effects of object property discrimination and action state on affordance compatibility effects. *Psychonomic Bulletin & Review*, *13*(3), 493–498. https://doi.org/10.3758/bf03193875

Treisman, M. (1963). Temporal discrimination and the indifference interval: Implications for a model of the "internal clock". *Psychological Monographs: General and Applied*, *77*(13), 1-31. https://doi.org/10.1037/h0093864

Tse, P. U., Intriligator, J., Rivest, J., & Cavanagh, P. (2004). Attention and the subjective expansion of time. *Perception & Psychophysics*, *66*(7), 1171–1189. https://doi.org/10.3758/bf03196844

Tucker, M., & Ellis, R. (1998). On the relations between seen objects and components of potential actions. *Journal of Experimental Psychology: Human Perception & Performance*, *24*(3), 830–846. https://doi.org/10.1037/0096-1523.24.3.830

Ungerleider, L. G., & Mishkin, M. (1982). Two cortical visual systems. In D. J. Ingle, M. A. Goodale, & R. J. W. Mansfield (Eds.), *Analysis of visual behavior* (pp. 549-586). MIT Press.

Vainio, L., Ellis, R., & Tucker, M. (2007). The role of visual attention in action priming. *Quarterly Journal of Experimental Psychology*, *60*(2), 241–261. https://doi.org/10.1080/17470210600625149

Vierordt, K. (1868). *Der zeitsinn nach versuchen.* Laupp.

Walker, J. T., & Scott, K. J. (1981). Auditory–visual conflicts in the perceived duration of lights, tones, and gaps. *Journal of Experimental Psychology: Human Perception and Performance*, *7*(6), 1327–1339. https://doi.org/10.1037/0096-1523.7.6.1327

Wearden J. H. (2008). Slowing down an internal clock: Implications for accounts of performance on four timing tasks. *Quarterly Journal of Experimental Psychology*, *61*(2), 263–274. https://doi.org/10.1080/17470210601154610

Wearden, J. H., Edwards, H., Fakhri, M., & Percival, A. (1998). Why "sounds are judged longer than lights": Application of a model of the internal clock in humans. *The Quarterly Journal of Experimental Psychology B: Comparative and Physiological Psychology*, *51*(2), 97–120.

Witt, J. K., & Riley, M. A. (2014). Discovering your inner Gibson: Reconciling action specific and ecological approaches to perception-action. *Psychonomic Bulletin & Review*, *21*(6), 1353–1370. https://doi.org/10.3758/s13423-014-0623-4

World Medical Association. (2013). World Medical Association Declaration of Helsinki: Ethical principles for medical research involving human subjects. *JAMA*, *310*(20), 2191–2194. https://doi.org/10.1001/jama.2013.281053

Xiong, A., Proctor, R. W., & Zelaznik, H. N. (2019). Visual salience, not the graspable part of a pictured eating utensil, grabs attention. *Attention, Perception, & Psychophysics*, *81*(5), 1454–1463. https://doi.org/10.3758/s13414-019-01679-7