How Key Press Movements are Represented in Memory: Evidence for Postural over Spatial Coding with Preview Pictures

Nadine Lassahn (s2990075)

Behavioural Management and Social Sciences (BMS), University of Twente

M12 BSc Thesis PSY (2024-2A)

Willem Verwey, 1st supervisor

Rob van der Lubbe, 2nd supervisor

Words: 4748

Date: 23.06.2025

Abstract

The common coding approach states that perceived events and planned actions use the same kind of internal codes. This study investigated whether seeing hand posture pictures or indications of a spatial location might serve as possible codes connected to the planned movement of pressing a key. Neutral preview pictures were added to prepare the required systems. The reaction times (RT) of 32 participants were measured to assess differences between Corresponding and Non-Corresponding pictures in a Posture (image of a hand pressing a specific key) and Spatial condition (indicating a key on the keyboard spatially). It was expected that Corresponding pictures would render shorter RTs in both conditions. The results supported this only for the Posture condition. Therefore, hand postures might represent key press movements in memory.

How Key Press Movements are Represented in Memory: Evidence for Postural over Spatial Coding with Preview Pictures

In research, the role of the motor cortex in carrying out movement is well established. The primary motor cortex (M1) has been found to play a major role in initiating body movement. Furthermore, research has been conducted focusing on which parts of the brain are involved in movement, but also on how specific movements are coded in the brain. Based on Graziano's model of ethological action maps, the motor cortex appears to contain functional zones, each responsible for ethologically relevant categories of behaviour, such as hand-to-mouth movements, defensive reactions, or reaching and grasping actions (Graziano, 2016). When certain zones were stimulated for the typical duration of movements, goal-oriented, species-specific actions were triggered, unlike isolated muscle twitches that occurred with short stimulation. For instance, stimulation in the face area elicited face movement and corresponding hand, shoulder, and mouth movement. It appears that no singular spot in the motor cortex elicits one specific movement; rather, actions are coded along an action map consisting of multiple zones that connect meaningful behaviour. Additionally, research indicates that when limb movement was restricted in mice, action maps changed implying that they are connected to the individual's experience and not just innate (Graziano, 2016).

Action maps provide a neural framework suggesting that motor behaviour is not coded in isolation but encoded into meaningful, coherent units. This study focuses on smaller-scale movements, such as key press movements and how they are coded in the brain. More specifically, this study investigated whether key press movements are represented in terms of spatial location, hand posture, or both. We turn to theoretical models such as the common coding approach and the binding and retrieval in action control framework (BRAC) to understand the cognitive mechanisms of such movement coding and binding.

Theoretical background

Common coding approach and BRAC

The common coding approach refers to the idea that actions are coded by their typical sensory feedback stimuli (Prinz, 1997; Stoet & Hommel, 2002). This means that perceived events and planned actions use the same type of internal codes. Hence, during motor planning, not only is the movement prepared, but one also anticipates connected sensory effects such as sound or visual images. Applied to key press movements, this could mean that preparing a key press with one of the fingers involves activating the visual image of the hand posture, the visual image of the key location, or both.

The BRAC framework by Frings et al. (2020) extends the common coding idea by proposing that actions are encoded as event-files. In such an event-file, stimuli, responses, and contextual cues of an action are bound together. Re-encountering one of those features then leads to the automatic retrieval of the whole event-file. For key press movements, this could mean that when encountering a similar feature, such as a visual image of a consistent hand movement or a visual image of a key location, the whole action event-file is triggered, and movement can be facilitated.

Spatial location

An individual's ability to remember and retain information about an object's identity and spatial location is often called visuo-spatial working memory (McAfoose & Baune, 2009). Further, Spiegel et al. (2014) investigated how movement planning influences the transfer of information into visuo-spatial working memory. Participants grasped a sphere and planned a placing movement to either a left or a right target in line with a directional arrow. Additionally, a cue appeared that either confirmed the planned movement or reversed the direction of the movement. The authors found improved memory performance and shorter reaction times in cues that were spatially compatible in relation to the planned movement.

They concluded that executing a planned movement recruits visuospatial memory resources. This suggests that spatial memory plays a role in preparing and executing movement. Applying this to key press movements raises the question of how spatial memory is connected to pressing the correct key on a keyboard. The results from Spiegel et al. (2014) align with the Simon effect, first introduced by Simon and Rudell (1967), which describes the phenomenon that people respond faster and more accurately when the location of a stimulus and the appropriate response correspond spatially with each other. For key press movements, this could mean that a visual picture of the spatial location of a specific key might facilitate the response time when pressing that key.

Hand posture

Previous research showed that the image of a hand posture can influence reaction time (RT) in grasping movements (Craighero et al., 2002). Building on this study, Vogt et al. (2003) used a visuomotor priming task to investigate whether the perspective of a person observing a hand posture, which was congruent or incongruent to their own hand, influenced motor response times. Firstly, participants received written instructions on a screen, telling them to perform a grasping movement toward a bar (clockwise or anticlockwise) based on a visual cue. Following this, a *fixation cue*, either a neutral hand without specific movement or a dot (acting as control) was presented. Next, a prime stimulus was shown, the image of a hand posture, congruent or incongruent with the prepared movement. Congruent pictures rendered shorter reaction times. This *congruency effect* reflects the phenomenon that perceptual representations of an observed action (such as a visual image) influence the reaction time of executing a planned movement. The results from Vogt et al.’s (2003) study are consistent with those of Craighero et al. (2002), who showed that the RTs of grasping movements were shorter when earlier presented with corresponding hand pictures.

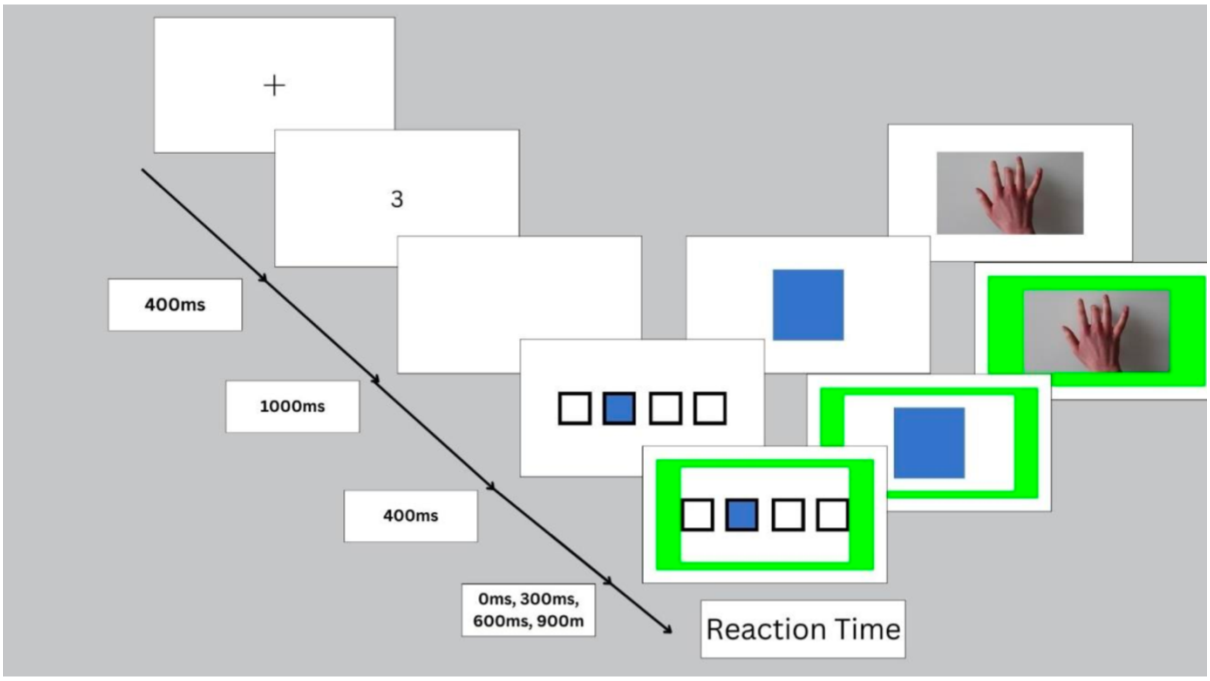
In addition to the congruency effect, Vogt et al. (2003) found that the perspective of the observed hand picture influenced RT, depending on which fixation cue (neutral hand or dot) was used. The hand images acting as prime stimuli were either presented from the participants' Own Perspective (how they would see their own hand) or from an observer's Other Perspective (how they would see another person's hand). Between the two perspectives, a similarly strong congruency effect occurred. However, when first shown the hand fixation cue, the congruency effect only occurred in the Own-Perspective condition. The authors explained this "Own-Perspective advantage" by the assumption that "body parts which appear in Own perspective can typically be predicted from the observers own motor planning" (Vogt et al., 2003, p. 949). They argue that during motor planning, the participants anticipated certain movements that selectively enhanced the visual processing of those body parts, hence, shorter RT with congruent pictures. However, when a body cannot be associated with a planned action (incongruent pictures), this body part is not enhanced and may even be suppressed. Conversely, when first presented with the dot fixation cue and not the neutral hand posture, effects were only observed for the Other-Perspective condition. For this observation, the authors argue that motor preparation is not necessary when encoding hand postures from an Other's Perspective. This is grounded in the assumption that we do not know what movement another person is about to execute. Rather than a planning-driven priming effect, the focus lies here on the stimulus itself that one is trained to encode very fast. As people are trained to interpret bodily movement from other people without any preparation, this might explain why an additional activation was not necessary.

These results indicate that specific hand movements might be visually coded as hand postures in memory. This is in line with the common coding approach that perceived features (such as hand pictures) share the same internal codes as the planning of an action. However, these codes seem to be perspective-sensitive. As Own Perspective movements needed an extra activation, this indicates that hand movement might be coded as visualising another person's movement and not one's own.

A recent study by Freiin Von Boeselager (2024) built upon those results and aimed to determine whether a congruency effect can also be observed when pressing keys on a keyboard. In this within-subjects design, participants had to first place their right hand on the keyboard with the letters H (index finger), J (middle finger), K (ring finger), and L (pinkie finger). Next, a fixation mark was shown that led attention to this specific point on the screen. Following this, participants saw a number corresponding to a specific key: 1 – H, 2 – J, 3 – K, 4 – L. They had to retain that information and then press the specific key later. Next, one of three conditions (Primes) was given. They either saw a hand posture from the Own-Perspective, a picture with four squares indicating the spatial location of a key, or a picture with a random symbol that served as the control. Pictures in the first two conditions either corresponded or did not correspond to the planned movement. After 0 ms, 300 ms, 600 ms, and 900 ms - referred to as the Interstimulus Interval - the go-signal appeared, and participants pressed the anticipated key. Figure 1 illustrates the study.

Figure 1

Timeline of one trial in Freiin Von Boeselager's (2024) study



Note. Sequence of a trial as it appeared to participants. From the top, on the fourth and sixth places, the three experimental conditions are shown from left to right: the spatial, the control and the hand posture conditions. The number in the second picture refers to which key needs to be pressed: 1 – H, 2 – J, 3 – K, 4 – L. The times indicate the amount of time in milliseconds the picture was shown to the participants. Reprinted from "*Does spatial location represent keypress movements better than hand postures?"* by P. Freiin Von Boeselager (2024) [Bachelor Thesis, University of Twente].

Results showed that incongruent pictures from the spatial condition rendered longer RTs, especially at ISIs of 300 ms and 600 ms. However, this effect was not apparent for ISIs of 0 ms and 900 ms. This might indicate that participants needed some time to encode the information in the first place before consistent pictures had an enhancing effect. On the other hand, after longer intervals, the Prime stimulus seems to be suppressed again. This is in line with the results of Vogt et al. (2003), which show that the effects of Prime occurred approximately between 300 ms and 700 ms, with a peak at 500 ms.

Surprisingly, there was no significant effect of incongruent hand posture pictures. However, it is important to highlight that Freiin Von Boeselager (2024) did not use preview pictures to activate motor preparation. As Vogt et al. (2003) showed, a preview picture increases the effect of a later prime due to activating the required hand systems. Another explanation is that some participants voiced having trouble recognising the exact hand movement in the posture condition. Hence, more research needs to be conducted to evaluate whether pictures of hand postures facilitate the reaction time of pressing a key.

Current Study

Building upon the studies conducted by Freiin Von Boeselager (2024) and Vogt et al. (2003), a reaction time test was executed to assess if hand posture and/or spatial location are involved in encoding key press movements in memory. Each participant took part in two conditions: the Spatial and the Posture conditions, referred to as the Prime conditions. As opposed to Freiin Von Boeselager (2024), but in line with Vogt et al. (2003), a neutral preview stimulus was given. Depending on the Prime, those were either neutral hand pictures (all fingers up – no key pressed) or four white squares, indicating no key pressed. Since the hand-posture pictures were presented from the participant's Own-Perspective, preview pictures were used to prepare the motor system. For each Prime condition, corresponding, non-corresponding, and neutral pictures were used to assess whether Correspondence influences the reaction time of a planned movement provided in the beginning. Corresponding pictures showed the exact hand posture, or four squares, one filled with blue, indicating the correct key on the keyboard. Non-corresponding pictures indicated another, wrong, key and neutral pictures indicated no key at all. As Vogt et al. (2003) found that the effect of Prime occurs between an ISI of 400 ms – 700 ms with a peak of 500 ms, the current study used 200 ms, 400 ms, 600 ms and 900 ms as time intervals between Prime and go-signal.

We expected that in the Posture and Spatial condition, non-corresponding pictures would interfere with the planned movement and, therefore, render longer RTs. Conversely, shorter RTs were expected for corresponding pictures. Additionally, we expected those effects to be especially present at ISIs of 400ms and 600ms.

Methods

Participants

Thirty-two participants took part in this research. The sample consisted of 19 female and 13 male participants. The age range was 19 to 28, with a mean of 22.25. Moreover, 14 people were German, seven Dutch, three Chinese and two Romanian. Other nationalities included Italian, Indian, Lithuanian, Canadian, Polish and Japanese.

Two sampling methods were used to gather participants. Firstly, the researcher used convenience sampling. Additionally, Psychology and Communication Science students at the University of Twente could voluntarily sign up and get 1.25 points as reward. Therefore, 23 participants received Sona credits.

Participants had to be between 18 and 35 years old, right-handed, have normal or corrected vision, have normal control over the right hand, are not heavy smokers and understand English instructions well. The local ethics committee at the Faculty of Behaviour, Management, and Social Science of the University of Twente approved this study.

Materials

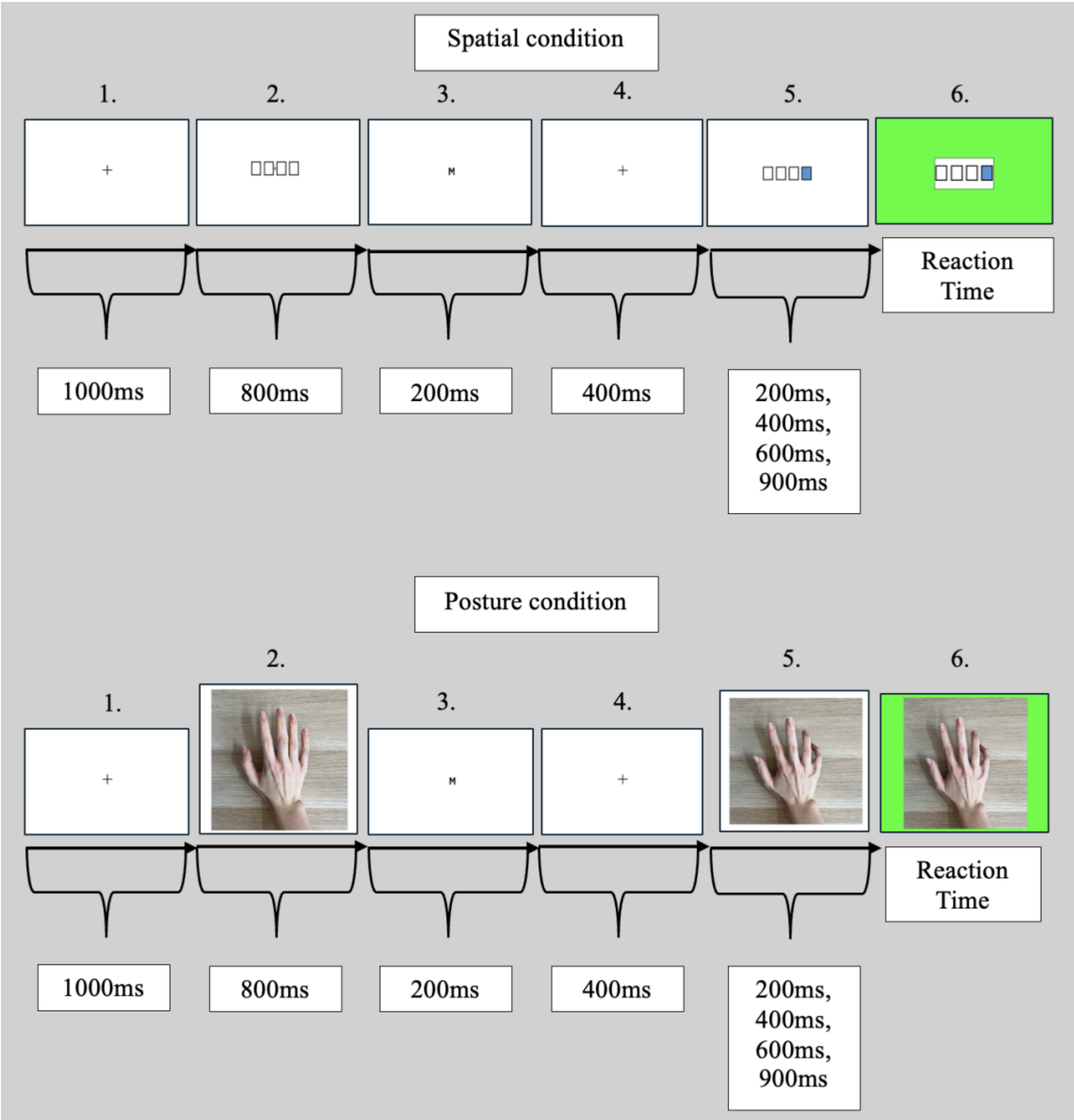
The research took place in the Flexperiment rooms in the BMS Lab of the University of Twente, which consisted of two chairs and a table. The technical devices the participants used were a monitor (AOC G2460PF), a computer (HP Z1 pc) and a keyboard. Qualtrics was used to gain consent and gather demographic data. Finally, E-Prime 3.0 was used to collect the data.

Task

A reaction time test measured how fast participants pressed one of four keys on a keyboard. In the beginning, participants were instructed to place their right hand on the keyboard with the letters H (index finger), J (middle finger), K (ring finger), and L (pinkie finger). The following describes one trial of the experiment. Firstly, they saw a fixation mark – X – for 1000 ms, which was used to lead attention to this specific point. Next, the preview stimulus (neutral hand/neutral location) was given for 800 ms to prepare the connected motor system. Following this, for 2000 ms, one of four letters was given: I, M, R, and P, which stood for **i**ndex, **m**iddle, **r**ing and **p**inkie finger. Participants were instructed to remember this letter without pressing the corresponding key yet. The following picture showed the fixation mark again for 400 ms. After this, the participants saw the Prime stimulus: the hand posture or spatial location. Those could be either corresponding, non-corresponding, or neutral to their planned movement. In the corresponding pictures, participants saw a hand posture or a spatial indication that aligned with the key they wanted to press. Non-corresponding pictures showed a different key. The neutral pictures showed a neutral hand movement (all fingers up – no key pressed) or no spatial indication. Each of these pictures was shown after 200 ms, 400 ms, 600 ms, or 900 ms. Finally, the go-signal occurred, indicated by a colour change in the surrounding area of the hand posture or spatial location picture – from white to green. At that point, participants pressed the keys they had been instructed to remember earlier, and reaction time was measured. Figure 2 illustrates the exact timeline of one trial per condition.

Figure 2

Timeline of a trial per condition



Note. The sequence of a trial as presented to participants. The first image shows the fixation mark, followed by a neutral stimulus. The third refers to which finger needs to be pressed. After a second fixation mark, either a corresponding, non-corresponding, or neutral picture appears. Both examples display a trial with pictures corresponding to the planned movement. The final image shows the go-signal, and participants pressed the key that was displayed in the third picture. The times indicate the amount of milliseconds the picture was shown to the participants.

The whole study included 352 trials that were divided across four blocks. Each block showed a mix of hand posture and spatial location trials. Corresponding, non-corresponding and neutral pictures were shown with probabilities of 63.6%, 27.3% and 9.1%, respectively. Trials where the participants pressed too early, too late or an incorrect key were not rerun. After each block, participants had a 1-minute break and were informed about their average RT and percentage of errors before the study automatically continued. Before starting the first block, 30 familiarisation trials were given to familiarise the participants with the experimental setup.

Procedure

Participants were asked to come to the lab, where they filled out the online informed consent form and demographic questionnaire, which included questions about age, gender, nationality, and handedness. Following this, the researcher gave them verbal instructions about the experiment, and the participants could ask questions. Next, the researcher showed them an instructions screen on the monitor. The participants were able to read through them at their own pace and started the experiment when they felt ready. The researcher left the room and took their mobile phone to avoid any distractions. The study took approximately 45 minutes to complete, and all participants took part in all conditions. After the experiment, the participants were asked how they felt and if any issues had occurred.

Analysis

In this within-subject design, two dependent variables were measured. First, the participant's reaction time (RT), which counted when the instructed key was pressed after the go-signal occurred and not later than 3000 ms. The mean RTs for each condition (Posture-Corresponding-200 ms, Posture-Corresponding-400 ms, etc.) for each participant were computed. The second dependent variable was error rate (ER), which was first computed as error proportions per condition per participant, after which an arcsine transformation was conducted to account for a non-normal distribution of error proportions per block (Winer et al., 1991). Furthermore, three independent variables were used for this design: Prime (Posture, Spatial), Correspondence (Corresponding, Non-Corresponding, Neutral) and the Interstimulus Interval (ISI: 200, 400, 600, 900), the time between the Prime stimulus and the go-signal.

The program RStudio, including the afex and emmeans packages, was used to analyse the data further. Firstly, the data was restructured from a wide to a long format. Next, demographic data was calculated. RTs and ERs were then analysed using a 2 x 3 x 4 repeated measures ANOVA design, two Prime, three Correspondence, and four ISI levels. To get more in-depth results, additional planned pairwise comparisons using t-tests were calculated between Prime, Correspondence and ISI, corrected with either the Holm or Bonferroni method. P-values lower than .05 were seen as statistically significant. R codes can be found in Appendix B.

Results

Reaction Time

The ANOVA showed a significant main effect of Correspondence (Corresponding, Non-Corresponding, Neutral) on RTs, $F(2,62) = 19.14$, $p < .001$, $\eta_p^2 = .38$. However, an additional interaction effect between Prime (Posture, Spatial) and Correspondence was found, $F(2,62) = 3.42$, $p = .04$, $\eta_p^2 = .1$, indicating that the effect of Correspondence might be influenced by the type of Prime.

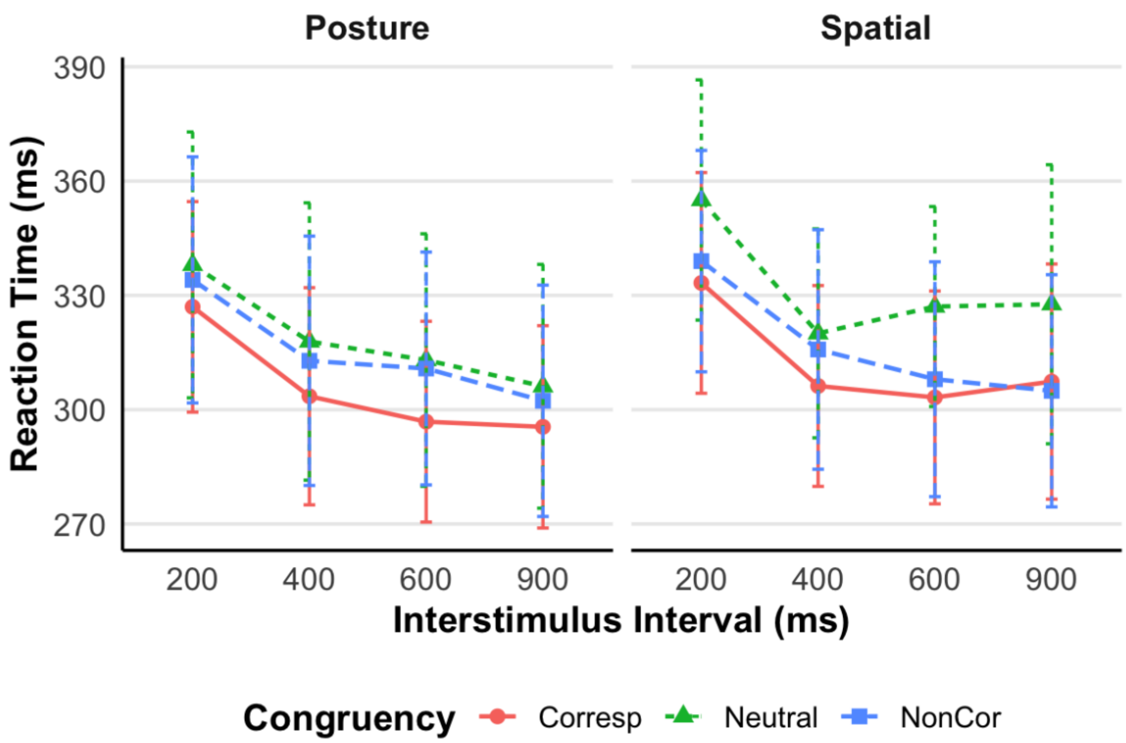
A planned pairwise comparison within the Posture condition revealed that RTs were significantly shorter for Corresponding pictures (M = 306 ms) than for both Non-Corresponding (M = 319 ms), $t(31) = -3.03$, $p = .01$, and Neutral pictures (M = 319 ms), $t(31) = -3.35$, $p = .006$. No significant difference between Neutral and Non-Corresponding pictures was observed, $t(31) = 1.37$, $p = .18$. This supports the hypothesis that, within the Posture condition, longer reaction times were rendered for non-corresponding pictures and shorter ones for corresponding pictures.

Within the Spatial condition, a similar planned pairwise comparison between Correspondence levels showed significantly shorter RTs for Corresponding ($M = 313$ ms) than for Neutral pictures ($M = 332$ ms), $t(31) = -5.02$, $p < .001$. RTs were also shorter for Non-Corresponding pictures ($M = 317$ ms) than for Neutral pictures, $t(31) = 3.65$, $p = .002$. Unexpectedly, a comparison between Corresponding and Non-Corresponding pictures showed no significant difference in RTs, $t(31) = -1.6$, $p = .012$. This means that participants had shorter RTs when seeing pictures indicating any kind of spatial location, Corresponding or Non-Corresponding, compared to Neutral pictures, confirming the previously found interaction effect between Prime and Correspondence. Additionally, a main effect of Prime was found to significantly influence RTs. Longer RTs were found in the Spatial condition (M = 321ms) than in the Posture condition ($M = 312$ ms), $F(1,31) = 10.48$, p=.0029, $\eta_p^2 = .25$.

Moreover, the Interstimulus Interval (ISI; 200 ms, 400 ms, 600 ms, 900 ms) had a significant main effect on RTs with $F(3,93) = 20.22$, $p < .001$, $\eta_p^2 = .39$. This means the duration between the Prime and the go-signal significantly affected RTs. Figure 2 shows that RTs seem to shorten in the Posture condition over time while only being significant in the Spatial condition between 200 ms and 400 ms. No interaction effect was found of Prime on ISI, $F(3,93) = 0.89$, $p = .45$, $\eta_p^2 = .03$, and Correspondence on ISI, $F(6,186) = 0.5$, $p = .81$, $\eta_p^2 = .02$.

Figure 3

Mean RTs divided by prime condition and distributed across ISIs



Note. Errors bars show a 95% confidence interval

An additional planned pairwise comparison between Corresponding and Non-Corresponding pictures with ISIs at 400 and 600 ms showed significant differences in the Posture 600 ms condition, with shorter RTs in the Corresponding (M = 297 ms) than in the Non-Corresponding condition (M = 311 ms). This confirms the effect of Correspondence on Prime within the Posture condition. All other comparisons showed no significant results. Table 1 displays the statistical outcomes.

Table 1

Comparison between Corresponding and Non-Corresponding pictures at ISIs 400 and 600 ms

Prime = Posture:					
Contrast	estimate	SE	df	t.ratio	p.value

Corresp_vs_NonCor_400ms	-9.31	5.73	31	-1.62	0.23
Corresp_vs_NonCor_600ms	-13.96	4.52	31	-3.09	0.013
Prime = Spatial:					
Contrast	estimate	SE	df	t.ratio	p.value
Corresp_vs_NonCor_400ms	-9.58	4.95	31	-1.93	0.19
Corresp_vs_NonCor_600ms	-4.77	5.06	31	-0.94	0.35

Errors

The ANOVA showed a significant effect of Correspondence on Error Rate (ER), $F(2,62) = 14.56$, $p < .001$, $\eta_p^2 = .32$. Further analysis showed that participants had the most errors in the Corresponding (4.0%), then the Non-Corresponding (3.7%) and lastly in the Neutral condition (2.2%). However, no significant differences were found in a planned comparison, using a t-test, of Corresponding and Non-Corresponding trials, $t(31) = 1.74$, $p = .28$. ISIs significantly influenced ERs, $F(3,93) = 19.41$, $p < .001$, $\eta_p^2 = .39$. An additional planned comparison between the ISIs showed that Error Rates increased the longer the interstimulus interval. The mean ER was 3.01% (SE = 0.1%, 95% CI [2.79%, 3.22%]) for 200 ms, 3.84% (SE = 0.18%, 95% CI [3.48%, 4.19%]) for 400 ms, 4.12% (SE = 0.22%, 95% CI [3.67%, 4.57%]) for 600 ms, and 4.83% (SE = 0.28%, 95% CI [4.25%, 5.4%]) for 900 ms. Prime was not found to be significant and did not influence ERs. Lastly, Correspondence x ISI was significant $F(6,186) = 2.84$, $p = .01$, $\eta_p^2 = .08$, indicating that the duration of the interstimulus intervals is important to whether Correspondence influences Error Rates. We expected an effect of Correspondence at ISIs of 400 ms and 600 ms. Unexpectedly, the Correspondence pictures showed the highest ERs and more errors were observed the longer the ISI.

Discussion

It was predicted that in the Posture and Spatial condition, pictures corresponding with the planned action would result in shorter reaction times (RTs), especially between interstimulus intervals (ISIs) of 400 and 600 ms.

The results support the prediction that pictures corresponding with the planned movement in the Posture condition resulted in shorter RTs. Therefore, the hypothesis regarding the posture condition can be accepted. This effect was especially observable at ISI 600ms. This outcome aligns with Vogt et al. (2003), who found that participants had a shorter reaction time when observing a picture of a hand that corresponded with their intended hand movement.

Additionally, the results of the current study partly differ from those reported by Freiin Von Boeselager (2024), who found no significant effects of Correspondence on Reaction Time on key press movements in the Posture condition. However, the present research added an additional neutral preview picture before the Prime onset, which might explain the difference in outcome. As also researched by Vogt et al. (2003), a preview picture is especially important when seeing a hand from an Own Perspective. They argue that such a preview might be necessary as one's own movement hardly comes unexpectedly. Therefore, when observing another hand, from one's own perspective, explicit information may be required to activate the systems involved in encoding the Prime. These results indicate that key press movements might involve internally represented hand postures.

Moreover, Vogt et al. (2003) found that the effect of Prime occurs mainly between 300ms and 700ms, with a peak at 500ms. They argue that before that, the brain does not have enough time to effectively encode the information given and act upon it. On the other hand, ISIs that are too long might result in the suppression of the given information. In the current study, a similar effect occurred. In the Posture condition, significant effects between Corresponding and Non-Corresponding pictures were observed, especially at ISI 600ms.

The Correspondence in the spatial location condition did not significantly influence RT. Therefore, this hypothesis needs to be rejected. This differs from previous research suggesting that the Correspondence of a spatial location prime shortens RT, especially at ISIs 300ms and 600ms (Freiin Von Boeselager, 2024). The divergence between the current and earlier studies suggests that preview pictures might influence the results, as this research added this part to the design. As opposed to the neutral posture pictures, which acted as activation for the required systems, the neutral spatial preview might have confused the participants because they only saw four blank squares. Additionally, some participants reported not having understood, or only very late in the experiment, that the spatial location pictures represented a key on the keyboard. This left them confused about the pictures presented to them. These comments might indicate that for the spatial location to be an important feature for key press movements, the direct knowledge that the spatial location is connected to a key is essential.

Another limitation that the participants reported was the noises outside the experimental rooms. Due to the nature of the rooms, some participants were bothered by the voices and the conversations of other people. Seven participants in particular reported to have felt interrupted. This might have had an influence on the whole experiment, as the nature of the task required concentration and a quiet environment.

In conclusion, this study supports the notion that key press movements are coded as hand posture movements in the brain. For this study design, a preview picture seemed to be necessary to activate the connected systems first. This might be because hand movements from one’s own perspective do not come unexpectedly, and the brain has already prepared them beforehand. In this study, participants saw another person’s hand from their own perspective; hence, the required system has not yet been activated. Unlike past research, this study could not find support for the influence of spatial location on key press movements. This could be due to the added neutral preview, which might have confused participants or a lack of awareness that the spatial pictures indicated a specific key. Finally, as spatial and hand posture codes are only two of many possible codes a person might use when pressing a key, future research might focus on whether different codes or a combination of hand posture and spatial codes are used. Moreover, further studies can focus on whether the effect of preview pictures extends to other types of movements, such as grasping movements.

References

Craighero, L., Bello, A., Fadiga, L., & Rizzolatti, G. (2002). Hand action preparation influences the responses to hand pictures. *Neuropsychologia*, *40*(5), 492–502. https://doi.org/10.1016/S0028-3932(01)00134-8

Freiin Von Boeselager, P. (2024). *Does spatial location represent keypress movements better than hand postures?* [Bachelor Thesis, University of Twente]

Frings, C., Hommel, B., Koch, I., Rothermund, K., Dignath, D., Giesen, C., Kiesel, A., Kunde, W., Mayr, S., Moeller, B., Möller, M., Pfister, R., & Philipp, A. (2020). Binding and Retrieval in Action Control (BRAC). In *Trends in Cognitive Sciences* (Vol. 24, Issue 5, pp. 375–387). Elsevier Ltd. https://doi.org/10.1016/j.tics.2020.02.004

Graziano, M. S. A. (2016). Ethological Action Maps: A Paradigm Shift for the Motor Cortex. In *Trends in Cognitive Sciences* (Vol. 20, Issue 2, pp. 121–132). Elsevier Ltd. https://doi.org/10.1016/j.tics.2015.10.008

McAfoose, J., & Baune, B. T. (2009). Exploring Visual–Spatial Working Memory: A Critical Review of Concepts and Models. *Neuropsychology Review*, *19*(1), 130–142. https://doi.org/10.1007/s11065-008-9063-0

Prinz, W. (1997). Perception and Action Planning. *European Journal of Cognitive Psychology*, *9*(2), 129–154. https://doi.org/10.1080/713752551

Simon, J. R., & Rudell, A. P. (1967). Auditory S-R compatibility: The effect of an irrelevant cue on information processing. *Journal of Applied Psychology*, *51*(3), 300–304. https://doi.org/10.1037/h0020586

Spiegel, M. A., Koester, D., & Schack, T. (2014). Movement planning and attentional control of visuospatial working memory: evidence from a grasp-to-place task. *Psychological Research*, *78*(4), 494–505. https://doi.org/10.1007/s00426-013-0499-3

Stoet, G., & Hommel, B. (2002). Feature integration between perception and action. In W. Prinz & B. Hommels (Eds.), *Common mechanisms in perception and action: Attention & Performance XIX* (pp. 538–552). Oxford University Press.

Vogt, S., Taylor, P., & Hopkins, B. (2003). Visuomotor priming by pictures of hand postures: Perspective matters. *Neuropsychologia*, *41*(8), 941–951. https://doi.org/10.1016/S0028-3932(02)00319-6

Winer, B. J., Donald, R. B., & Kenneth, M. M. (1991). *Statistical principles in experimental design* (3rd ed.). New York : McGraw-Hill.

Appendix A

AI Statement

During the preparation of this work I used Grammarly and Word in order to check the grammar and spelling. Additionally, I used ChatGPT to assist me in programming certain codes in R-Studio. After using those tools, I reviewed and edited the content as needed and take full responsibility for the content of the work

Appendix B

```
library(tidyverse)
library(janitor)
library(tidyr)
library(afex)
library(readxl)
library(emmeans)
library(ggplot2)
library(dplyr)
library(effectsize)

##Demographic Data
#Age
Key_Press_Demo %>%
  select("Age") %>%
  summary()

sd(Key_Press_Demo$Age, na.rm = TRUE)

#Nationality
table(Key_Press_Demo$Nationality)

unique(Key_Press_Demo$`Other nationality`)

#Gender
table(Key_Press_Demo$Gender)


### REACTIOM TIME DATA

# From wide to long format
headers <- Raw_Data[1:3, ]
data <- Raw_Data[-c(1:3), ]

headers_t <- as.data.frame(t(headers))

new_colnames <- paste(headers_t$V1, headers_t$V2, headers_t$V3, sep = "_")

colnames(data) <- c("Subject", "Stats", new_colnames[-c(1:2)])

data_long <- data %>%
  pivot_longer(cols = -c(Subject, Stats),
             names_to = "Condition",
             values_to = "RT") %>%
  separate(Condition, into = c("PictureType", "Congruency", "Duration"), sep = "_") %>%
  mutate(
    RT = as.numeric(str_replace(RT, ",", ".")),
    Subject = factor(Subject),
    Duration = factor(Duration),
    Congruency = factor(Congruency),
```

```
  PictureType = factor(PictureType)
 )

view(data_long)

#Mean RT
mean_RT_by_condition <- data_long %>%
  group_by(PictureType) %>%
  summarise(mean_RT = mean(RT, na.rm = TRUE))

print(mean_RT_by_condition)

#ANOVA RT
model <- aov_car(RT ~ PictureType * Congruency * Duration +
                   Error(Subject / (PictureType * Congruency * Duration)),
                 data = data_long)

summary(model)

#partial eta squared
eta_squared(model, partial = TRUE)


#Planned Comparison RT and Congruency
em <- emmeans(model, ~ Congruency | PictureType)
summary(em)

contrast(em, method = list(
  Corresp_vs_Neutral = c(1, -1, 0),
  Corresp_vs_NonCor  = c(1, 0, -1),
  Neutral_vs_NonCor  = c(0, 1, -1)
), adjust = "holm")

##Planned Comparison RT, Duration, Congruency
em_duration <- emmeans(model , ~ Duration | PictureType * Congruency)

pairs(em_duration, adjust = "holm")

summary(em_duration)

duration_results <- pairs(em_duration, adjust = "holm")
summary(duration_results)
View(as.data.frame(duration_results))

#Planned Comparison RT, Congruency, Duration
em_cor_noncor <- emmeans(model , ~ Congruency | PictureType * Duration)

summary(em_cor_noncor)
view(em_cor_noncor)
```

```
em_filtered <- em_cor_noncor %>%
  as.data.frame() %>%
  filter(Duration %in% c("X400", "X600"),
         Congruency %in% c("Corresp", "NonCor"))

Cor_noncor_duration_results <- pairs(em_cor_noncor, adjust = "holm")

summary(Cor_noncor_duration_results)
view(Cor_noncor_duration_results)


# 95% CI
em_df <- em_df %>%
  mutate(
    t_crit = qt(0.975, df),
    CI_lower = emmean - t_crit * SE,
    CI_upper = emmean + t_crit * SE
  )

#Viszalization RTs

em_df <- as.data.frame(em_duration)

em_df$Duration <- gsub("^X", "", em_df$Duration)

ggplot(em_df, aes(x = Duration, y = emmean,
                  color = Congruency,
                  linetype = Congruency,
                  shape = Congruency,
                  group = Congruency)) +
  geom_line(size = 0.8) +
  geom_point(size = 2.5) +
  geom_errorbar(aes(ymin = CI_lower, ymax = CI_upper),
                width = 0.1, linewidth = 0.6) +
  facet_wrap(~ PictureType) +
  labs(
    x = "Interstimulus Interval (ms)",
    y = "Reaction Time (ms)",
    color = "Congruency",
    linetype = "Congruency",
    shape = "Congruency"
  ) +
  theme_minimal(base_size = 14) +
  theme(
    axis.title = element_text(face = "bold"),
    axis.text = element_text(size = 12),
    legend.title = element_text(face = "bold"),
    legend.position = "bottom",
    strip.text = element_text(size = 13, face = "bold"),
    panel.grid.minor = element_blank(),
```

```
    panel.grid.major.x = element_blank(),
    axis.line = element_line(size = 0.6, color = "black")
  )
### ERROR DATA

headers_error <- Error_Proportions[1:3, ]
data_error <- Error_Proportions[-c(1:3), ]

headers_error_t <- as.data.frame(t(headers_error))

new_colnames_error <- paste(headers_error_t$V1, headers_error_t$V2, headers_error_t$V3,
sep = "_")

colnames(data_error) <- c("Subject", new_colnames_error[-1])

data_error_long <- data_error %>%
  pivot_longer(cols = -Subject,)
             names_to = "ErrorCondition",
             values_to = "ErrorRate") %>%
  separate(ErrorCondition, into = c("PictureType", "Congruency", "Duration"), sep = "_")
%>%
  mutate(
    ErrorRate = as.numeric(str_replace(ErrorRate, ",", ".")),
    Subject = factor(Subject),
    Duration = factor(Duration),
    Congruency = factor(Congruency),
    PictureType = factor(PictureType)
  )

view(data_error_long)

#Mean Error Rate
mean_ER_by_Congruency <- data_error_long %>%
  group_by(Congruency) %>%
  summarise(mean_ErrorRate = mean(ErrorRate, na.rm = TRUE))

print(mean_ER_by_Congruency)

##ANOVA Error Rate
model_Error <- aov_car(ErrorRate ~ PictureType * Congruency * Duration +
                 Error(Subject / (PictureType * Congruency * Duration)),
               data = data_error_long)

summary(model_Error)

# Error partial eta squared
eta_squared(model_Error, partial = TRUE)

## Planned Comparison Error Rate, Congruency and Duration
em_error_all <- emmeans(model_Error, ~ Duration | PictureType * Congruency)
```

```
summary(em_error_all)

# Pairwise contrasts (comparing all durations)
ER_contrast_all <- contrast(em_error_all, method = "pairwise", adjust = "bonferroni")
summary(ER_contrast_all)

##Planned Comparison Error Rate and Duration

#Pairwise contrast
ER_contrast_duration <- contrast(em_duration_error, method = "pairwise", adjust =
"bonferroni")
summary(ER_contrast_duration)

##Planned Comparison Error Rate, Congruency
em_error_congruency <- emmeans(model_Error, ~ Congruency)
summary(em_error_congruency)

#Pairwise Contrast
ER_contrast_congruency <- contrast(em_error_congruency, method = "pairwise", adjust =
"bonferroni")
summary(ER_contrast_congruency)
```