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The Role of Modal and Amodal Representations in Action Planning

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Zusammenfassung

Im Rahmen der *Theory of Event Coding* (TEC) haben Forscher von Belegen sowohl für als auch gegen Abstraktion im Sinne einer Generalisierung beim sogenannten „response-effect (R-E)“ - Lernen berichtet. Als Teil der Forschungseinheit FOR2718, befasst mit dem übergreifenden Thema der *modalen* und *amodalen Kognition*, möchte die vorliegende Arbeit empirisch feststellen, ob Abstraktion beim R-E - Lernen 1. im Sinne einer Generalisierung von Exemplaren auf die übergeordneten Kategorien (Experiment 1), 2. im Sinne einer abstrakten Repräsentation räumlicher Konzepte (Experiment 2), und 3. im Sinne einer Generalisierung von Bildern auf semantische Bedeutung (Experiment 3) nachgewiesen werden kann. Die Ergebnisse von Experiment 1 und 2 lassen nicht auf Generalisierung schließen. Der in Experiment 3 aufgetretene Effekt könnte durch *phonologische Umkodierung* aufgetreten sein und somit das Ergebnis verfälschen. Für Experiment 1 – 3 errechnete Dichtediagramme deuten auf eine *bimodale Verteilung* der Kontrollgruppen hin. Laut neueren Erkenntnissen (Sun et al., 2020) könnte dies auf eine *propositionale* Natur des Gelernten hindeuten, nicht aber auf *automatisch* erworbenes Wissen, so wie es bei Forschung im Rahmen von TEC üblicherweise angenommen wird. Zahlreiche dieser Studien berichten eher kleine Effektgrößen. Experiment 4 soll darüber Aufschluss geben, ob die durchschnittliche Effektgröße durch aufgabenrelevante Handlungseffekte während der Lernphase erhöht werden kann. Die Ergebnisse von Experiment 4 sprechen dafür, während das Dichtediagramm auch bei größeren Effekten auf eine bimodale Verteilung hinweist.

Abstract

In the context of the Theory of Event Coding (TEC), researchers found evidence for and against abstraction in the sense of generalization in response-effect (R-E) learning. Against the background of the research unit FOR2718, concerned with the overarching topic of *modal* and *amodal* cognition, the present work set out to test with a series of experiments whether abstraction can be found in R-E learning experiments 1. in the sense of generalization from exemplars to the corresponding categories (Experiment 1), 2. in the sense of an abstract representation of spatial concepts (Experiment 2), and 3. in the sense of generalization from a picture to the corresponding semantic meaning (Experiment 3). No signs of generalization were found in Experiments 1 and 2, whereas the effect obtained in Experiment 3 could also have occurred because of *phonological recoding* and thus be confounded. Kernel density plots calculated for Experiment 1 - 3 show a bimodal distribution in all respective control groups. Considering recent literature (Sun et al., 2020), this could point to a *propositional* nature of the learned knowledge rather than to automatically acquired knowledge as commonly assumed by research in context of TEC. Considering the latter, numerous studies on R-E learning report rather small effect sizes. Experiment 4 was designed to see, if the average effect size can be increased by turning the action effects task-relevant during the acquisition phase task. The results show that this is indeed the case, and the kernel density plot shows that the distribution remains bimodal even with larger effects.

Contents

1 Introduction

This PhD-thesis contributes to research on the nature of representations used by humans to plan and execute motor actions as part of the overarching framework of the DFG research unit “Modal and Amodal Cognition – Functions and Interactions” (FOR 2718). This research unit aims to shed light on the type of mental representations underlying humans’ functioning in different fields of cognitive psychology (e.g., action, perception, language, …), focusing on the putative dichotomy of modal versus amodal representations. Project A2 of this research unit particularly focuses on the nature of the representations involved in planning and executing motor actions. In this introductory section, I am first going to give a global overview on a selection of influential theories on action planning and action control before focusing on the part of this literature that is most relevant for my research question: The *Theory of Event Coding* (TEC; Hommel et al., 2001). Then, I will introduce the topic of *modal* and *amodal* cognition, which serves as an overarching principle in various fields of cognitive psychology. Subsequently, I will establish a connection between the theoretical foundation of the literature on human action and the specific aspect that I aim to emphasize in this thesis: The role of *modal* and *amodal* representations in human action planning. In this context, *Ideomotor Theory* (IT; Harleß, 1861; James, 1890) and multiple experimental methodologies utilized in Response-Effect (R-E; alternatively known as Action-Effect or A-E) learning will play a major role, along with some of the available empirical evidence in this domain. A closer look at contradictory evidence regarding the presence of abstract, *amodal* representations in action planning then leads to the main research questions of this thesis.

1.1 Human action: From Woodworth to the Planning and Control Model of Motorvisual Priming

Numerous theories on human action suggest that a distinction must be made between the early and late phases of a movement (e.g., Glover, 2002; Jeannerod, 1986; Milner & Goodale, 2006; Thomaschke et al., 2012; Woodworth, 1899). According to these theories, human action must be divided into two separate phases: An early *action planning* phase and a late *action control* phase. Some of them even postulate a different nature of the representations involved in *action planning* and *action control*. In this section, I will briefly describe some of the theories that, throughout the years, have provided the stable foundation for research on human action.

Robert S. Woodworth was one of the first scientists in psychological research to design a line of experiments explicitly with the aim to shed light on the nature of the processes responsible for the control of goal-directed movements. In 1899, he published his monograph on the accuracy of voluntary movement, which was since then cited by numerous researchers of different fields (see Elliott et al., 2001, for a review). Most relevant for the purpose of deducing my own research aims and the subject of this thesis from a broader theoretical background on human action is his two-component model (Woodworth, 1899). He derived this model from the results of experiments in which he had measured the spatial accuracy and consistency of aiming movement endpoints after participants had made horizontal back-and-forth movements with a pencil on paper according to instructions. He found out that during the *early* part of most aiming movements, the movement speed was quite high and the movement itself seemed stereotyped (Elliott et al., 2001). As the pencil approached the target, that is, in the *late* parts of the movement, the speed decelerated, and the movement seemed more discontinuous. Hence, Woodworth hypothesized that such aiming movements consist of an *initial, ballistic phase*, in which the motor action is initiated, and a *later corrective phase*, in which the movement is monitored and adjusted. According to his theory, the initial impulse is subject to *central control* and its aim is to move the limb in question (here the hand) close to the target. As soon as the target region is reached, the hand is subjected to so-called *current* or *feedback-based control* (Elliott et al., 2001; Woodworth, 1899). In this second phase, visual information on the relative positions of both hand and target is processed with the aim to adjust the movement, if necessary, so that the pencil reaches the target and the movement is stopped there. In conclusion, Woodworth postulated two stages in motor actions: *Movement initiation* and *movement control*. The forthcoming sections will demonstrate that various scientists have based their research on this two-stage model and adapted it, resulting in the development of other influential theories and models.

In 1986, the French neuroscientist Marc Jeannerod conducted a study that examined how people's finger grip formation differed when performing a natural grasping movement. The study compared two groups: one consisting of healthy individuals and the other comprising individuals with brain lesions. The participants performed the task under two conditions, one with visual feedback and one without (Jeannerod, 1986). The results strongly suggest that the cerebral cortex plays an important role in grip formation control during grasping visual objects: The integration of both visual and somatosensory information from the hand performing the task seems to be vital for the grip formation being adapted in a way that the object can be successfully grasped. According to these results, it can be interpreted that concrete (or *modal*) visual information on the environment is involved during the control or adjustment of a movement during its execution. The discovery backs the early two-stage model proposed by Woodworth (1899).

Jeannerod's approach was then taken further by Milner and Goodale, who developed the Perception-Action Model (PAM) in 1995, based on data from case studies of patients with lesions in either the dorsal or the ventral cortical pathway and their neuropsychological symptoms (visual form agnosia: Milner et al., 1991; and optic ataxia: Jeannerod, 1986; Perenin & Vighetto, 1988). With the PAM, the authors attempted to establish a new perspective on the functional organization of the cortical pathways involved in visual processing by postulating a difference between two cortical pathways. Building on previous literature on the functional separation of two visual streams (i.e., Ungerleider & Mishkin, 1982), Milner and Goodale suggested that visual information is processed by two functionally different cortical pathways: The *dorsal stream* and the *ventral stream*. Each anatomical structure is related to a subsystem that processes visual information in a different way, the "vision-for-action" system and the "vision-for-perception" system. While the first system is linked to the *dorsal stream* and responsible for *action initiation and execution*, the second system is linked to the *ventral stream* and to systems associated with higher cognitive functions and processes involved in *action planning* (e.g., memory, object recognition). More concretely, the "vision-for-perception" system creates an internal, perceptual representation of the visual environment that is necessary for the *planning* of a concrete action (Milner & Goodale, 2006), while the "vision-for action" system of the PAM is mainly concerned with how visual information is processed to control the *execution* of a previously planned movement (Milner & Goodale, 2006). In conclusion, the PAM distinguishes clearly between *action planning* and *action selection* on one side and *action initiation* and *action execution* on the other side, not only conceptually but also anatomically. The authors emphasize, that the specification of the initial parameters of a movement is using "bottom-up" visual information provided by the dorsal stream and therefore must be part of the "vision-for-action" system and clearly separated from the action planning process (Goodale & Milner, 2004), which distinguishes the PAM clearly from a competing model described in the next paragraph.

The *Planning and Control Model* proposed by Glover (2002) assumes the involvement of different representations in *action planning* and *action control*. Glover and Dixon (2001a) reported that the trajectory of a movement is affected by the presentation of an optical illusion in its early stages, but that this effect decreases when moving closer to the target. The authors hypothesized that this influence of illusion effects on motor actions is due to a difference between the visual representations used in planning and control of an action (Glover & Dixon, 2001a). They postulate the existence of movement plans for reaching and grasping movements before the movement is initiated. Reaching movements should therefore be affected by contrasting the actual visual information of the target and its surroundings with the stored information of past reaching experiences, given a certain similarity of the environment and the circumstances. According to the authors, once a movement plan containing the movement dynamics and trajectory has been established, a duplicate is dispatched to the control component (Glover & Dixon, 2001a). This is a crucial difference to the PAM (Milner & Goodale, 2006), as the Planning and Control Model takes planning as “responsible for such things as selecting an appropriate target […]. Beyond these selection processes, however, planning also determines the initial kinematic parametrization of the movements, including their timing and velocity.” (Glover, 2004b, p. 4). The authors found empirical support for their model in a study on motor adaptation to optical illusions (Glover & Dixon, 2001b). They examined in their study two different aspects of the vision-action-relation: First, they evaluated how the course of a reaching movement was affected by an orientation illusion. Second, the adaptation of the motor system to an optical illusion over multiple trials was tested. The results of 16 participants going through a reaching task and a perception task support the Planning and Control Model: As the model assumes, that the *planning* of an action is influenced by the context around the target, whereas the *control* of motion is unaltered by external conditions, the decrease of an illusion effect over time is in line with the models' predictions (Glover & Dixon, 2001b). To point out crucial differences to the competing PAM (Milner & Goodale, 2006) discussed in the anterior paragraph, it has to be mentioned that *action planning* as described by the PCM cannot be seen as identical to *perception* of the PAM: Glover (2004a, p. 58) states that “…the planning-control model is not simply a reformulation of the two-stream hypothesis" as the *inferior parietal lobe* (IPL) is regarded as the central area of the posterior cortex regions associated with *planning*. Therefore, the *planning output* can demonstrate features of both the ventral and dorsal stream due to the visual input received by the IPL from both streams. Nevertheless, according to Glover (2004a), it should be noted that the influence of ventral stream processes on planning does not equate planning with perception (as in the PAM). Note, however, that Franz et al. (2005) addressed some methodological objections to Glover's work regarding the so-called "dynamic illusion effect"[1]. The results of two experiments with an improved methodology suggest that "[…] the dynamic illusion effects, as reported by Glover and Dixon […] are artifactual" (Franz et al., 2005, p. 1374). As the dynamic illusion effect under no-vision conditions is, according to Glover and Dixon (2001a; Glover, 2002, 2004b), the central evidence on which their model was built, Franz et al. (2005) argue that, given their results, the Planning and Control Model should be rejected. Other studies with distinct methodological approaches further corroborate back this conclusion (Handlovsky et al., 2004; Meegan et al., 2004).

A more recent model, originated from contradictory evidence in the field of motorvisual dual tasks, is the *Planning and Control Model of Motorvisual Priming* (PCM; Thomaschke et al., 2012). Typically, in this type of dual tasks, in a first task (T1) a stimulus (S1) elicits one particular response (R1), depending on a predefined stimulus-response (S-R) mapping. While T1 is carried out, a secondary

[1] Glover and Dixon (2001a) call the discovery that contextual visual illusions, such as the Ebbinghaus-Titchener illusion, have a significantly greater impact on initial stages of a motion compared to later stages, the *dynamic illusion effect* (Franz et al., 2004).

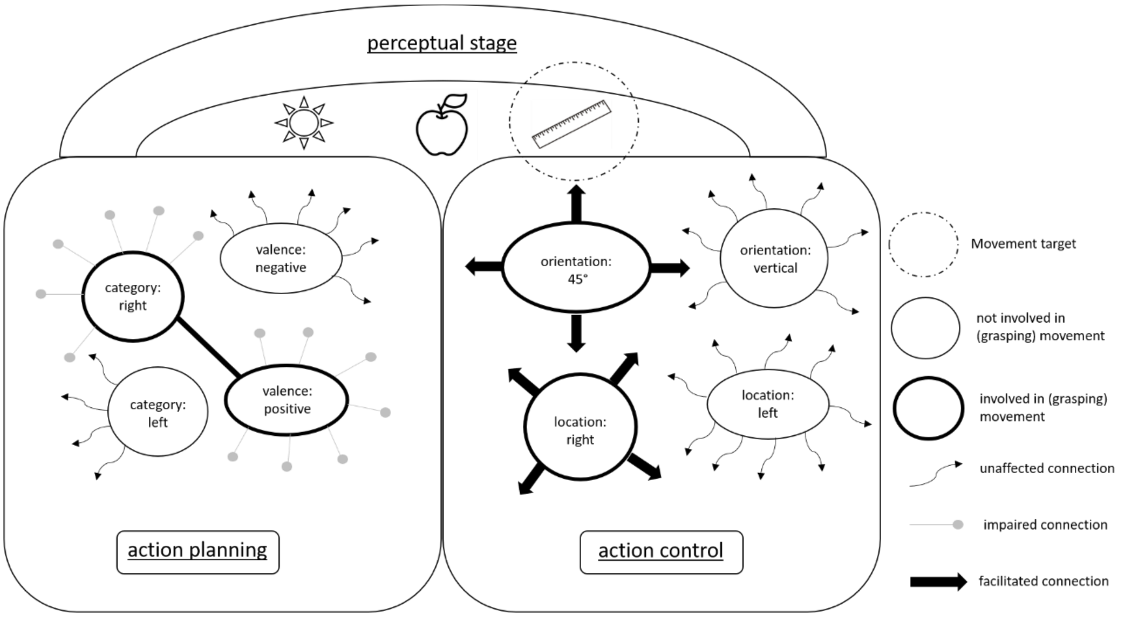
task (T2) starts, and participants have to respond with a second response (R2) to a second stimulus (S2) that is often harder to discriminate than S1. R1 and S2 can either be consistent or inconsistent in relation to a certain dimension, e.g., spatially, but also semantically. According to Thomaschke et al. (2012), there seems to be evidence for R1-S2 consistency *impairing* the perception of S2 (e.g., Kunde & Wühr, 2004; Müsseler & Hommel, 1997; Nishimura & Yokosawa, 2010; Stevanovski et al., 2006), but also evidence for R1-S2 consistency *facilitating* the perception of S2 (e.g., Hommel & Schneider, 2002; Müsseler et al., 2005; Paprotta et al., 1999). This mixed evidence led to the development of the PCM of motorvisual priming. Thomaschke et al. (2012) argue, that *motor planning* involves primarily categorical or abstract or *amodal* representations while *motor control* involves primarily spatial and more concrete or *modal* representations. According to the authors, motor actions seem to *impair* on one hand the perception of abstract (*amodal*) features while they *enhance* the perception of spatial (*modal*) features[2]. This seems to be the case because mental representations have different functions in *action planning* and in *action control*: In action *planning*, separate representations (e.g., of an action goal, of my own motor capacities, of environmental information) are bound together to form an action plan. For being carried out correctly, this action plan needs to be free of interference by other cognitive processes like visual perception, therefore *impairing* these other processes. In action *control*, on the contrary, a continuous reprocessing of spatial representations (e.g., of the exact position of the hand when performing a grasping

[2] The terms *modal* and *amodal* are explained in detail in chapter 1.2 of the introduction.

movement), in order to match the actual movement to the action plan, is needed. In this case, a fine-grained perception of the environment *facilitates* the adjustment of a movement according to a certain goal (e.g., grasping an object) and also the other way around. Figure 1 illustrates the *facilitation* and *impairment* of perceptual processes in action planning and movement control. As mentioned in the previous paragraph, similar hypotheses regarding the different nature of the representations relevant in action planning and movement control were already made by Glover (2004) as well as Glover and Dixon (2001a). The PCM of Motorvisual Priming is illustrated and exemplified in Figure 1.

Figure 1

The Planning and Control Model of Motorvisual Priming (Thomaschke et al., 2012)



Note. The movement target (a ruler) of a grasping movement is indicated by a discontinuous circle in the perceptual stage. On the left panel can be observed that the connections of the representations bound into an action plan (the light grey lines with a dot at the end) are therefore *impaired* towards other cognitive processes, while the connections of non-involved representations remain unaffected (visualized by curved arrows). The right panel shows, on the other hand, that the connections of representations involved in the grasping movement are *facilitated* towards other perceptual processes during movement control (shown by thick, black arrows). This figure is adapted from Thomaschke et al. (2012).

To sum up this first introductory chapter, an overview over various influential theories on the nature of the representations involved in action planning and action control shows that all of them make a fundamental distinction between *early planning* and *late control* processes. Some of them, like Glover and Dixon's Planning and Control Model and the PCM of Motorvisual Priming by Thomaschke et al. (2012), do even distinguish between *categorical representations* involved in *action planning* and *spatial representations* involved in *action control*. This differentiation will play a major role in developing the main hypothesis of this thesis.

1.2 Action planning according to the Theory of Event Coding

As mentioned before, action planning and action execution/control are often considered as two separate processes, relying on representations of a different nature (e.g., Glover & Dixon, 2001a; Milner & Goodale, 2006; Thomaschke et al., 2012). Based on this distinction, contemporary psychological research rarely focuses on both early action planning and late action control processes, but typically focuses only on one type of process. Inside the larger frame of the research unit, our project aims at investigating if, and if yes to what extent, the distinction into early planning and late control processes is as clear-cut as postulated by numerous researchers. The focus will first be on literature on *action planning* and the representations used in planning processes. Hence, the *Theory of Event Coding* (TEC; Hommel et al., 2001; Hommel et al., 2019) will be introduced as the main theoretical background for my empirical research, followed by core assumptions of *Ideomotor Theory* (IT; Harleß, 1861; James, 1890). In the subsequent chapters, I will describe two experimental approaches related to TEC that are central to my research: The so-called "*induction*" approach (Elsner and Hommel, 2001) and the concept of *response-effect compatibility* (REC; Kunde, 2001).

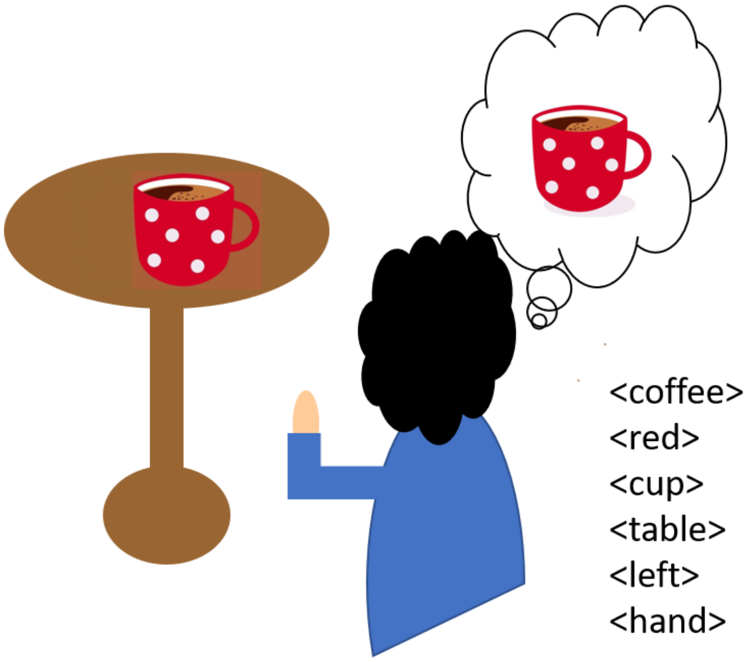
1.2.1 Basic assumptions of TEC and IT

TEC is an influential theoretical framework concerned with action *planning* (Hommel et al., 2001). According to TEC, perception and action are integrated during action planning: They share a common representational domain (see also Prinz, 1990): The authors "claim that perceiving and action planning are functionally equivalent, inasmuch as they are merely alternative ways of doing the same thing: internally representing external events" (Hommel et al., 2001, p. 860). Another central assumption of TEC is that the information perceived when observing a stimulus event is processed by different cortical areas and sent through structurally distinct cortical circuits, thus leading to the different stimulus features being coded in distinct areas. This conveys the idea that these individual feature codes are integrated into an event file by means of a neurophysiological integration process. A third claim of TEC is that the cognitive codes representing stimulus events are of the same nature as the codes that represent action plans. According to Hommel et al., this is the case, because both of them denote (stimulus) events in the environment (i.e., *distal events*), thus meaning that the respective distal feature codes must preserve the distal characteristics of the perceived event.

The key concept that defines TEC is the so-called *event code* or *event file* (exemplified in Figure 2). An *event file* is composed of the simple feature codes that represent the distal features of the corresponding event (Hommel et al., 2001). Numerous features of distal events can be processed by multiple sensory modalities. Thus, the integration of information from different sensory modalities compensates for the limitations of a single modality. Feature codes play a pivotal role in merging and consolidating this information. An event/action, for example, grasping a cup situated on the table, is coded by integrating the simple feature codes of that event into a so-called "event file". An example for such simple feature codes would be <red>, <cup>, <left>, <hand>: These simple codes are bound together into an event file, so that an actor, who wants to have a sip of coffee, forms the action plan in his mind of grasping the red cup with the left hand (see Figure 2). According to TEC, the distal coding of events and action plans entails these simple feature codes to be modality-unspecific (*amodal*) and abstract: "[…] it […] allows perception and action planning to abstract from domain- and modality-specific […] coding characteristics and refer instead to an events informational content" (Hommel et al., 2001, p. 861).

Figure 2

Illustration of one of TEC's core assumptions.



Note. An actor wants to have a sip of coffee and forms an action plan in order to achieve that goal. This action plan or *event file* consists of the simple, modality-unspecific feature codes needed to form a complete action plan (in this case grasping) or event file: The red cup, containing coffee, is positioned on the table to the actor's left, reachable with their left hand.

Another central part of TEC is based on assumptions of IT (Harleß, 1861; James, 1890; later rediscovered by Greenwald, 1970; Hommel, 1998; Prinz, 1997; see Shin et al., 2010, for a review). A core assumption of IT is, that motor actions are selected by anticipating the consequences of these actions on the environment. This makes sense from an ecological point of view, as learning, for example, how to perform a certain action like cracking a nut, seems to take place in humans and animals by forming mental associations between actions and outcomes (e.g., Elsner & Hommel, 2001; Kunde, 2001; Maes, 2006). This core assumption of IT is also incorporated into the framework of TEC, as stated in the beginning of this section: In the example of the person thirsty for coffee, this person was able to infer a) where to find the coffee and b) which chain of actions to perform on what objects in the environment to finally obtain the cup with the fresh coffee inside and drink from it (see Figure 2). In short: The person knew (or had learned), what impact their action would have on the environment, and was able to channel this information to show goal-oriented behaviour.

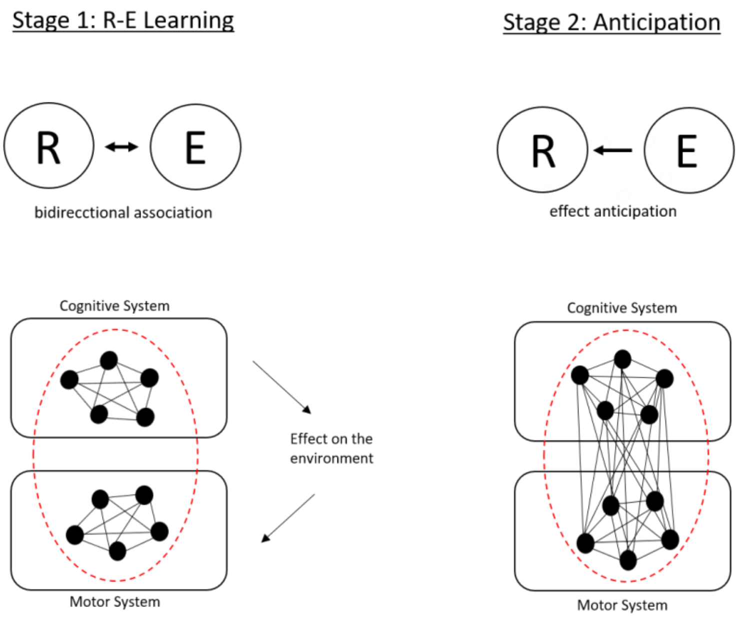
Important for the research aim of this thesis (see Chapter 2) is the IT-related common coding theory (Prinz, 1990). According to this theory, perception and action share a common representational code, so that “actions are coded in terms of the distal perceptual effects they evoke in the environment” (Waszak et al., 2012, p. 944). This means, that *perceiving* the effect of an action on the environment would involve the same representation as the *performance* of the action itself and vice versa.

1.2.2 Response-effect learning and response-effect compatibility

Incorporating assumptions of TEC, Elsner and Hommel (2001) proposed a two-stage model, in which the first stage is a prerequisite for the second stage (see Figure 3). In the first stage, motor patterns are generated at random and produce a movement which leads to an effect on the environment or action effect. Such an action effect can be described as a specific, perceivable change between an actor and his environment (Elsner & Hommel, 2001), which leads to a specific activation pattern in the cognitive system. The activation of both motor and sensory pattern at the same time leads to an integration of the corresponding feature codes (see Figure 3, left panel), so that in the future, the activation of one pattern leads to the activation of the other pattern and vice versa. This idea of two functionally different subsystems of the nervous system goes back to Harleß (1861), who postulated a sensory unit or *sensorium* and a motor unit or *motorium* (Pfister & Janczyk, 2012).

Figure 3

The two-stage model proposed by Elsner & Hommel (2001).



Note. The upper panel shows the relation between response and effect in each stage. The lower panel of the figure is adapted from Elsner and Hommel (2001).

According to the authors, learning of the R-E relationship in the first stage is not explicit, but rather automatic/implicit. In the second stage, the adequate movements for achieving a particular goal are selected. The cognitive system selects the appropriate movements by activating the representational codes of that goal (see Figure 3, right panel). As associations were built between motor actions and their perceivable effects during the first stage of the model, an effect code is very likely to also activate the associated motor pattern. Therefore, motor patterns are selected in an effect-oriented and automatic manner by anticipating the consequences of their effects (e.g., Kunde et al., 2002; Kunde et al., 2007; see Figure 3, right upper panel). Noteworthy, Harleß (1861) already used the expression “action effects” in his work on voluntary action and even hints at the contextual dependency of these effects (Pfister & Janczyk, 2012), so that his ideas can clearly be seen as a background for the model proposed by Elsner and Hommel (2001).

In the context of TEC, a considerable amount of research explores the establishment of bidirectional associations between motor actions and their consequences. An influential experimental methodology employed to evaluate these action-effect associations is referred to as the so-called *"induction"* approach (Elsner & Hommel, 2001; see also Dignath et al., 2014; Hoffmann et al., 2009; Hommel et al., 2003; Wolfensteller & Ruge, 2011; Ziessler & Nattkemper, 2011, as examples). Induction experiments mirror the two stages of the model of Elsner and Hommel (2001) and typically comprise an *acquisition phase*, in which an action is contingently paired with an effect, and a subsequent *test phase*, in which the former action effect is used as an imperative stimulus eliciting a certain response. For example, during the first phase, a left key press might elicit a high pitch tone, while a right key press might elicit a low pitch tone. This acquisition phase often comprises around 200 trials, so that bidirectional associations between the key presses and the respective tone pitches (or other action effects, depending on the design) can be formed (Elsner & Hommel, 2001; Hommel et al., 2003). Those associations are then tested in the test phase that can either consist of a free-choice or a forced-choice task. In either task, the tones are presented as stimuli that signal to participants either that they can choose one of the two keys to press (free-choice task) or that they have to respond according to a previously announced stimulus-response (S-R) mapping (e.g., a high pitch tone requires a left key press in response; forced-choice task). In the first case, the percentage of acquisition-congruent choices is measured (e.g., Elsner & Hommel, 2001, Exp. 2-4; Eichfelder et al., 2022; Sun et al., 2020, Exp.1), in the latter case the reaction times (RTs) and percentages of error (PEs) (e.g., Elsner & Hommel, 2001, Exp. 1; Hommel et al., 2003). If, in a free-choice task, the percentage of acquisition-congruent choices exceeds a value of 50.0%, this is interpreted as a response bias towards the response (e.g., a left key press) that was associated with the imperative stimulus (e.g., a high pitch tone) as an effect during the acquisition phase. The occurrence of a response bias respectively shorter RTs and smaller PEs in the group with a congruent R-E mapping points towards a successfully formed, bidirectional R-E association. Interestingly, Janczyk et al. (2022) replicated Experiment 3a of Elsner and Hommel (2001) in a multi-lab study. In this experiment, participants were free to choose the left or right key during the test phase as a response to tones displayed as stimuli. Participants showed a response bias towards the acquisition-congruent response, so the authors were able to replicate the effect reported by Elsner and Hommel (2001; Experiment 3a), though with an effect of about half the size. This experimental approach, especially with a free-choice task in the test phase, is of a high relevance for the experiments presented in this PhD-thesis.

A second experimental approach that tests assumptions of IT, respectively TEC, is the REC approach (Kunde, 2001; see also Földes et al., 2018; Janczyk et al., 2015; Koch & Kunde, 2002, as examples), aiming directly at the anticipation of the sensory consequences of motor actions. In short, this approach shows that responses are facilitated if the action-contingent effects share representational codes with the response based on a dimensional overlap. In his Experiment 1, Kunde (2001) established the basic effect as an isolated phenomenon for the first time: The participants were required to react to an imperative stimulus, which was a color patch, by pressing one of four keys arranged horizontally. Every response option corresponded to the illumination of one of the four boxes on the screen, which were also horizontally arranged and spatially compatible. In blocks of 16 trials, the keypresses produced either a spatially compatible effect (for instance, pressing the far-left key led to the illumination of the box on the far-left side of the screen) or a spatially incompatible effect (for instance, pressing the far-left key led to the illumination of the box on the far-right side of the screen). The relation between R and E was predictable in each block. The RTs and PEs were measured and compared between R-E compatible and incompatible blocks. It turned out that participants reacted faster and less error-prone when the anticipated effect appeared on the same side as the response that was carried out, than when the effect appeared on the incompatible side (Kunde, 2001, Exp. 1). Further research interpreted this result as a priming effect of the anticipated effects on compatible responses (Janczyk & Lerche, 2019).

The two abovementioned approaches – R-E learning through induction and REC, both based on compatibility effects – were typically used by experimental researchers to investigate core assumptions of TEC respectively IT (e.g., Wolfensteller & Ruge, 2012, for R-E learning; Janczyk et al., 2015; Pfister & Kunde, 2013, for REC; Janczyk et al., 2022, for both). While the *induction approach* (Elsner & Hommel, 2001) investigates the *associations* between R and E, REC mainly presumes to show that, for coding an action, the *anticipated* (perceptual) *consequences* of that action are essential. As explained above in this section, TEC assumes that perception is mainly coded in a modality-unspecific, *amodal* way (Hommel et al., 2001). As TEC also assumes common coding (Prinz, 1990), the representations of actions during the action planning phase would also have to be coded *in an abstract way.* This assumption was emphasized by Thomaschke et al. (2012) in their PCM: According to the model, action planning consists in selecting a response in each situation and therefore equals *response selection*. This process establishes a modality-unspecific, abstract representation of any given action. Other studies (e.g., Janczyk & Kunde, 2020, Kunde et al., 2012; Wirth at al., 2015) have specified response selection as effect anticipation, determining the first operation during the period of the latter. Paelecke and Kunde (2007) actually state that effect anticipation equals response selection. Importantly for our purposes, this means that the representations used in action planning through effect anticipation are supposed to be *abstract*. More about the representational foundations in cognitive psychology and their relevance for this PhD-thesis will be explained in the next section.

1.3 Representational foundations in Cognitive Psychology

1.3.1 *Modal* versus *amodal* representations

In this section I want to introduce the role of the topic of *modal* and *amodal* cognition as an overarching principle in different fields of cognitive psychology and explain how the terminology *modal* versus *amodal* is used in our research. In order to further describe the terminology of the research unit that will be used throughout my thesis, I first want to sum up the taxonomy of Reed[3] (2016), who distinguishes, among others, between two types of cognitive processing: *Modal* and *amodal* processing. *Modal* processing is supposed to be specific for a particular sensory modality or domain, for example the visual or auditory domain. If one walks, for example, through the zoo and sees a Flamingo, they will process its visual features (the color of the plumes, the shape of the beak…) in a *modal* way inherent to the visual domain. On the other hand, *amodal* processing is supposed to be modality-unspecific but rather integrates information from various sensory modalities. If, for example, I am recognizing the Flamingo as a member of the abstract category "bird", I need to integrate several of its features into one *amodal* percept: The abovementioned visual features plus other sensory information (e.g., the sounds it makes, its behaviour). In conclusion, Reed's (2016) taxonomy provides a useful framework for understanding the nature of the representations involved in cognitive processes that are subject to different fields of psychological research.

[3] Reed (2016) refers to the work of Barsalou (1999), Chun et al. (2011), Collins and Quillian (1969) and Rosch and Mervis (1975).

According to Kaup et al. (2022), it depends on the field of investigation within cognitive psychology which type of mental representations are being assumed. For example, the representations used in higher-level domains of cognition (e.g., thinking, memory, and language processing) are thought to be of a symbolic, *amodal* nature (e.g., Barsalou, 1999; Fodor, 1975; Pylyshyn, 1984; Reed, 2016). These symbolic representations rather represent a more abstract category (e.g., “dinosaurs” or “birds”), leaving out all irrelevant details that would be inherent to each exemplar of a category (e.g., the pink feathers of a flamingo). Remembering the taxonomy of Reed (2016), the represented meaning of the word “bird” would comprise features of a variety of exemplar birds and can therefore be considered more abstract or more *amodal*. Furthermore, the abstract representation of “bird” does not depend on any sensory, *modal* characteristics result of particular sensory experiences. Another example used by Kaup et al. (2022) is the meaning of the word “melody”. Although it definitely refers to auditory features, its mental representation no longer comprises a specific exemplar melody. The mental representation of “melody” has become more abstract than any particular past auditory experience. Consider again the mental representation of the category “bird”, mainly based on visual features: As with “melody”, its symbolic representations are abstracted from the sensory experience, in this case a visual experience. Taking into account the examples, it seems as if the symbolic representations of both share a representational format, although the entities they relate to are perceived with different sensory modalities (auditory vs. visual). In conclusion, it can be assumed that abstract, symbolic representations are modality-unspecific or *amodal.*

Investigation on perception, on the contrary, typically assumes that mental representations depend on the sensory modality of the entity they represent and that they keep characteristics of that entity (Kaup et al., 2022). If, for example, I perceive the dove that lives in my garden, I seem to create a specific representation that keeps many of the specific features of that particular dove. These features can be of various modalities, for example, visual (the color of the plumes) and auditory (the typical sound it makes when searching for food) at the same time. The representations of different entities can be qualitatively completely distinct, depending on the sensory modality that characterizes an entity for the major part. Taking this into account, these representations seem to be concrete, modality-specific and therefore *modal.*

Considering research on conceptual knowledge (e.g., Pecher, 2013), not all mental representations have to be either *modal* or *amodal* but can be of a *hybrid* nature: In this case, the representation of the concept "bird" would not only consist of a *modal* component formed by sensory experiences of birds that were made in the past, but also of a symbolic, *amodal* component that is the sum of typical, "birdlike" attributes (Kaup et al., 2022). These mental representations of hybrid nature are highly relevant for the research unit, as a strict dichotomy between both formats is not believed to exist. Instead, the perspective of a continuum ranging from highly abstract to modality-specific representations persists.

1.3.2 *Modal* and *amodal* representations in human action

In the first chapters of this introductory section, some influential theories in the field of human action were described and TEC (Hommel et al., 2001) was further outlined, a theory especially important for the research on action planning this thesis is mainly concerned with. According to these theories, *action planning* is mainly based on more *amodal representations* and explained by TEC (Hommel et al., 2001) while *action control* is based on more *modal representations* and explained, among others, by PAM (Milner & Goodale, 2006). However, some empirical results are contradicting this assumption. As this thesis focuses on the *action planning* part, some contradictions in context of TEC that do not fully support the predictions made by this theory will be outlined in this section.

First, looking at induction experiments (e.g., Elsner & Hommel, 2001, 2004; Hommel, 1996), the action effects during the acquisition phase and the imperative stimuli during the test phase are *physically identical* (e.g., a high pitch tone). As one core assumption of TEC is, that an event file is formed by simple, modality-unspecific (*amodal*) feature codes, this should also be true for *anticipated* events. Considering the usage of physically identical effects/stimuli, the nature of the representations involved in action planning is unclear: Is it an *amodal abstraction* of the action effects or rather the *modal information* provided by these effects?

Second, looking at some results from REC experiments, it seems as if *modal representations* could also be involved in action planning. Kunde (2003) showed that RTs are longer after a key-press that triggered a long-lasting tone compared to a tone of a short duration. Assuming that the tone durations are represented in a modality-specific, *modal* way, it perfectly makes sense that it takes longer to anticipate an action effect with a longer duration. An abstract, *amodal* representation of the features <long> and <short>, on the other hand, should not lead to a difference in RTs. Similarly, Dignath and Janczyk (2017) and Dignath et al. (2014) showed, that RTs are also shorter if an effect is triggered after a short response-effect interval compared to a long response-effect interval. Another study pointing into the same direction was conducted by Koch and Kunde (2004) who used uttered color words as responses and visual effects (the written-out color words). They found a larger REC effect when the color word was written in the corresponding color compared to a different color, a result pointing at anticipated effect representations maintaining aspects of their sensory analogues. Considering these results, early action planning might not only invoke *amodal*, but also *modal* representations.

In the next section, I want to focus more closely on studies that tested for abstraction in the sense of generalization. One study reported such a generalization effect in a typical induction experiment (Hommel et al., 2003; Exp. 1) whereas there is contradictory evidence in the field of REC (Földes et al., 2018; Koch et al., 2021).

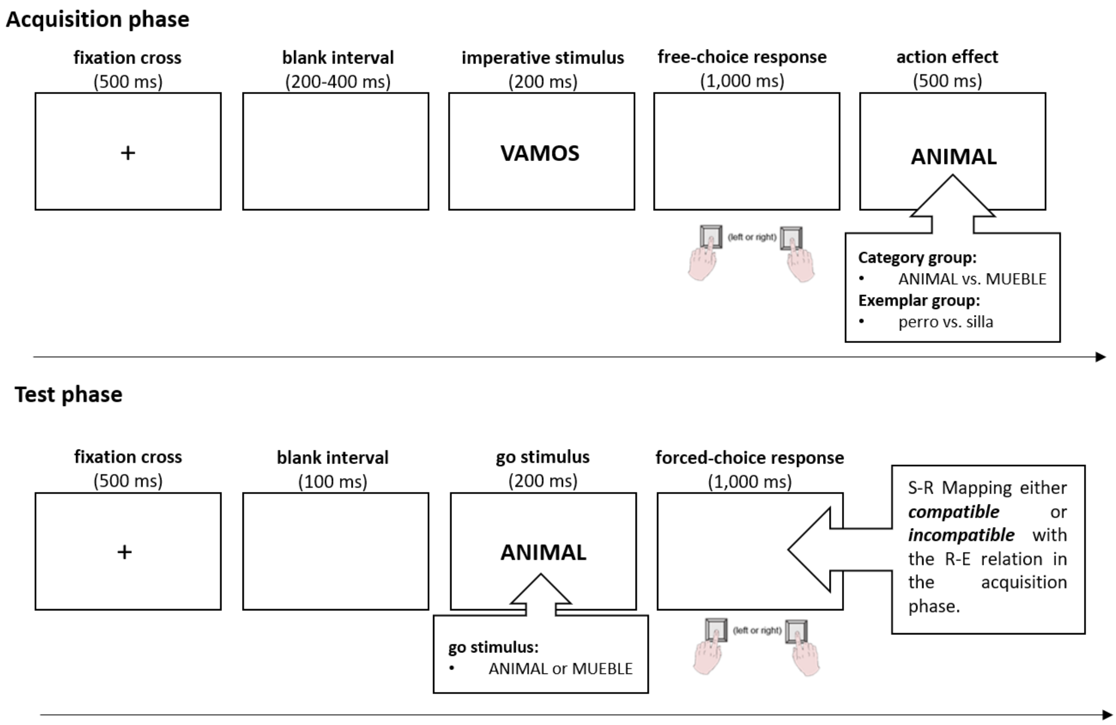
1.4 Mixed evidence on abstract representations in R-E learning

1.4.1 Evidence in favor

The main goal of Experiment 1 by Hommel et al. (2003) was to examine the extent to which bidirectional associations between actions and their effects would generalize to unfamiliar effects falling within superordinate categories (see Rosch et al., 1976). In order to accomplish this, two groups were contrasted based on the action effects they received during an acquisition phase. The first group, referred to as the *category group*, received a word describing a category such as "furniture" in response to a key press. The second group, referred to as the *exemplar group*, received a specific example of the broader category, such as "chair" (both words in Spanish). Both groups received 5.0% of catch trials during the acquisition phase, in which the catch stimulus “fruit” in Spanish appeared and the space bar had to be pressed within 2,000 ms. Hommel et al. (2003) presented these catch trials so that the task-irrelevant action effects had to be processed by the participants at least in a part of the time (p. 972). During the subsequent test phase, only category words were utilized as stimuli, which means that for the *category group*, the stimuli and effects were physically and semantically identical during both the acquisition and the test phase (see Figure 4 for details on the experimental design).

Figure 4

Experimental Design of Experiment 1 by Hommel et al. (2003).



Note. The upper panel shows an example for a typical acquisition phase trial of the category group, the lower panel shows a typical test phase trial. The action effects and stimuli are depicted in Spanish as in the study of Hommel et al. (2003, Experiment 1). The imperative stimulus "vamos" is Spanish for „go", the action effects in the category group are Spanish for "animals" and "furniture", the action effects in the exemplar group are Spanish for "dog" and "chair".

The test phase procedure was the same for both groups: In a forced-choice task, participants had to respond to a stimulus (a category word: "furniture" or "animal" in Spanish) with a certain key press (see Figure 4). However, for 50.0% of the participants, the word-key-mapping was the same as during the acquisition phase (*compatible condition*), whereas for the other 50.0% the mapping was reversed (*incompatible condition*). If no differences in a compatibility effect would show between the *category* and the *exemplar group*, this would point towards *amodal* representations in the sense of semantic generalization during action planning.

Hommel et al. (2003) analyzed both acquisition phase and test phase data. During the test phase, mean RTs and PEs were analyzed as a function of group and mapping, using the mean acquisition phase RT as a covariate in the RT analysis, which yielded a significant effect of mapping, $F(1, 135) = 8.93$, $p = .003$[4]. This indicates faster responses with a *compatible S-R-mapping* in respect to the acquisition phase than with an *incompatible mapping*. Separate analyses conducted by Hommel et al. (2003) confirmed that the congruency effect was present in both practice groups, *category group*: $F(1, 60) = 4.50$, $p = .04$ and *exemplar group:* $F(1, 74) = 4.51$, $p = .04$[5]. The authors concluded that action effects do generalize to related stimuli, especially if they refer to the same category (Hommel et al., 2003). Considering the assumptions of TEC, these results point towards an integration of two types of codes into an event file, ones that represent the *immediate consequences* of an action, and ones that get activated *indirectly* when the primary codes are activated. In this case, the superordinate category “furniture” was supposedly activated by the activation of the corresponding exemplar word “chair”. This generalization effect was seen by the authors as a sign of abstraction during the test phase, evidence for the usage of abstract, *amodal* representations.

[4] This result was reported without a *p* value in the original paper. This *p* value was calculated in base R using the pf() function. The same is true for the rest of the reported values.

[5] The interaction between the factors group and R-E mapping was not reported in the original paper. From the results section of Experiment 1 in Hommel et al. (2003, p. 974) it can be concluded though that the interaction was not significant.

Hommel et al. (2003) conducted two further experiments concerned with the role of *similarity* and *feature-overlap* in R-E learning. The authors believe that similarity and feature-overlap are crucial factors, as the knowledge of an action leading to a specific outcome empowers the cognitive system to generalize to other, comparable or feature-sharing outcomes. In their Experiment 2, they reported within-category generalization from one set of exemplars to different exemplars of the same category, while in their Experiment 3, they reported generalization from a set of words ("orange" and "blackboard" in Spanish) to different words that refer to a mutual perceptual feature ("circle" and "rectangle" in Spanish). Similarly, a recent study (Esser et al., 2023) investigated the transfer of acquired R-E associations to effect stimuli that convey *similarity* to the original effects. Their Experiment 1 implemented similarity as being a member of the same category whereas their Experiment 2 implemented similarity as a resemblance in the set of movements that is typically carried out when using an object shown on a picture (i.e., a picture of a paintbrush was used as an effect and a picture of a pencil was shown as a test phase stimulus in the "similar" condition). The results of Esser et al. (2023) support the findings of Hommel et al. (2003): Not only learned response effect stimuli had an influence on RTs, but also unlearned, similar response effects did so. Or, with the words of the authors, "The action effect once bound to an action is used to select an action if a similar effect for which no action has been learned yet is presented." (Esser et al., 2023, p. 1). These results and the possible impact of RTs as a measure, compared to the percentage of acquisition-congruent choices as in free-choice tasks, will be further discussed in the course of this thesis (Section 6).

1.4.2 Contradictory evidence

Contradictory evidence for the abstract, *amodal* representation of action effects has been reported in REC studies, though: Initially, Koch and Kunde (2002) conducted two experiments in which participants were required to utter color words (e.g., "red" or "blue"), followed by the display of these colors written out as words on a screen (visual action effects). The REC effect observed was larger when the color word and its color were compatible (for example, "green" written in green) than in an incompatible condition (for example, “green” written in red). This outcome suggests that there is abstraction occurring from the verbal response to the visual effect. However, there remains the possibility that the act of reading a color word automatically leads to phonological recoding that is either consistent or inconsistent with the verbal response. To eliminate this possibility, Földes et al. (2018) conducted an REC experiment without phonological overlap between the verbal response and the auditory effect in a bilingual context. In the bilingual condition, if the response was given in German (e.g., "Schwein"), the English translation (e.g., "pig") was utilized as an auditory action effect. In contrast, in the monolingual condition, a phonological overlap existed (e.g., "Schwein" was spoken as a response, and the auditory effect was also "Schwein"). An REC effect was observed in the monolingual condition with phonological overlap, but not in the bilingual condition. Furthermore, Koch et al. (2021) conducted a study in which they utilized the same category words as verbal responses as Hommel et al. (2003, Exp.1; "animals" and "furniture" in German) in an REC experiment, and either the same category words or exemplars of these categories ("horse" and "chair" in German) as auditory effects. However, they did not observe an REC effect in their study.

In another recent study, Janczyk and Miller (2023) examined whether response effects must be entirely predictable in order to influence response selection or if some degree of variability is acceptable as long as the most relevant aspect of dimensional overlap with the responses (e.g., location) can be inferred in each trial. Participants performed a typical REC task with an overlap between R and E on the spatial dimension (left versus right effects respectively responses). In a fixed-location group, the exact position of the action effect was predictable, whereas in a random-location group, the effect did appear either on the left or right side of the screen center, but the exact position changed randomly in each trial. The authors reported that the effects in the fixed-location condition did seem to facilitate the response when their location was compatible to the latter. For the random-location condition, the results were subject to interindividual differences: Some participants seem to be able to infer the fundamental characteristics that overlap with responses and have the potential to impact action selection. Interestingly, in these cases, the compatible responses seemed to be rather inhibited than facilitated.

1.4.3 Pilot study

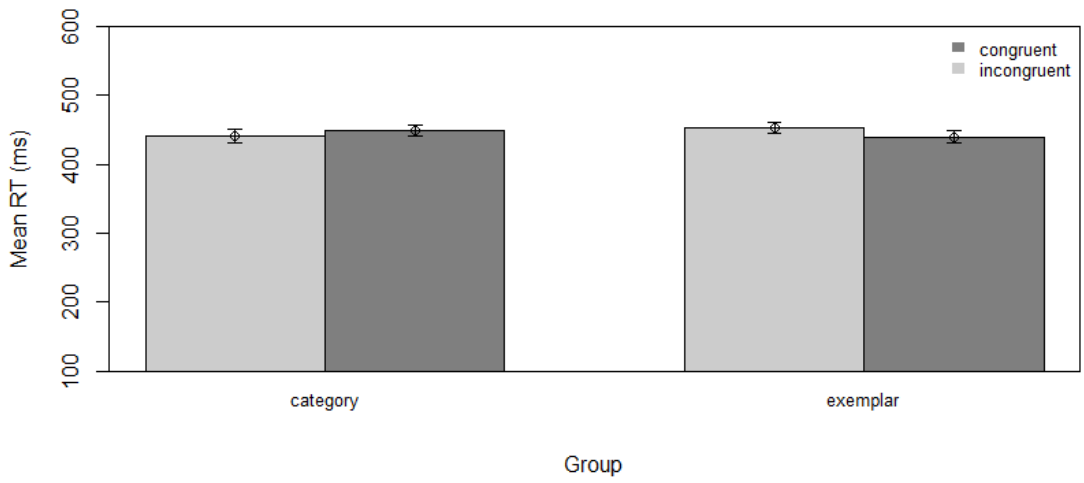
Given this mixed evidence for abstract (*amodal*) representations in planning motor actions, it's a goal of this work to shed light on the role of these types of representations by empirically addressing the existing inconsistencies. Therefore, the first aim was to replicate Experiment 1 by Hommel et al. (2003) as an online study to gather pilot data. The main results and conclusions are described briefly in this section, while more detailed information on method, results, and discussion can be found in Appendix A.

Experiment 1 of Hommel et al. (2003) is a typical induction experiment with 200 acquisition phase trials, including 5.0% of catch trials and a forced-choice test phase comprising 80 trials. Due to the circumstances of the COVID-19 pandemic it was decided to replicate this experiment as an online study and to use the results as pilot data for the development of an own line of experiments to assess abstraction in R-E learning. The experimental design was the same as in the original study discussed in the beginning of this section (see Figure 4 for details).

In total 293 participants were tested. The decision for this rather large number of participants was made because of the online format of the study. Unfortunately, due to programming issues that were only discovered after data collection was finished, the number of catch trials per person differed between participants (range: 2-17 catch trials) and there was no limit for the response time. Thus, only the participants with 9 or more catch trials were included in the analyses. After applying further exclusion criteria, the final sample consisted of 140 participants ($n_{\text{exemplar group}} = 80$, $n_{\text{category group}} = 60$).

Figure 5

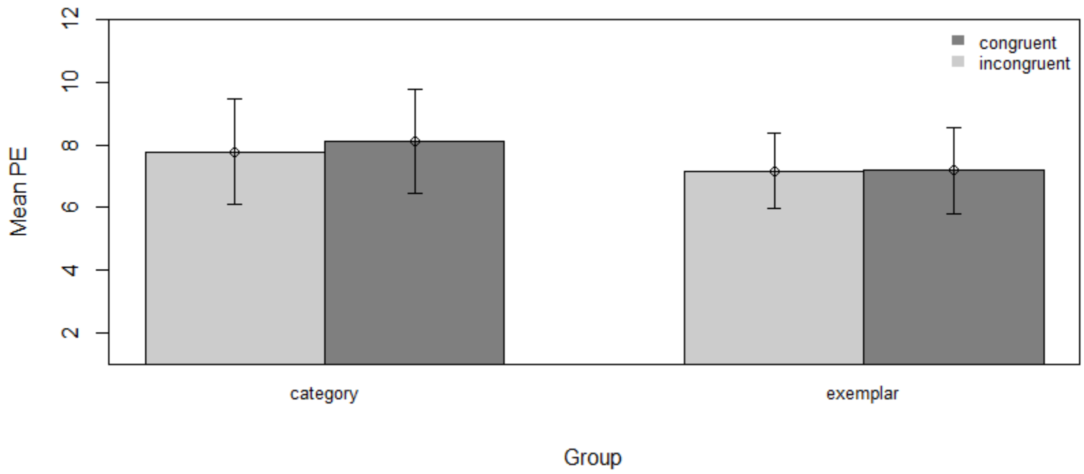
Mean test phase RTs as a function of group and R-E mapping.



Note. The light grey bars show the mean RTs in the incongruent condition. The dark grey bars show the mean RTs in the congruent condition. The error bars show the standard errors of the means.

Figure 6

Mean PEs as a function of group and R-E mapping.



Note. The light grey bars show the mean PEs in the incongruent condition. The dark grey bars show the mean PEs in the congruent condition. The error bars show the standard errors of the means.

Figure 5 depicts the mean correct test phase RTs as a function of group *(category* vs. *exemplar*) and mapping (*congruent* vs. *incongruent*), Figure 6 illustrates the distribution of the mean PEs in each group. Analyses were as in the original study. Analyzing the RTs, the findings of Hommel et al. (2003) could not be replicated, as the main effects of group, $F(1, 135) = 2.22$, $p = .138$, $\eta_p^2 = .02$, and mapping, $F(1, 135) = 0.29$, $p = .590$, $\eta_p^2 < .01$, did not reach significance. The interaction was also not significant, $F(1, 135) = 0.98$, $p = .323$, $\eta_p^2 < .01$. The same was true for the PEs: The main effects of group, $F(1, 136) = 1.09$, $p = .298$, $\eta_p^2 = .01$, and mapping, $F(1, 136) = 0.05$, $p = .829$, $\eta_p^2 < .01$, did not reach significance, and neither did the interaction of both factors: $F(1, 136) = 0.05$, $p = .819$, $\eta_p^2 < .01$. An additional Bayesian ANOVA that was run on RTs provided further evidence for the respective null-hypotheses as all Bayes Factors (BFs) < 1 (see Appendix A for details). According to Morey et al. (2016), a BF quantifies the comparative evidence in favor of one statistical model over another by evaluating the ratio of their respective evidences. This ratio provides a measure of support for a particular model in relation to the alternative model. An aim of the present study was to quantify and compare the evidence for the alternative hypothesis of generalization with the evidence for the null hypothesis of no generalization.

No evidence was found for the presence of generalization from exemplars to the corresponding category and thus more abstract (*amodal*) representations during action planning in the pilot study. The possibility exists, though, that a) the online format could have led to rather poor data quality, and that b) RTs and PEs as measures might not be able to perfectly reflect the presence of *amodal* representations respectively abstraction. That was the reason to start our own line of experiments with a conceptual replication of Hommel et al. (2003, Exp. 1; see Section 3.1).

2 Main hypothesis and research aim

Given the mixed evidence for generalization and thus abstract (*amodal*) representations in planning motor actions, the aim of the experiments outlined in this dissertation is to shed light on the role of these types of representations by empirically trying out variants of experiments to see, if it is possible at all to find abstraction in the sense of generalization in R-E learning. In short, the main goal is to test whether some sort of generalization—and thus abstraction of action effects—can be observed in induction experiments, and if yes, under which conditions.

Before describing each of the experiments and discuss their results in the following sections, the hypothesis that led to the design of these experiments will be briefly outlined:

Hypothesis: No signs of generalization (in case of category words and exemplars) or abstraction (in case of pictures and concept words) will be found in R-E learning tasks following the *induction logic* (Elsner & Hommel, 2001). The roles of *modal* and *amodal* representations in human action are not as clearly divided into action planning (*amodal*) and action control (*modal*) as presumed up to now in contemporary theories and empirical research. This by implication would argue against abstract, *amodal* representations in action planning.

3 Empirical studies: Experiment 1 - 3

In order to achieve the main research aim of this PhD-thesis, a series of experiments were run, designed to test whether effects, measured by researchers in context of TEC and IT in past studies (e.g., Elsner & Hommel, 2001, 2004; Hommel, 1996) generalize to abstract (*amodal*) action effects, and if the results are then replicable if a) a free-choice test phase is used instead and b) the nature and abstractness of the chosen effects/stimuli vary in each experiment. The fundamental question addressed in ***Experiment 1*** is whether, when using semantic stimuli, the representations of the effects generalize to a higher hierarchical level in R-E learning. ***Experiment 2*** was designed to test if abstract concepts like “up” and “down” are semantically represented. ***Experiment 3*** then is concerned with the question whether visual information in the form of rather simple pictures is abstracted to the corresponding semantic meaning. See Table 2 for an overview of the effects respectively stimuli used in all three experiments.

Table 2

The effects / go stimuli and catch stimuli used in Experiment 1 – 3.

Experiment 1

group	effect 1	effect 2	catch stimulus
control	MÖBEL	TIERE	FRUCHT
experimental	STUHL	KATZE	APFEL

Experiment 2

group	effect 1	effect 2	catch stimulus
control	OBEN	UNTEN	MITTE
experimental			

Experiment 3

group	effect 1	effect 2	catch stimulus
control	APFEL	KATZE	HAUS
experimental			

Note. The upper panel shows the go stimuli respectively effects and catch stimuli of Experiment 1, the middle panel those of Experiment 2 and the lower panel those of Experiment 3. The colors were inverted during the experiment, i.e., the stimuli were presented in white against a black background.

It was decided to employ a free-choice test phase task in our line of experiments instead of a forced-choice task, and thus measure a different dependent variable. The following section describes the differences between both types of tasks and explains why the decision for a free-choice task was taken. The terms "free-choice" and "forced-choice" have first been used by Berlyne (1957) in a study on the influence of conflict on the execution of manual responses. In this study, participants chose freely between different manual responses. RTs were measured and compared to the outcome of a forced-choice task, where participants had to react with a predefined response to each stimulus (e.g., blue patch → right key press), resulting in overall higher RTs in free-choice- than in forced-choice tasks. This result has been replicated (e.g., Janczyk et al., 2015; Keller et al., 2006, Naefgen et al., 2018) and was attributed by Berlyne (1957) to the fact, that a conflict emerges between two simultaneously activated responses in free-choice tasks, as a choice between at least two options must be made. Pfister et al. (2011) suggested, that acquired R-E relations are expressed more efficiently during the test phase if the task is free-choice rather than forced-choice. Based on these findings and additional studies employing free-choice test phases (Dignath et al., 2014, Exp. 1; Eder et al., 2015, Exp. 5; Elsner & Hommel, 2001, Exp. 2-4), a decision was made for a free-choice task and the percentage of acquisition-congruent choices as the dependent variable, hoping to achieve a more sensitive measure of R-E learning than with a forced-choice task. For each participant, a percentage of congruent choices larger than 50.0% (the value that expresses a chance level of choices) indicates an individual response bias towards the acquisition-congruent choice option during the test phase.

3.1 Experiment 1

The main question behind Experiment 1 was, whether, using semantic stimuli, participants would generalize from an exemplar word (e.g., "chair"), associated to a certain motor action (e.g., a left keypress), to the superordinate category (e.g., "furniture"). Thus, Experiment 1 of Hommel et al. (2003) was conceptually replicated, but with a free-choice test phase containing intermixed no-go trials to prevent participants from pre-planning their responses (as in Dutzi & Hommel, 2009). It was expected to replicate the basic R-E learning effect in a *control group* with *category words* as action effects, meaning that a response bias would be measured during the test phase. If the *experimental group*, which received *exemplar words* as effects during the acquisition phase, exhibits a response bias of the same or a similar magnitude, it would indicate complete generalization. A smaller response bias or the absence of one in this group would suggest that either less generalization or no generalization at all has occurred.

All calculations and plots for Experiment 1 and all subsequent experiments in this thesis were made using R version 4.2.2. The following packages were used: The package BayesFactor (Morey et al., 2021), the diptest package (Maechler, 2021), the effectsize package (Ben-Schachar et al., 2020), the Anova() function from the car package (Fox & Weisberg, 2019), the ez package (Lawrence, 2016), the mousetrap package (Kieslich et al., 2022), the sm.density.compare() function of the sm package (Bowman & Azzalini, 2021), the anova_out() function of the schoRsch package (Pfister & Janczyk, 2016) and the tidyverse package (Wickham et al., 2019).

3.1.1 Method

Open practices statement. This experiment was pre-registered on aspredicted.org: https://aspredicted.org/g8gu4.pdf. The data are publicly available on OSF: https://osf.io/z3qc4/.[6]

Participants. Ninety-nine University of Bremen students participated in exchange for course credit, and additional six participants from the Bremen area volunteered without compensation. After excluding five participants based on exclusion criteria, the final sample size was $N = 100$ (mean age = 25.43 years; 77 females, 23 males, 0 non-binary; 88 right-handed, 12 left-handed, 0 ambidextrous). All of the participants indicated that they were either native German speakers or had advanced written and spoken proficiency in German, and also reported normal or corrected-to-normal vision. Furthermore, all participants were unaware of the study's hypotheses.

Exclusion criteria. In order to facilitate creation of bi-directional associations, three participants who pressed the left and right key less than 80 times (out of a maximum of 100) during the acquisition phase were excluded from further analyses and replaced, in line with a criterion used by Hommel et al. (2003). Furthermore, two participants who erroneously responded in more than 20.0% of the no-go trials were excluded and replaced.

The size of the sample was established utilizing Bayesian sequential sampling relying on BFs. The research employed pre-defined stopping rules as

[6] The results of Experiment 1 are published in Eichfelder et al. (2023).

delineated by Schönbrodt and Wagenmakers (2018) and Schönbrodt et al. (2017). A $BF_{10} > 1$ supports the alternative hypothesis, while $0 < BF_{10} < 1$ supports the null hypothesis. According to the stopping rules, the sampling process would be stopped when certain criteria were met:

1. When a $BF_{10} < 1/10$ was calculated for the one-sample *t* test of the *control group*, meaning that participants have reacted at chance level during the test phase instead of showing a response bias (RB) towards the acquisition-congruent response (an RB is present if the percentage of congruent choices is larger than 50.0%). This would mean that R-E associations were either not learned at all or learned, but not used, during the acquisition phase.

2. When a $BF_{10} \geq 6$ was calculated for the one-sample *t* test of the *control group* (suggesting that learning took place for this group), and at the same time, a BF_{10} of ≥ 6 or $< 1/6$ was calculated for the *two-sample t test* comparing both groups. The first result would mean that no (full) generalization occurred. The second result would mean that generalization occurred, as there would not be a difference in the size of the RB between groups. In the first case, a Bayesian *t* test would be calculated for the *experimental group* to assess, whether signs of partial generalization can be observed ($BF_{10} > 1$).

3. When a maximum number of $n = 50$ participants per group has been reached.

The 100 participants were assigned randomly to one of four conditions resulting from the combination of group (*control group* vs. *experimental group*) and R-E mapping during the acquisition phase within each group (thus $n = 25$ participants per condition). From a minimum total sample of $N = 40$ on, the BF were monitored after the data of each 4 additional participants were collected. All participants took part in a lab experiment in single sessions of 35 - 45 minutes.

Stimuli and Apparatus. The stimuli were presented and the responses were collected through a regular PC that was connected to a 17-inch CRT monitor. The stimuli used were either the *category words* "Möbel" and "Tiere" or the *exemplar words* "Stuhl" and "Katze," all in capital letters and written in white against a black background with a height of approximately 1 cm. Catch stimuli were the word “Frucht” for the *category group* and “Apfel” for the *exemplar group*. Participants responded using the "D" and "L" keys on a standard QWERTZ keyboard as left and right response keys respectively, while the spacebar was used as the response key in catch trials.

Table 1

R-E mapping combinations during the acquisition phase for both groups and stimuli of the test phase.

	Acquisition phase			Test phase
Group	**Counterbalanced R-E mapping**	**Response**	**Effect**	**Stimuli**
Control	1	Left	FURNITURE	FURNITURE ANIMALS XXXXX
		Right	ANIMALS	
	2	Left	ANIMALS	
		Right	FURNITURE	
Experimental	1	Left	CHAIR	
		Right	CAT	
	2	Left	CAT	
		Right	CHAIR	

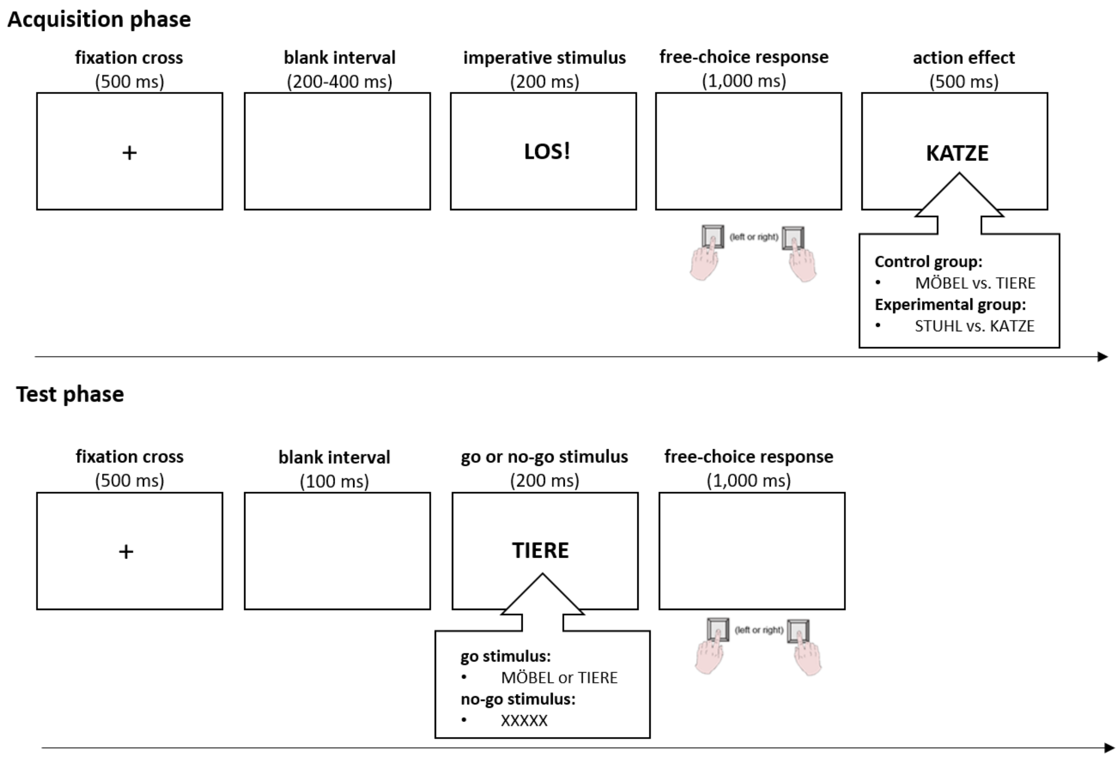
Note. The stimulus in no-go trials was "XXXXX". The stimuli for catch trials in the acquisition phase were FRUIT for the control group and APPLE for the experimental group, respectively. All stimuli in the actual experiment were in German language. Table adapted from Eichfelder et al. (2023).

Task and Procedure. The experiment was conducted in sound-attenuated cabins with dimmed light sources. The trial sequence of the *acquisition phase* is shown in the upper panel of Figure 7. Each trial started with a white cross appearing in the center of the screen for 500 ms, followed by a blank period of a randomly selected duration between 200 and 400 ms. Next, a stimulus was presented in the center of the screen for 200 ms, which was the German word "Los!" written in white letters on a black screen background. This signaled the participants to quickly press the left or right key within 1,000 ms. The keys produced different visual effects based on group and R-E mapping, as shown in Table 1. The effect words were fully dependent on the preceding response's identity, so that stable R-E associations could be established. Participants were told to choose freely between both keys, but to press them about equally often and to avoid response patterns like alternating both key presses. In the *control group*, the effect words were the *category words*, whereas in the *experimental group*, the effect words were the corresponding *exemplar words*. The R-E mapping was counterbalanced in each group, as shown in Table 1. Catch trials were included in 5.0% of the acquisition phase trials, consistent with Experiment 1 of Hommel et al. (2003), and appeared at random positions throughout the block. During catch trials, the catch words "Frucht" (*control group:* German for "fruit") or "Apfel" (*experimental group*: German for "apple") in capital letters appeared instead of the regular effect words, and participants had to respond by pressing the space bar as quickly as possible within 2,000 ms. During the experiment, errors were fed back by displaying an error message on the screen for 500 ms. If the participant responded too slow with an RT longer than 1,000 ms, the trial was classified as an omission, and if the participant responded too quick with an RT shorter than 100 ms, the trial was classified as an anticipation error. In these cases, the error message displayed on the screen for 500 ms either said "zu schnell!" ("too fast!") or "zu langsam!" ("too slow!"), respectively. All erroneous trials were stored and repeated at a random position within the acquisition phase. Each trial was followed by a 2,000 ms intertrial interval before the start of the next trial.

After 200 valid acquisition phase trials, the test phase started with the display of the test phase instructions. These were identical for both groups. An exemplary trial sequence for the test phase is shown in the lower panel of Figure 7. Each trial started with a fixation cross in the center of the screen for 500 ms, followed by a blank interval of 100 ms. In half of the trials, an imperative go-stimulus (one of the two category words, equally frequent) was displayed on the screen for 200 ms, and participants were required to respond with a left or right key press in a free-choice task. In the other half of the trials, the letter string "XXXXX" was displayed in the center of the screen as a no-go stimulus, and participants had to refrain from responding. If participants made any errors, such as anticipation, omission or commission errors (i.e., a response was given in a no-go trial), they were given feedback by displaying an error message for 500 ms, and the trial was repeated at a random position in the block. The error message in case of the commission errors said “please do NOT react”. Go trials and no-go trials were randomly intermixed.

Figure 7

Trial sequence and design of acquisition phase and test phase.



Note. Trial sequence and design of the acquisition phase are shown in the upper panel and trial sequence and design of the test phase are shown in the lower panel. The example in the acquisition phase is of the *experimental group*. The stimulus words are presented in German as in the actual experiment. Figure adapted from Eichfelder et al. (2023).

Design and Analyses. Only valid acquisition trials and correct test phase trials were considered further for analyses. The percentage of errors in no-go trials was measured, participants with more than 20.0% of no-go reactions were excluded from further analyses. Separate one-sample *t* tests were calculated for the *control group* and for the *experimental group*, comparing the individual response biases in each group against a value of 50.0%, which is considered to represent a random choice mode. A two-sample *t* test was calculated for group comparison. The BF was monitored for each *t* test. The BF_{10} values were calculated in R with default settings of a Cauchy prior on the standardized effect size with a scale parameter of $(\sqrt{2})/2$ and a noninformative Jeffreys prior on the variance. In addition to the Bayesian approach, frequentist *t* tests were also included for comparison purposes. Similar results were obtained using both approaches.

3.1.2 Results

Acquisition phase. 2.59% of the trials were recorded as anticipations, 4.70% as omissions, and 0.88% as missed catch trials with an RT exceeding 2,000 ms. These trials were excluded from further analyses. Both response keys were used almost equally often, with an average of 99.96 times per participant for the left key and an average of 100.04 times per participant for the right key. To determine response biases during the acquisition phase, the number of left responses was divided by the number of right responses for each participant, resulting in a range of biases from 0.71 to 1.33.

During the acquisition phase, the mean RT was 380 ms for the *control group* and 403 ms for the *experimental group*. According to Bayesian- as well as frequentist two-sample *t* tests, these values did not differ significantly from each other, $BF_{10} = 0.54$, $t(98) = -1.46$, $p = .148$, $d = -0.29$.

Test phase. Anticipations, omissions, and commission errors (recorded in 0.01%, 0.47%, and 2.35% of all trials, respectively) were excluded from further analyses. The mean RT for go trials was 433 ms in the *control group* and 413 ms in the *experimental group*, and there was no significant difference between the two groups, as evidenced by $BF_{10} = 0.85$ and $t(98) = 1.78$, $p = .078$, and $d = 0.36$.

The dependent variable for subsequent analyses was the percentage of acquisition-congruent choices, which was computed separately for each participant. Mean percentage of congruent choices per group is illustrated in Figure 8, which shows that the percentage of congruent choices in the *control group* is noticeably different from the expected chance level of 50.0%. This suggests an RB in this group, $BF_{10} = 48.01$, $t(49) = 3.69$, $p = .001$, and $d = 0.52$. Therefore, it appears that the *control group* indeed learned R-E associations during the acquisition phase.

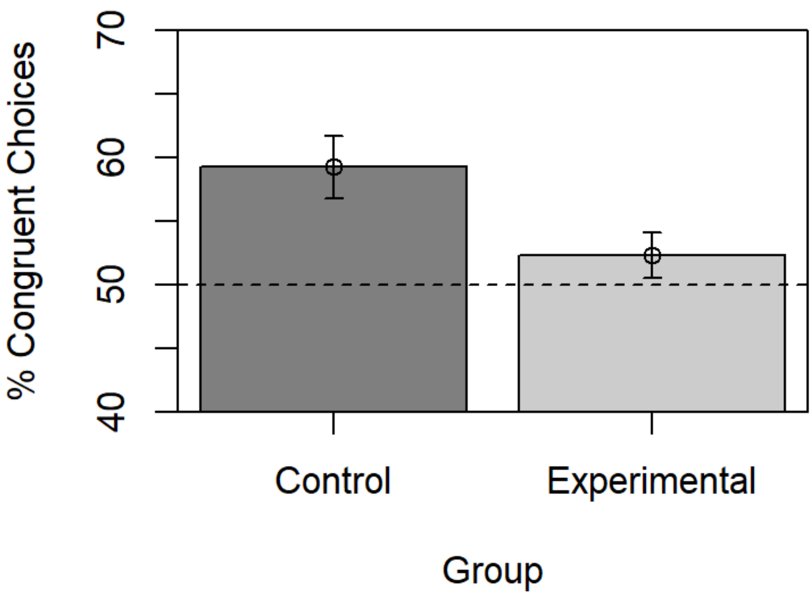
However, as shown in Figure 8, the *experimental group* exhibits a noticeably lower percentage of congruent choices compared to the *control group*. Moreover, the comparison of the two groups provides some indication in favor of the alternative hypothesis of a group difference. This is supported by $BF_{10} = 1.95$ and a significant difference according to the frequentist *t* test, $t(98) = 2.25$, $p = .027$, $d = 0.45$.

The percentage of congruent choices in the *experimental group* is near, and not significantly different from, chance level, $BF_{10} = 0.32$, $t(49) = 1.26$, $p = .212$, $d = 0.18$. These results do not show evidence for a response bias in the *experimental group*.

Considering the available evidence, it seems that there is limited evidence for the notion of (complete) generalization in the *experimental group*, at best. At most, the evidence points to the possibility that the performance of the *experimental group* is not significantly different from chance level.

Figure 8

Mean percentage of congruent choices for each group.



Note. The dashed horizontal line at 50.0% indicates the expected value when choices were made at chance level. The error bars depict the standard errors of the means.

3.1.3 Discussion

The goal of this experiment was to re-assess the question of hierarchical generalization (from exemplars to superordinate categories) in R-E learning, given a pool of mixed evidence in literature plus the results of our pilot experiment. The objective of this experiment was to test for generalization of action effects in a conceptual replication of Hommel et al. (2003, Exp. 1) with the crucial difference of employing a free-choice task in the test phase instead of a forced-choice task as in the original study, because a free-choice task was suggested being more sensitive than a forced-choice task (Herwig et al., 2007; Pfister et al., 2011). Our experiment findings do not indicate any evidence for generalization from exemplar words to their superordinate categories. Instead, the data provide support for the conclusion that R-E associations are limited to stimuli that are identical to those used during the acquisition phase, and not established with semantically related stimuli, such as category words.

First, I need to address a limitation of the present results: They suggest that strong evidence for a response bias was found in the *control group*, using Jeffreys' (1961) suggestions[7]. However, when comparing the evidence for a difference between the two groups, the $BF_{10} = 1.95$ falls in an inconclusive range, with slightly more support for the alternative hypothesis. Additionally, the evidence for the null hypothesis (no response bias) in the *experimental group* can be seen as substantial for the H_0 ($BF_{10} = 0.32$) but near the proposed threshold for inconclusiveness. Still, the results of the frequentist *t* tests do fully reflect the BFs, so that it seems probable that indeed very little, if all, evidence for hierarchical generalization from exemplars to superordinate categories was found.

Secondly, a reason for the discrepancy of our results compared to the results of Hommel et al. (2003, Exp. 1) could lie in a crucial design difference, as the decision was made to employ a free-choice test phase and, subsequently, the percentage of acquisition-congruent choices was selected as the dependent variable. Herwig et al. (2007) suggested that R-E associations are acquired only in free-choice tasks, which are assumed to assess intention-based action control, and not in forced-choice tasks. Nonetheless, Naefgen et al. (2018) and Naefgen and

[7] Jeffreys (1961) proposed a scale for interpreting Bayes factors (BF) as follows: $BF_{10} < 1/10$ indicates strong evidence in favour of the null hypothesis (H0); BF_{10} between 1/10 and 1/3 suggests substantial evidence supporting H0; BF_{10} between 1/3 and 3 is considered inconclusive; BF_{10} between 3 and 10 provides substantial evidence supporting the alternative hypothesis (H1); and $BF_{10} > 10$ indicates strong evidence in favour of H1.

Janczyk (2018) have articulated a dissenting view on this statement. On the other hand, Pfister et al. (2011) demonstrated that R-E associations can be established regardless of the task used in the acquisition phase, as long as the test phase employs a free-choice task. When designing this experiment, the belief was held that an individual response bias might more readily reflect acquired R-E relations in observable behavior as do RTs and PEs. Still, no signs of generalization were observed in the *experimental group*. This topic will be revisited in Chapter 4 and in the general discussion in Chapter 6.

3.2 Experiment 2

Having obtained the results of Experiment 1, a conceptual replication of Hommel et el. (2003, Exp. 1), the question was if generalization could be found in another way than from exemplars to their superordinate categories. Experiment 2 set out to test if participants would represent spatial concepts, that are presented as visual effects, in an abstract, *amodal* way. Therefore, the concepts “up” and “down” were associated as action effects to certain bodily movements (left and right keypresses). During the acquisition phase, the *control group* was exposed to the concept words "up" and "down" as action effects, while the *experimental group* received visual effects (see Table 2 at the beginning of Chapter 3) located either above or below the screen center. During a free-choice test phase, only the concept words were presented as imperative stimuli. Considering the results of Experiment 1, it was expected to find a response bias towards the acquisition-congruent choice in the *control group*, whereas it was not expected to find such a bias in the *experimental group*. This result would suggest that concepts are not represented in an abstract, *amodal* way but rather, as suggested by the results of Experiment 1, in a more *modal* way (i.e., when effects and stimuli are physically identical).

3.2.1 Method

Open Practices Statement. This study was preregistered on aspredicted.org, a pdf is publicly available here: https://aspredicted.org/uy265.pdf. The data are publicly available on osf.io: https://osf.io/y9awz/?view_only=fba046fd8c1c41508c43f037b07172e0.

Participants. 111 students from the University of Bremen participated for course credit. After 11 participants were excluded from further analyses due to exclusion criteria (see below), the total sample consisted of N = 100 participants (mean age = 24.99 years; 72 females, 28 males, 0 non-binary; 88 right-handed, 11 left-handed, 1 ambidextrous). All participants reported to be either native German speakers or to have advanced written and spoken knowledge of German and normal or corrected-to-normal vision. All participants were naïve to the hypotheses of this experiment.

The exclusion criteria were the same as in Experiment 1. 10 participants had to be replaced because they did not press the left and the right key at least 80 times each (out of a maximum of 100) during the acquisition phase. Additionally, one participant who responded in more than 20.0% of the no-go-trials had to be replaced. The sample size was determined applying Bayesian sequential sampling based on BFs, employing the same ex ante stopping rules as described in Experiment 1.

The monitoring of the BFs and the assignment of the participants to each of the combinations of the counterbalancing variables (group and R-E Mapping) was identical to Experiment 1. All participants took part in the experiment in a single session of approximately 35 - 45 minutes.

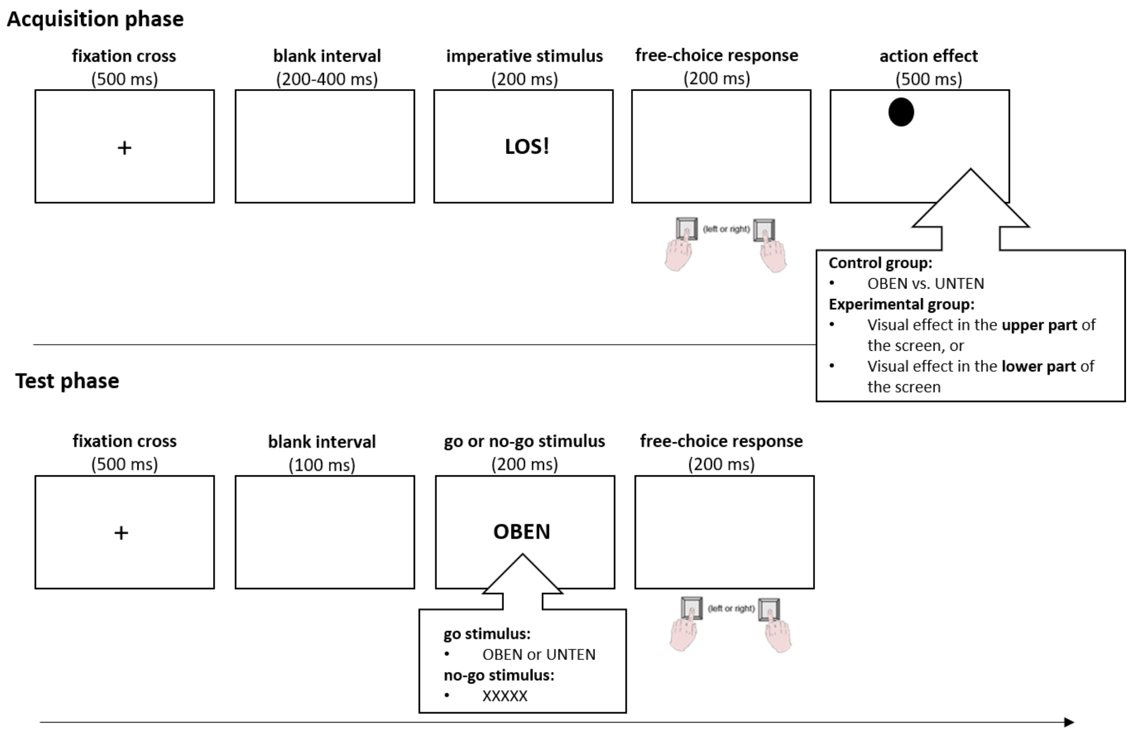
Stimuli and Apparatus. Stimulus presentation and response collection was identical to Experiment 1. The concept words 'UP' and 'DOWN' in German or a visual stimulus (a white dot on a black background) in the upper or lower part of the screen served as stimuli (see Table 2, middle panel). The concept words were written in white color against a black screen background, with a height of approximately 1 cm. The "D" and the "L" key of a standard QWERTZ keyboard served as left and right response keys, respectively, and the spacebar served as the response key in catch trials.

Task and Procedure. The procedure was identical to Experiment 1. Again, participants were first verbally and by written instructions informed about the acquisition phase task. The course of each trial was also identical to Experiment 1. Each key would produce a different visual effect, depending on group and mapping. Participants received the same acquisition phase instructions as in Experiment 1. The catch stimulus was either the word "MIDDLE" in German or a white dot in the screen center, depending on the group. Erroneous trials were defined and treated as in Experiment 1.

As in Experiment 1, participants received written instructions regarding the test phase task after having completed the acquisition phase task. The course of the test phase trials was again identical to Experiment 1. The imperative stimulus in each trial was one of the concept words ('UP' or 'DOWN' in German), demanding a left or right response. Once more, half of the trials were designated as no-go trials, in which the letter string "XXXXX" was displayed at the center of the screen, signifying that participants needed to abstain from responding. Again, all invalid trials were stored and repeated.

Figure 9

Trial sequence and design of acquisition phase and test phase.



Note. Trial sequence and design of the acquisition phase are shown in the upper panel and trial sequence and design of the test phase are shown in the lower panel. The example in the acquisition phase is of the *experimental group*. The stimulus words are presented in German as in the actual experiment. Note, that during the experiment the colors were inverted, i.e., the stimuli were presented in white against a black background.

The trial sequence of the ***acquisition phase*** is visualized in Figure 9 (upper panel). Each keypress triggered the appearance of a white effect against a black background (e.g., R1 → E1; R2 → E2) in the screen center for 500 ms. The R-E mapping was reversed for half of the participants (*n* = 25) in each group. In the *control group*, these effect words were the concept words. In the *experimental group*, the effects were the appearance of a white dot in the upper or lower part of the screen, respectively. In 5.0% of the acquisition phase trials, the catch stimulus "MIDDLE" in German (*control group*) or a centrally presented white dot (*experimental group*) appeared instead of E1 and E2, respectively. The catch trials were introduced at arbitrary locations throughout the acquisition phase, the catch response was identical to Experiment 1. All errors were treated as in Expeeiment 1.

The trial sequence in the ***test phase*** is also visualized in Figure 9 (lower panel). In half of the 200 trials, the two concept words ('UP' and 'DOWN' in German) appeared as go stimuli and required a left or a right response in a free-choice task, that is, participants were allowed to choose freely between both keys in these trials. Anticipation, omission and commission errors were again fed back to the participants by displaying an error message for 500 ms, then stored and repeated at a random position later in the block. Go trials and no-go trials were randomly intermixed, as in Experiment 1.

Design and Analyses. The trials considered for further analyses and all conducted analyses were identical to Experiment 1.

3.2.2 Results

Acquisition phase. Omissions were recorded in 3.68% of all trials, anticipations in 3.82%. Catch trials were missed in a 0.78% of all trials. The two response keys were chosen about equally often, with the left key being pressed an average of 100.08 times per participant and the right key being pressed an average of 99.92 times per participant. Individual response biases ranged from 0.71 to 1.44. Mean RTs were 354 ms for the *control group* and 358 ms for the *experimental group*. A two-sample t test revealed no significant difference, $t(98) = -0.26$, $p = .793$, $d = -0.05$.

Test phase. Trials with anticipations (0.02%) and omissions (0.30%) were excluded from further analyses. Commission errors were recorded in a 2.17% of all trials. Mean RT in go trials was 419 ms for the *control group* and 406 ms for the *experimental group*. The mean percentages of congruent choices per group are visualized in Figure 10.

The one-sample t test within the *control group* showed a significant response bias, $t(49) = 3.12$, $p = .003$, $d = 0.44$, and the $BF_{10} = 10.57$ further supports the alternative hypothesis. It appears that this group has acquired an R-E association during the acquisition phase.

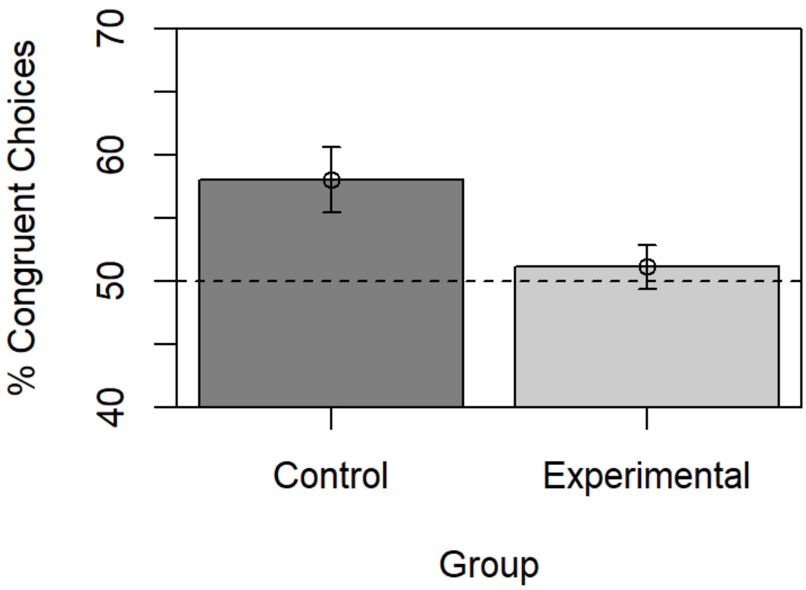
The two-sample t test was significant, $t(98) = 2.23$, $p = .028$, $d = 0.45$, and the corresponding $BF_{10} = 1.87$ yields further evidence towards the alternative hypothesis of a group difference, although in an inconclusive range.

This latter result speaks against an abstraction of the action effects in the *experimental group*. As in Experiment 1, there was also a closer analysis of the *experimental group*, comparing its performance to chance level. The response bias did not differ significantly from 50.0%, $t(49) = 0.64$, $p = .526$, $d = 0.09$, and the

$BF_{10} = 0.18$ provides evidence favoring the null hypothesis. Thus, no signs of abstraction could be observed in this group.

Figure 10

Mean percentage of congruent choices in the control and the experimental group.



Note. The dashed horizontal line at 50.0% indicates the expected value when the response choice was entirely random and the error bar displayed for each group represents the standard error of the means.

3.2.3 Discussion

The results of Experiment 2 do overall confirm the results of Experiment 1, although the response bias in the *control group* is descriptively less pronounced than in the control group of Experiment 1. Still, a small but significant difference between groups was found in this experiment, confirming the findings of Experiment 1: As the bias towards acquisition-congruent choices is not of the same size in both groups and a separate analysis of the (relative) experimental groups shows that there is no significant RB in these groups, it seems as if the concept words “up” and “down” are not represented in an abstract manner (i.e., no semantic extension from a visual effect to a concept word seems to have taken place).

Nevertheless, the limitations regarding the strength of evidence addressed in the discussion part of Experiment 1 are even more relevant here, with an RB in the *control group* (BF_{10} = 10.57) that ranges close to the threshold from strong to substantial evidence for the H_1, according to Jeffreys’ (1961) suggestions. The evidence for a *difference between groups* (BF_{10} = 1.87) is in an inconclusive range, however, according to these suggestions, the evidence for the null hypothesis (no response bias) in the *experimental group* (BF_{10} = 0.18) can be interpreted as substantial. As in Experiment 1, the results of all three frequentist *t* tests do reflect the BFs though, so that very little, if any, evidence for an abstract (*amodal*) representation of the concepts “up” and “down” is suggested by the data.

In total, the data of Experiment 2 seem to confirm the conclusions of Experiment 1: No evidence for generalization was found, and that is true for the *hierarchical generalization* from exemplars to superordinate categories as well as for the *semantic representation* of the concepts “up” and “down”.

3.3 Experiment 3

Experiments 1 and 2 did not reveal evidence for generalization towards more abstract (*amodal*) representations in R-E learning, neither in the sense of generalization from exemplars to superordinate categories nor in the sense of a semantic representation of visually presented. Experiment 3 was conducted to include another variation of abstraction into our line of experiments. This experiment investigates the question whether visual information in the form of pictures is translated to the corresponding semantic meaning. This seems particularly promising, because Dudschig et al. (2021), in a study investigating if the perception of different surface materials interacts with linguistic processing in the same way as object or sound perception, reported that "surface material information is quickly integrated with other information sources—in this specific case, linguistic information […]" (p. 12). The visual stimuli used in that study were pictures displaying different material characteristics (e.g., a calm water surface for the characteristic "smooth"). Participants were first shown a short sentence containing material information word for word (e.g., "this material is smooth"), followed by a visual stimulus that can either be congruent or incongruent with the sentence information. Participants then had to choose if sentence and picture matched or mismatched. The results of Dudschig et al., against the background of literature on multisensory integration (e.g., Koelsch et al., 2004; Proverbio & Riva, 2009; Spence, 2011), suggest that visual and linguistic information are integrated at an early stage, leading to the assumption that a similar integration could occur if simple pictures and corresponding linguistic labels would be used as effects respectively stimuli in a third experiment with the same experimental setup as Experiments 1 and 2. If generalization can be observed at all in an R-E learning setup, it should be observable in an abstraction from pictures to the corresponding semantic meaning.

Considering the results of Experiment 1 and 2 it was of additional interest to find out if a) the participants really do acquire the correct R-E relations during the acquisition phase and if b) they are influenced by this knowledge while performing the test phase task. Thus, a post-session questionnaire with two multiple-choice questions regarding the R-E relation during the acquisition phase and an open question regarding response strategies during the test phase was administered to the participants directly after the session (see Appendix B).

3.3.1 Method

Open Practices Statement. This study was preregistered on aspredicted.org, an anonymized version of the pre-registration is available via https://aspredicted.org/bq3ay.pdf. The data are publicly available on osf.io: https://osf.io/mdxza/?view_only=d196a061984544ad8d400472097b6b1a.

Participants. 109 students from the University of Bremen participated for course credit or monetary compensation. 9 participants were excluded due to exclusion criteria and replaced. Again, the total sample consisted of N = 100 participants (mean age = 25 years; 68 females, 32 males, 0 non-binary; 86 right-handed, 14 left-handed, 0 ambidextrous). All participants fulfilled the same criteria as described in Experiments 1 and 2. Sample size was determined as in Experiments 1 and 2. All participants took part in the experiment in a single session of approximately 35 - 40 minutes.

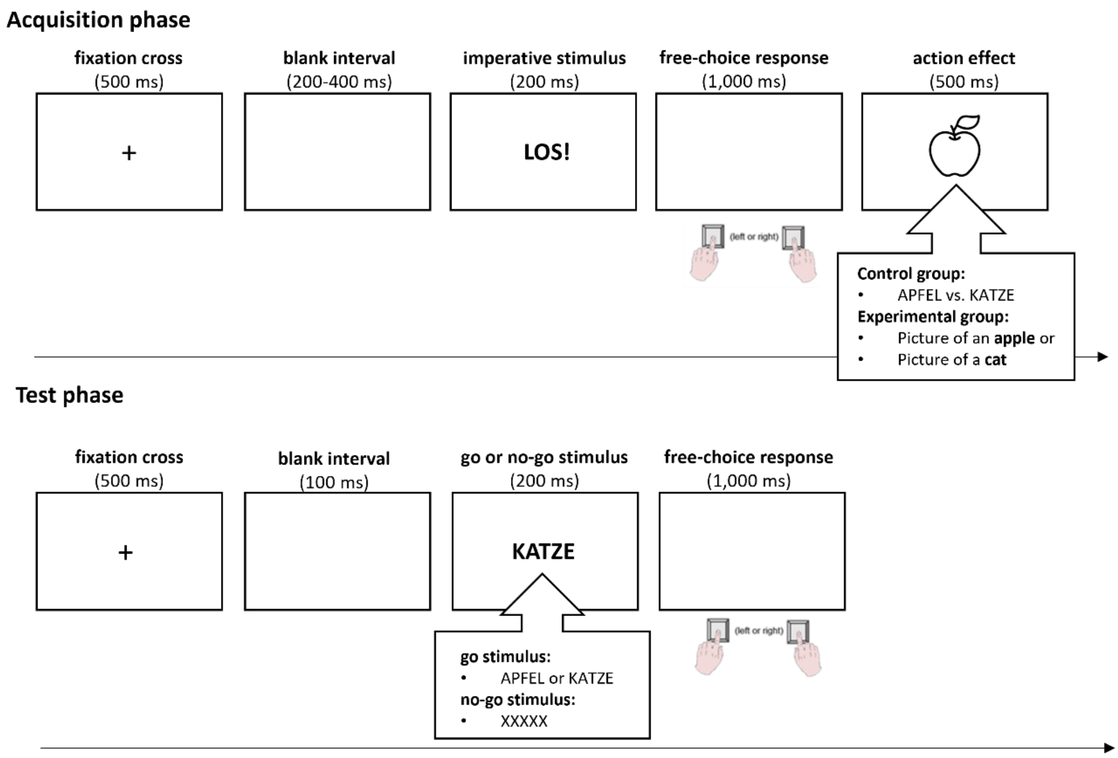
Stimuli and Apparatus. Stimulus presentation and response collection was identical to Experiments 1 and 2. The words 'CAT' and 'APPLE' in German or the corresponding picture of either a cat or an apple in the screen center served as stimuli. The words were written in white color against a black background, with a height of approximately 1 cm. The "D" and the "L" key of a standard QWERTZ keyboard served as left and right response keys, respectively, and the spacebar served as the response key in catch trials.

Task and Procedure. The procedure was identical to Experiments 1 and 2. Participants were instructed to press the space bar as fast as possible when the catch stimulus ("HOUSE" in German or the picture of a house) appears in the catch trials. As in Experiments 1 and 2, all erroneous trials (responding faster than 100 ms or slower than 1,000 ms; failed responses in catch trials) were stored and repeated later in the block. The lower panel of Table 2 gives an overview over the effects used in Experiment 3.

As in Experiments 1 and 2, participants received written instructions about the test phase task after having completed the acquisition phase. The course of the test phase trials was identical to Experiments 1 and 2. The imperative stimulus in each trial was one of the two words ('CAT' or 'APPLE' in German), demanding a left or right response. Again, half of the trials were considered no-go-trials in which a meaningless letter string ("XXXXX") appeared in the screen center, indicating that participants had to withhold any response. All erroneous trials (too fast and too slow reactions; reactions in no-go trials) were stored and repeated.

Figure 11

Trial sequence and design of Experiment 3.



Note. Trial sequence and design of the acquisition phase are shown in the upper panel, and trial sequence and design of the test phase are shown in the lower panel. The example in the acquisition phase is of the *experimental group*. All stimulus words are presented in German.

The trial sequence of the ***acquisition phase*** is visualized in Figure 11 (upper panel). Each keypress triggered the appearance of a white effect against a black background (e.g., R1 → E1; R2 → E2) in the screen center for 500 ms. The R-E mapping was reversed for half of the participants in each group. In the *control group*, these effects were the words “APPLE” or “CAT” in German. In the *experimental group*, the effects were the pictures of an apple or a cat (white pictures on a black background), respectively. In 5.0% of the acquisition phase trials, the catch stimulus “HOUSE” in German (*control group*) or a centrally presented picture of a house (*experimental group*) appeared instead of E1 and E2, respectively. Catch trials and all types of errors were treated as in Experiments 1 and 2.

A typical trial sequence of the ***test phase*** is visualized in Figure 11 (lower panel). In half of the 200 trials, one of the two words ('CAT' and 'APPLE' in German) appeared as go stimuli and required a left or a right response in a free-choice task. The other half were no-go trials as in the first two experiments. Error messages and error handling was identical to Experiments 1 and 2.

Design and Analyses. The trials considered for further analyses and all conducted analyses were identical to Experiments 1 and 2.

3.3.2 Results

Acquisition phase. Omissions were recorded in 3.13% of all trials, anticipations in 2.81%. Catch trials were missed in 0.17% of all trials. The two response keys were chosen about equally often, with the left key being pressed an average of 99.52 times per participant and the right key being pressed an average of 100.48 times per participant. Individual response biases during the acquisition phase ranged from 0.75 to 1.47. Mean RTs were 381 ms for the *control group* and 370 ms for the *experimental group*. A two-sample t test revealed no significant difference, $t(98) = 0.68$, $p = .500$, $d = 0.14$.

Test phase. Trials with anticipations (0.01%) and omissions (0.44%) were excluded from further analyses. Commission errors were recorded in a 1.81% of all trials. Mean RT in go trials was 417 ms for the *control group* and 419 ms for the *experimental group*. A two-sample t test on test phase RTs revealed no significant difference, $t(98) = -0.10$, $p = .918$, $d = -0.02$. The mean percentages of congruent choices per group are visualized in Figure 11.

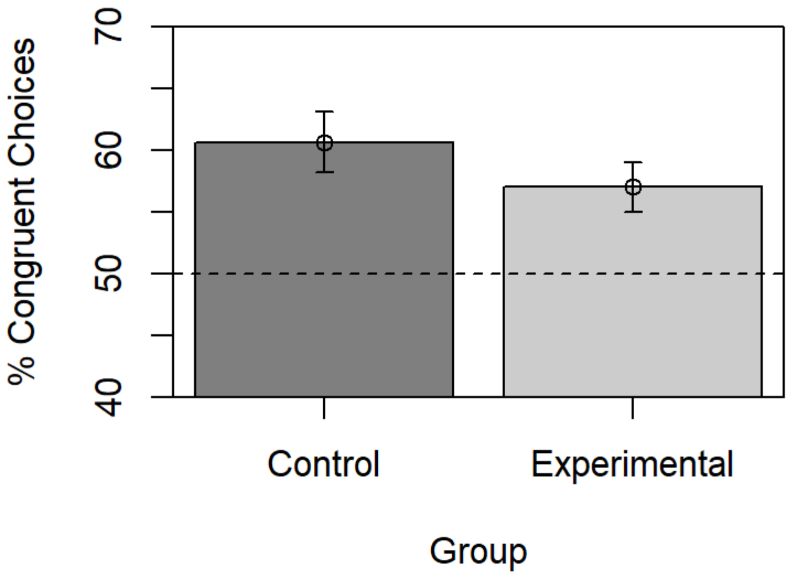
The one-sample *t* test within the *control group* showed a significant response bias, $t(49) = 4.33$, $p < .001$, $d = 0.61$, and the $BF_{10} = 301.70$ further supports the alternative hypothesis. It appears that this group has acquired an R-E association during the acquisition phase.

The two-sample *t* test did not reach significance, $t(98) = 1.14$, $p = .257$, $d = 0.23$, and the corresponding $BF_{10} = 0.37$ does not speak for a difference between the groups, although it is just located in an inconclusive range.

As in Experiments 1 and 2, the *experimental group* was analyzed more closely, comparing its performance to chance level. The response bias differs significantly from 50.0%, $t(49) = 3.48$, $p = .001$, $d = 0.49$, and the $BF_{10} = 26.64$ provides evidence favoring the alternative hypothesis. Thus, abstraction seems to be present in this group as well as in the control group, and arguably, the RB was of the same size in both groups.

Figure 11

Mean percentage of congruent choices per group in Experiment 3



Note. The dashed horizontal line at 50.0% indicates the expected value when the response choice was entirely random and the error bar displayed for each group represents the standard error of the means.

Questionnaire results

Within the experimental group, 54.0% (27 people) have reported to have used some sort of response strategy during the test phase task, whereas 46.0% (23 people) have reported a random response mode. Of the 54.0% that have used a response strategy, 51.8% (14 people) reported to have used a strategy that was explicitly related to the acquisition phase. 25.9% (7 people) reported to have transferred the *expectations* created by the acquisition phase instructions to the test phase task (although this was not indicated by the test phase instructions). 18.5% (5 people) of the participants reported the use of a response strategy, but unrelated to the acquisition phase task. 2,7% (1 person) reported to have used a strategy without describing it. The R-E relation was reported correctly by 92.0% of the participants.

Within the *control group*, 72.0% (36 people) of the participants reported to have used a response strategy during the test phase while 28.0% (14 people) reported to have responded by chance. Of the 72.0% that have used a response strategy, 52.8% (19 people) reported to have used a strategy that was explicitly related to the acquisition phase. 11,1% (4 people) reported to have transferred the *expectations* created by the acquisition phase instructions to the test phase task, 2.8% (1 person) reported to have thought that something was expected from them, but without a relation to the acquisition phase task. 30.6% (11 people) of the participants reported the use of a response strategy, but unrelated to the acquisition phase task. 2.8% (1 person) reported to have used a strategy without describing it. The R-E relation was reported correctly by 90.0% of the participants.

3.3.3 Discussion

The results obtained in Experiment 3 reveal that participants seem to generalize from pictures to the corresponding semantic content, in contrast to the generalization from exemplars to superordinate categories as in Experiment 1 and from visually presented locations to the corresponding concept words as in Experiment 2. The difference in the results can possibly be explained in terms of the *semantic congruency effect.* Semantic congruency typically means that pairs of visual and auditory stimuli can be congruent or incongruent in terms of their identity and/or their meaning (Spence, 2011). In research on memory, for example, the semantic congruency effect refers to the discovery that individuals demonstrate improved memory for items presented in a context that aligns with, rather than contradicts, their existing semantic knowledge (e.g., Bein et al., 2015). This effect is investigated in lab experiments for example by assessing the outcomes of displaying congruent or incongruent visual information and environmental sounds. According to Spence (2011), an example for this is a barking sound displayed together with a picture of either a dog (congruent) or a cat (incongruent), as used in a study by Hein et al. (2007). Considering this and the study by Koch and Kunde (2002) described in Section 1.4.2, it appears highly likely that *phonological recoding* of the presented images takes place upon their exhibition to the participants. Since the stimuli utilized in Experiments 1 and 2 preclude such an occurrence, the disparity in the results may potentially be elucidated by the phenomenon of phonological recoding.

The questionnaire results seem to back the R-E learning effect that took place in the experimental group, as not only 92% of the participants reported the R-E relations correctly but also a majority, compared to the control group, reported some sort of response strategy used in the test phase task. This result brings up the question of the nature of the knowledge that is learned during the acquisition phase and led to the exploratory analyses described in the next section.

4 Exploratory analyses for Experiments 1 – 3

Looking at our results and considering other recent findings (Sun et al., 2020, Exp. 1), it seems possible that the individual response bias as a measure does not reflect R-E associations as described by Elsner and Hommel (2001), but rather knowledge of a different nature. In Experiment 1 of Sun et al., participants performed an induction experiment with a free-choice test phase and administered a questionnaire after the test phase to evaluate participants' awareness of the acquired R-E relations and the effect of task instructions on individual response strategies. A vast majority of the participants did indeed report the R-E relations correctly, regardless of having received detailed information on these relations beforehand or not. A response bias was observed in both groups. Nevertheless, on an individual level, it was discovered that the group-level response bias observed by Sun et al. was primarily due to a small number of participants with very large response biases, whereas the majority performed at or near chance level and did not show a response bias. In conclusion, a *bimodal distribution* of the percentages of congruent choices was observed by the authors. Sun et al. hypothesized that free-choice tasks, different from forced-choice tasks, foster the usage of *deliberate response strategies* by the participants. Considering this, the bimodal distribution obtained in their Experiment 1 does not point towards an *automatic* nature of the effect, as assumed in "typical" R-E learning experiments (e.g., Elsner & Hommel, 2001), but rather towards *propositional knowledge* (see Mitchell et al., 2009) with respect to the acquisition phase that was inferred during the test phase by those participants with a very large response bias. Mitchell et al. question the traditional conviction about associative learning according to which the acquisition of knowledge about events in the environment and their interrelations occurs through the mere establishment of associations between the mental representations of those events (e.g., Pavlov, 1927). According to this "classic" view, associative learning is "[…] an unconscious, automatic process that is divorced from higher-order cognition" (Mitchell et al., 2009, p. 183), whereas, according to a propositional approach to learning, “[…] associative learning depends on effortful, attention-demanding reasoning processes. The process of reasoning about the relationship between events produces conscious, declarative, propositional knowledge about those events.” (Mitchell et al., 2009, p. 186). Considering the results of Sun et al. (2020, Exp. 1) in this light, the participants with an almost perfect RB seem to have been consciously aware not only of the acquired R-E relations, but also of the instructions they received during the acquisition phase. Thus, it is not likely that unaware conditioning has taken place, and the knowledge used during the test phase task seems to be rather of propositional nature.

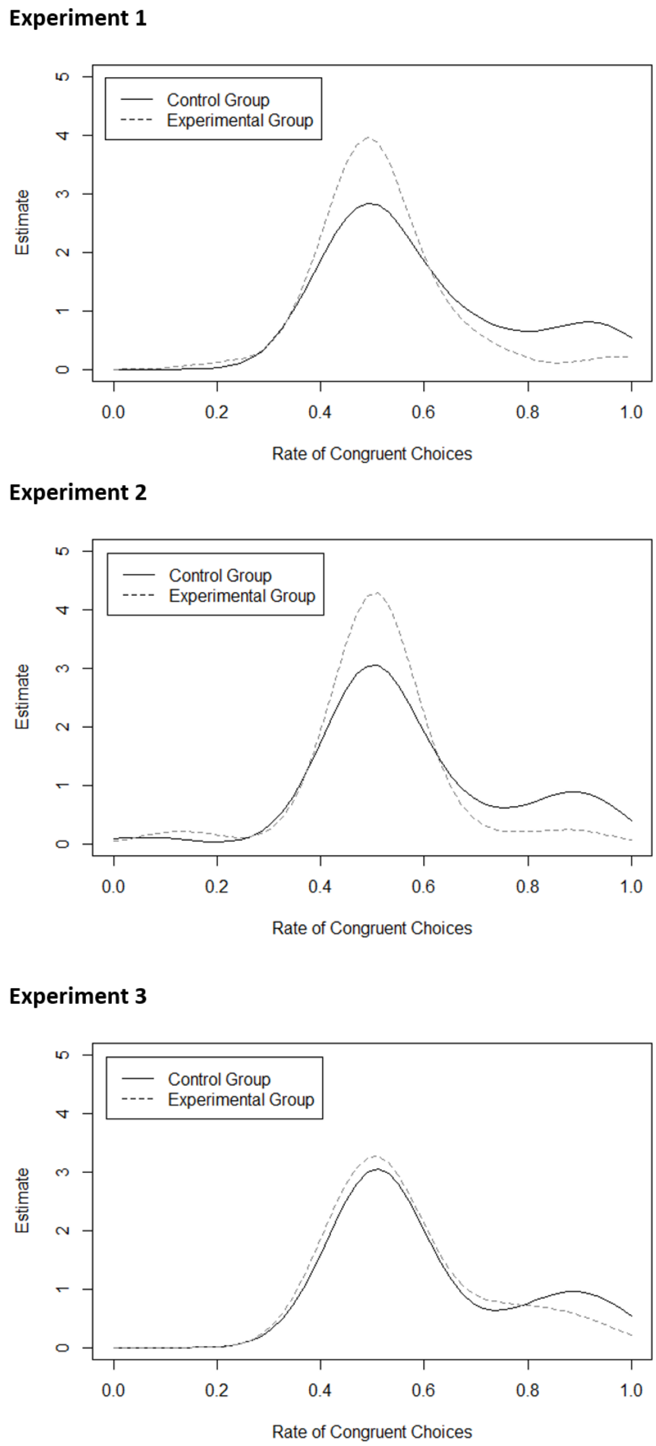
In a second study, Sun et al. (2022) employed a design with acquisition phase and test phase combined in one trial. Their objective was to differentiate the direct consequences of inferred causal relations (i.e., the usage of *propositional knowledge*) from the impacts of long-lasting bidirectional associations (Sun et al., 2022). According to the authors, the fact that effects can “[…] occur after very limited learning and be demonstrated within a very limited test phase” (p. 8) do point more into the direction of *propositional knowledge* rapidly being inferred by the participants than towards the occurrence of *automatic learning*. Considering their results and looking at the distribution of the data of Sun et al. (2020, Exp. 1), the following reasoning could also apply to the distribution of the data of Experiments 1 - 3: Assuming that the acquisition of R-E associations occurs *automatically* and that the stimuli automatically elicit a response tendency towards the associated response, the distribution of the percentage of congruent choices would be expected to be *unimodal* with the peak shifted into the direction of > 50%.

4.1 Results

In light of this, the respective distributions were visualized in kernel density plots (see Figure 12) for a better understanding. Additionally, the percentages of congruent choices in the control groups and experimental groups of Experiments 1 – 3 were examined, respectively, by calculating the bimodality coefficient (BC; SAS Institute Inc., 1990; see also Freeman & Dale, 2013; Pfister et al., 2013). Then the respective values were compared with the threshold value of $BC_{crit} = 0.55$. Higher values of BC indicate a *bimodal distribution*, while lower values indicate a *unimodal distribution*.

Figure 12

Kernel density plots for Experiments 1 – 3



Note. The plots show the distribution of the data of Experiment 1, 2 and 3, respectively. In all three plots, the distribution of the control group is visualized by a continuous line while the distribution of the experimental group is visualized by a discontinuous line.

The upper panel of Figure 12 shows the kernel density plot calculated with the data of Experiment 1. The distribution of the rate of congruent choices in the *control group* indicates a bimodal distribution: A considerable number of participants seems to have chosen their responses randomly, as indicated by the peak of the control group distribution at 50%. The plot also shows a second, smaller peak around 90%, indicating that some *control group* participants show a very high rate of congruent choices. Employing the method outlined by Kieslich et al. (2022), BCs of 0.65 and 0.50 were obtained for the *control* and *experimental group*, respectively. These results provide further support for the existence of a bimodal distribution in the *control group*.

The middle panel of Figure 12 shows the kernel density plot calculated with the data of Experiment 2. At a first glance, it seems as if the dependent variable in the *control group* is bimodally distributed, as in Experiment 1. This was not statistically confirmed by the BC though: $BC_{control} = 0.30$; $BC_{experimental} = 0.11$. The BC of the *control group* does clearly not reach the threshold of 0.55, from which on it could be affirmed that a bimodal distribution is present[8]. Yet, the mere visual impression is certainly bimodal. The lower panel of Figure 12 shows the kernel density plot calculated with the data of Experiment 3. The plot clearly indicates a bimodal distribution for the *control group*, whereas the *experimental group* does not seem to be distributed bimodally. Calculating the respective BCs though, data of both groups seem to be distributed bimodally in this experiment, $BC_{control} = 0.71$,

[8] The *dip test of unimodality* (Hartigan & Hartigan, 1985), a test calculating a *p*-value that indicates the likelihood of the data being unimodal, applied to the data of Experiment 2, indicates that there isn't significant evidence to reject the null hypothesis of unimodality as well.

$BC_{experimental}$ = 0.67. In conclusion, visually, the respective control groups show a coherent pattern and seem to be bimodally distributed in all three experiments, although the statistical tests do not confirm this for Experiment 2.

4.2 Discussion

The results of the exploratory analysis of Experiment 1 point into the same direction as the results of Sun et al. (2020, Exp. 1): The data of the control group seem to be bimodally distributed, so that a few participants with an almost perfect RB seem to drive the overall effect in this group. The highest peak in the kernel density plot (Figure 12, upper panel) is observable around chance level, meaning that the majority of the participants seem to have responded randomly. Considering Mitchell et al. ‘s (2009) assertions on the nature of the knowledge acquired by associative learning, it seems possible that those participants with an almost perfect RB have acquired *propositional knowledge* about the R-E relations during the acquisition phase and about rules, sometimes inferred from the acquisition phase instructions, they believed to be connected to these relations (e.g., to equally distribute the left and right key presses, but without patterns). In the opinion of Mitchell et al., the influence of the acquisition phase instructions, given both verbally and on-screen, is further proof for a propositional rather than associative nature of the acquired knowledge: As a study of Lovibond (2003) showed that knowledge acquired by experience and verbally acquired knowledge are represented in a similar way, the authors conclude that “[…] the knowledge acquired by experience is propositional in nature” (Mitchell et al., 2009, p. 190).

It is thus highly probable that the knowledge acquired by the control group by the experience made during the acquisition phase is of propositional nature.

The results of the exploratory analysis of Experiment 2 do not contradict these conclusions. The R-E learning effect was quite small even in the control group (see Section 3.2.2), pointing towards the eventuality that the abstraction from visual stimuli to corresponding spatial concepts could merely be impossible to observe with this kind of experimental design (this argument will be reiterated in Chapter 6.1). In this case, the absence of a bimodal distribution, as indicated by the respective BCs, does not necessarily mean that the nature of the learned knowledge is not propositional. Moreover, a bimodal distribution is clearly visible for Experiment 2 in the respective kernel density plot (see middle panel of Figure 12).

Concerning Experiment 3, the results of the exploratory analysis show that both groups seem to be distributed bimodally (see lower panel of Figure 12), although visually this seems only be true for the control group. This points towards the presence of individuals with very high RBs in both groups. As discussed in Chapter 3.3.3, the R-E learning effect in the experimental group of Experiment 3 hints at the fact that abstraction in the sense of generalization from pictures to their corresponding semantic meaning indeed seems to be observable in experiments following the *induction logic*. Following again the reasoning of Mitchell et al. (2009), as in the discussion of the exploratory analysis of Experiment 1, it is probable that the knowledge acquired by both groups during the respective acquisition phase is of propositional nature and was inferred during the test phase.

Additionally, the questionnaire results of Experiment 3 also point towards the usage of propositional, rule-based knowledge in both groups, as the majority of the participants reported to have used some sort of response strategy (see Section 3.2.2).

Taken together, the exploratory analyses of Experiment 1 – 3 do point towards a propositional nature of the acquired knowledge. Considering the rather small effect sizes obtained in all three experiments, it would be more informative for future research in the field of R-E learning to see, if a) the average effect size can be increased and b) the bimodal distribution of the data would still be present with larger effect sizes. For this reason, Experiment 4 was designed in an attempt to increase effect sizes in experiments following the *induction logic*.

5 A methodological advancement: Experiment 4

The reasons why Experiment 4 was designed, which differs both methodically and in terms of the research question from the presented series of experiments, were threefold: On one hand there is the fact that plenty of research on R-E learning employs free-choice acquisition phases (e.g., Eder et al., 2015; Elsner & Hommel, 2001; Hommel et al., 2003; Sun et al., 2020). Herwig et al. (2007) even argue, that R-E learning can exclusively occur when the task is free-choice, and a study of Herwig and Waszak (2009) backs this claim empirically, but rather small learning effects are reported (e.g., Elsner & Hommel, 2001; Eichfelder et al., 2023; Janczyk et al., 2023. Moreover, Eder and Dignath (2017) reported more rapid learning of R-E associations in a condition where the effect had to be produced intentionally, leading to the question if R-E learning can be facilitated by turning the action effects task-relevant. More evidence for an R-E learning effect obtained in a forced-choice acquisition phase task comes from Wolfensteller and Ruge (2011), who found such an effect in a series of four experiments. Note, though, that the authors did not instruct participants to produce a certain effect during the acquisition phase.

Secondly, results from REC experiments show a pronounced REC effect with task-relevant action effects: For example, using wheel rotations as the to-be-performed action and the (corresponding or not) moving of an airplane display as action effect, Janczyk et al. (2015) reported that the obtained REC effects in three experiments were larger when participants had to pay attention to the action effects than when they did not. With this result, the authors confirmed a finding of Janczyk et al. (2012), who suggested that attention to action effects is one of two crucial factors to determine the REC effect (Janczyk et al., 2015). The notion of attention being crucial when obtaining this kind of effects goes back to the concept of intentional weighting (Ansorge, 2002; Memelink & Hommel, 2013) which captures the notion that individuals possess the ability to evaluate the relative significance of representations and, consequently, enhance or diminish their influence (Janczyk et al., 2015). A third argument that contributed to the development of Experiment 4 is motivation research, more precisely the motivational power of game-like elements, postulated, for example, by Sailer et al. (2013; p. 28). The authors defined gamification as follows: “The basic idea of gamification is to use the motivational power of games for other purposes not solely related to entertaining purposes of the game itself. This idea originally coming from marketing spread to different contexts involving business and education. Gamification environments are currently used with aims as diverse as influencing environmental behavior, motivating for physical workout, fostering safe driving behavior, or enhancing learning in schools and training" (Sailer et al., 2013). Considering the rather small effect sizes (mentioned above) obtained with rather "boring" acquisition phase tasks (e.g., pressing a left or right key and producing a high or low pitch tone, respectively), the idea emerged that applying this definition of Gamification to the lab context by designing a gamified task with different levels of difficulty would also lead to an enhanced R-E learning effect compared to a "classical" induction task (as in Elsner & Hommel, 2001, for example).

Taken together, these three arguments led to the main hypothesis of our experiment: In a group with task-relevant action effects during the learning phase and a game-like element to the task, the R-E learning effect will be more pronounced compared with a control group performing a typical induction task. If this were true, this would provide a tool for future investigation of generalization and abstraction with larger a priori effects. More specifically, a *control group*, whose acquisition phase task was to produce high and low pitch tones by pressing the left or right "ctrl" key (classical induction task) was compared with an *experimental group*, whose acquisition phase task was to reproduce a tone sequence by producing high and low pitch tones with the abovementioned keys. As the sequence had to be reproduced, the action effects (the tones) were task-relevant, and the participants' attention had to be focused on the key-tone relation. As a game-like element, an increasing difficulty of sequence reproduction was implemented. The sequences started out with a length of two tones. After having reproduced three of these two-tone sequences correctly, the participant "levels up", and one tone was added to the sequence (until a maximum length of five tones). After each erroneous trial, the sequence length was reduced by one tone and the participant again had to perform the task correctly three times in a row to "level up". Note that each sequence is put together randomly and can consist of any combination of the high and low pitch tone.

5.1 Method

Open practices statement. This study was pre-registered on aspredicted.org, a pdf is publicly available at: https://aspredicted.org/uw862.pdf. The data are publicly available on osf.io: https://osf.io/ny6bq/?view_only=2d23294db7f549c487fca623cfd7ea62.

Participants. 100 students of the University of Bremen participated for course credit or monetary compensation, three people of the Bremen area participated out of interest. Three participants were excluded due to exclusion criteria and replaced. The final sample consisted of $N = 100$ participants (34 male, 64 female, 0 non-binary; mean age = 24.45 years; 90 right-handed, 8 left-handed, 2 ambidextrous). All participants fulfilled the same criteria as described in Experiments 1 - 3. Sample size was determined as in Experiments 1 - 3. All participants took part in the experiment in a single session of approximately 40 minutes.

Participants. Sample size was determined as in Experiment 1 – 3. The stopping rules and thresholds do not differ from those applied in Experiment 1 – 3. The study involved 100 participants who were randomly assigned to one of four experimental conditions deriving from the possible combinations of the counterbalancing variables: Group (Control/"Classic" vs. Experimental/"Intentional") and tone-key mapping during the acquisition phase within each group. 25 participants were assigned to each condition. All participants took part in the experiment in single sessions of approximately 35 - 45 minutes.

Stimuli and Apparatus. Stimulus presentation and response collection were performed using a typical personal computer linked to a 17-inch cathode ray tube (CRT) display. As action effects, two sinusoidal tones (400 Hz [low frequency] and 800 Hz [high frequency], duration: 200 milliseconds) were presented to the participants via speakers connected to the PC. The speakers were calibrated before each experimental session so that the tones were perfectly audible but not disturbingly loud. During the test phase, these tones were utilized as stimuli indicating "go" actions. Furthermore, a bell ringing sound lasting approximately 200 ms was employed as the stimulus indicating a "no-go" action (i.e., to withhold all responses). The left and right "ctrl" key of a standard QWERTZ keyboard served as left and right response keys, respectively.

Task and Procedure. The experiment was conducted in sound-attenuated cabins with dimmed light. The trial sequence of the acquisition phase is shown in Figure 13, upper panel. As the nature of the acquisition phase task ("classic" induction logic task vs. "intentional" learning task) was the crucial manipulation in Experiment 4, the trial sequence differs for each group.

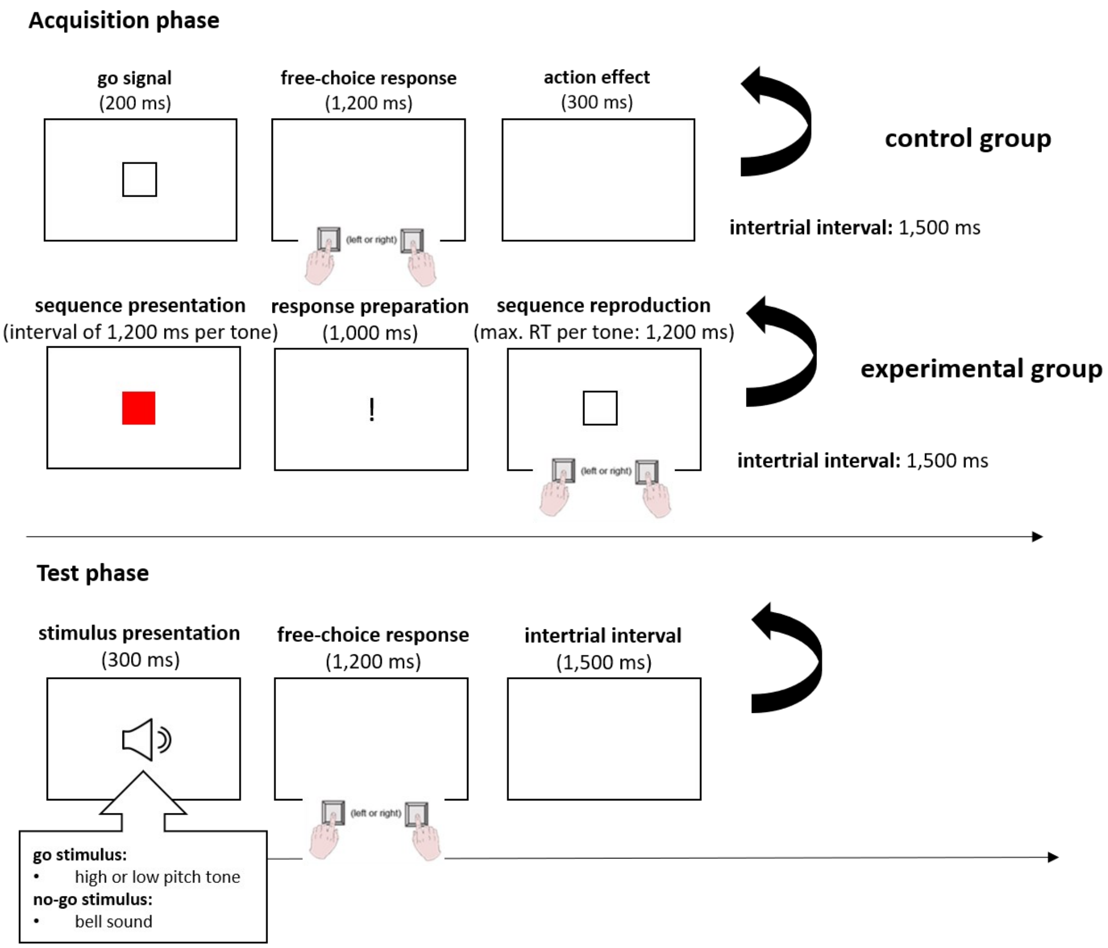
For the *control group*, each trial started with a white square appearing on a black screen background for 200 ms as a go signal. Then, the participants have a time period of 1,200 ms to press either the right or the left "ctrl" – key in a free-choice task to produce either a high or a low pitch tone. The respective tone was then presented for 300 ms. After an intertrial interval of 1500 ms, the next trial started (see upper part of the upper panel of Figure 13 for the design). Responses with an RT > 1,200 ms were considered omission errors and fed back with an error message ("please react faster!" in German) for 500 ms. Reponses with an RT < 100 ms were considered anticipation errors and also fed back with an error message ("you reacted too fast" in German). The effect tones were fully contingent upon the identity of the preceding response, allowing for the formation of stable associations between responses and effects. Participants were told to choose freely between both keys but to press them about equally often and to avoid response patterns like alternating both key presses, as in Experiment 1 – 3. All erroneous trials were repeated at a random position within the block.

For the *experimental group*, the trial sequence started with a red square that was visible throughout the presentation of the tone sequence that had to be reproduced. The tones were presented in intervals of 1,200 ms, so that the duration of the appearance of the red square depended on the sequence length. The sequences started with a length of 2 tones and reached a maximum length of 5 tones. After the presentation of the to-be-reproduced sequence, an exclamation mark was shown for 1,000 ms as a signal for response preparation. Afterwards, the sequence had to be reproduced. Each response had to be given during the appearance of a white square on the screen center inside a time frame of 1,200 ms. For example, in a two-tone sequence, a white square appears and the first tone (duration: 300 ms) is produced by pressing one of the “ctrl” keys. Pressing the key makes the first square disappear. Then, a second square appears in place of the first one, and a second response has to be given (see lower part of the upper panel of Figure 15). Note, that the participant does not know the tone-key mapping in the beginning and has to find out by trying which tone is produced with each key. After having reproduced a sequence correctly three times, one tone was added to the sequence. After committing an error, the sequence was reduced by one tone and it took again three correct trials to reach the next level. Omission and anticipation errors were fed back as in the control group. Producing an erroneous tone led to the error message “wrong key” in German, displayed for 500 ms. All erroneous trials were repeated at a random position within the block.

Both groups were yoked in the sense that they performed roughly the same number of key presses during the acquisition phase. Due to the design, this led to an overall longer acquisition phase for the *experimental group*: Each trial starts with the presentation of the tone sequence that has to be reproduced subsequently, so that the total time of a trial is longer than for the *control group.* This is visualized in Figure 13.

Figure 13

Trial sequence and design of acquisition phase and test phase.



Note. The upper panel shows the acquisition phase trial sequences for both groups. While the control group had to complete a "classical" induction logic task, the experimental group had to reproduce a tone sequence in a task with ascending difficulty. In the test phase, the percentage of acquisition-congruent choices was measured.

The test phase began for both groups after having completed the acquisition phase task. Each go trial started with the appearance of a white square in the screen center for 200 ms while in parallel either a high or a low pitch tone was presented for 300 ms. Then, the participant had 1,200 ms to choose the left or the right key in response. If no error was committed (omission and anticipation errors were defined as in the acquisition phase), the next trial started after an intertrial interval of 1,500 ms. In case of erroneous trials, the corresponding error messages (as in the acquisition phase) were displayed for 500 ms. Each no-go trial started with the presentation of a white square in the screen center for 200 ms, but instead of a tone, a bell sound was displayed. This sound indicated to withhold all responses for 1,200 ms. In case of commission errors, the error message “please don’t react” in German was displayed for 500 ms. Go trials and no-go trials were randomly intermixed. All erroneous trials were repeated at a random position within the block.

After having completed the experimental session, a questionnaire was administered to the participant (see Appendix C). It consisted of two multiple-choice questions to assess, if the R-E relations were learned effectively, and one open question to assess individual response strategies.

Design and Analyses. The trials considered for further analyses and all conducted analyses were identical to Experiments 1 – 3.

5.2 Results

Acquisition phase.

The acquisition phase had on average a duration of 7.48 minutes in the *control group* and of 12.18 minutes in the *experimental group*. Mean RTs were 279 ms for the *control group* and 274 ms for the *experimental group*. A two-sample *t* test revealed no significant difference, $t(98) = 0.40$, $p = .687$, $d = 0.08$.

Control group. Anticipations were recorded in 3.44%. of the trials, omissions in 0.69%. Both response keys were used about equally often (left key:

average of 101.24 times per participant, right key: average of 98.76 times per participant). Individual RBs ranged from 0.89 to 1.30.

Experimental group. Anticipations were recorded in 7.14%, omissions in 2.84%, and the wrong tone was produced in 6.33% of the trials. The number of incorrectly reproduced sequences per person ranged from 2 to 31.

Test phase.

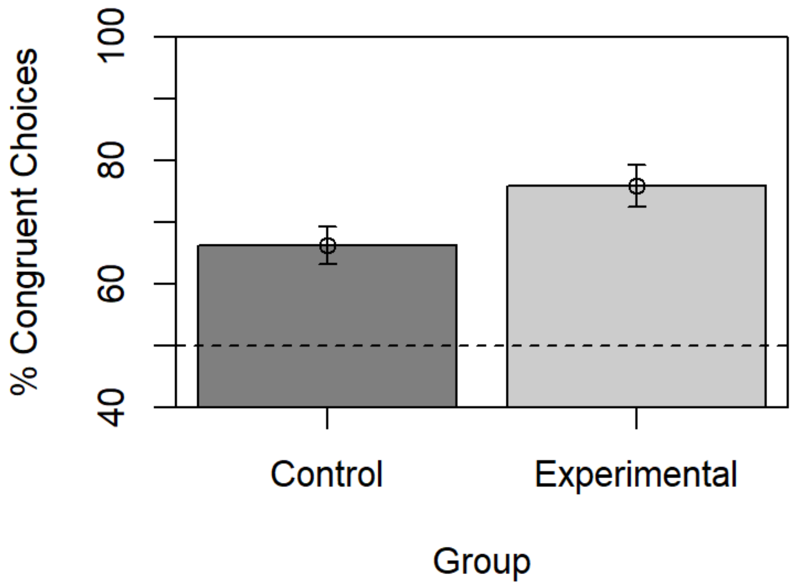
Trials with omissions (1.11%) were excluded from further analyses. The percentage of anticipations was < .001. Mean RT in go trials was 695 ms for the *control group* and 689 ms for the *experimental group*. The percentage of congruent choices was then calculated for each participant and used as a dependent variable in the following analyses. The mean percentages of congruent choices for the groups are visualized in Figure 14.

The Bayesian one-sample *t* tests showed a significant response bias within both groups, for the *control group*: $t(49) = 5.31$, $p < .001$, $d = 0.75$, $BF_{10} = 6{,}691$ and for the *experimental group*: $t(49) = 7.61$, $p < .001$, $d = 1.08$, $BF_{10} = 14{,}762{,}969$. An R-E association clearly seems to have been learned during the acquisition phase by both groups. The evidence for the effect can be considered as large within both groups following Jeffreys' (1961) suggestions.

The two-sample *t* test was significant, $t(98) = 2.13$, $p = .035$, $d = -0.43$, and the corresponding $BF_{10} = 1.55$ yields further, though only small, evidence towards the alternative hypothesis of a group difference. Given this, the R-E learning effect seems to be indeed more pronounced in the *experimental group* compared to the *control group*.

Figure 14

The percentage of acquisition-congruent choices per group.



Note. The dashed horizontal line at 50.0% indicates the expected value for a random response mode. Error bars are the standard errors of the means.

Questionnaire results

In the *experimental group*, 82.0% (41 people) of the participants reported to have used a response strategy during the test phase whereas 18.0% (9 people) reported to have responded by chance. Of the 82.0% that have used a response strategy, 56.1% (23 people) reported to have used a strategy that was explicitly related to the acquisition phase. 12.2% (5 people) reported to have transferred the *expectations* created by the acquisition phase instructions to the test phase task (although this was not indicated by the test phase instructions). 22.0% (9 people) of the participants reported the use of a response strategy, but unrelated to the acquisition phase task. 4.9% (2 people) reported to have used a strategy without describing it. The R-E relation was reported correctly by 96.0% of the participants.

In the *control group*, again 82.0% (41 people) of the participants reported to have used a response strategy during the test phase while 18.0% (9 people) reported to have responded by chance. Of the 82.0% that have used a response strategy, 48.8% (20 people) reported to have used a strategy that was explicitly related to the acquisition phase. 9.8% (4 people) reported to have transferred the *expectations* created by the acquisition phase instructions to the test phase task, 4.9% (2 people) reported to have thought that something was expected from them, but without a relation to the acquisition phase task. 29.3% (12 people) of the participants reported the use of a response strategy, but unrelated to the acquisition phase task. 7.3% (3 people) reported to have used a strategy without describing it. The R-E relation was reported correctly by 82.0% of the participants.

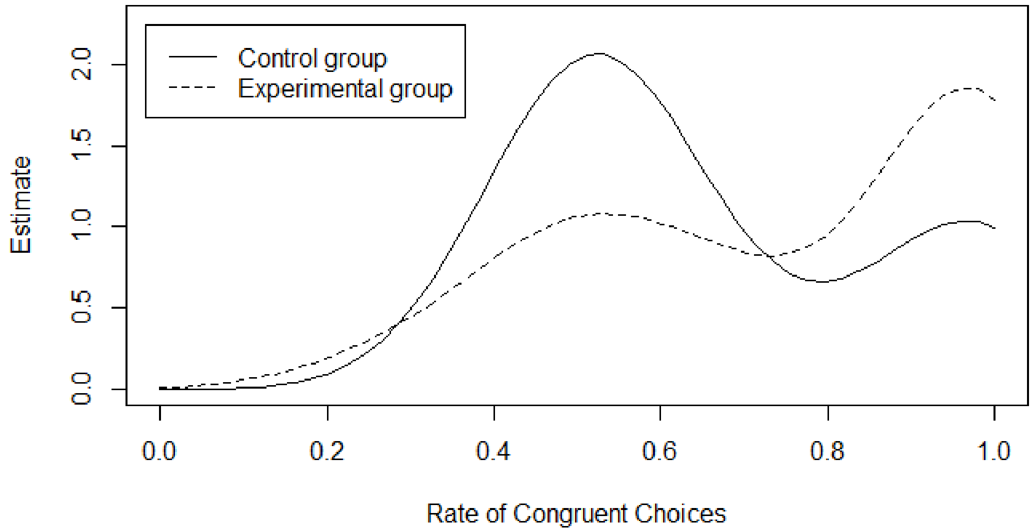
Overall, the results of the open question do not differ significantly between the two groups. This was statistically confirmed by Pearson's Chi-squared test on a Boolean variable called "strategy" that indicates either strategy use or a random response mode, $\chi^2(1) < 0.001$, $p > .999$. 82.0 % of the participants reported to have used a response strategy in both groups, similar percentages (56.1% respectively 48.8%) reported that the strategy had to do with the acquisition phase instructions. Interestingly, in both groups only few participants explicitly mentioned expectations that they inferred during the test phase. The *control group* participants seem to have transferred the acquisition phase instructions, especially the instruction of dividing the left and right key presses approximately equally, to the test phase task. However, this cannot be true for the *experimental group* participants, as they did not receive such instructions. The R-E relation was reported correctly by a higher percentage of participants in the *experimental group* than in the *control group*, a result that backs our hypothesis of an enhanced learning effect with task-relevant action effects and game-like elements to the task.

5.3 Exploratory analyses

The same additional analyses as for Experiments 1 – 3 were conducted for Experiment 4 as well. Figure 15 shows the kernel density plots for both groups, leading to the assumption of a bimodal distribution of the data in each of them.

Figure 15

Kernel density plot for each group of Experiment 4



Note. Both groups seem to be bimodally distributed, the control group with the higher peak shifted towards a rate of 0.5 (random response mode), whereas the higher peak of the experimental group is shifted towards a rate of 1.0 (almost perfect bias).

Interestingly, the distribution of the *control group* seems to behave in reverse to that of the *experimental group*, as the most defined peak of the *control group* distribution is at 50.0% (chance level) whereas the most defined peak of the *experimental group* distribution is almost at 1.0 (perfect response bias).

The calculation of the BC for each group shows that both groups are distributed bimodally. Both the $BC_{control} = 0.72$ and the $BC_{experimental} = 0.65$ are larger than the threshold of $BC_{crit} = 0.55$, therefore indicating a bimodal distribution in both groups.

5.4 Discussion

Both of our hypotheses were confirmed: R-E learning has taken place in both groups and the learning effect is more pronounced in the *experimental group* with task-relevant response effects during the acquisition phase and a game-like element to the task. This result is backed by the additional analyses: The *experimental group* distribution peaks at the highest rates of congruent choices, which means that the majority of the participants has responded with a perfect response bias. The *control group* distribution in comparison peaks at chance level, as observed in the respective control groups of Experiments 1 – 3. Additionally, this experiment had been an explorative way to see if a larger effect can be obtained by using task-relevant effects, compared to the rather small effect sizes previously reported by researchers in the field of R-E learning (e.g., Elsner & Hommel, 2004; Herwig et al., 2007). This goal was also achieved, but several aspects should be disentangled in future research:

First, for the participants of the *experimental group*, the tone sequence was heard twice per acquisition phase trial. This fact might have influenced R-E learning observed in this group, especially in comparison to the *control group*.

Second, an enhanced R-E learning effect can be observed in the *experimental group*, but the question remains open if this effect is due to a propositional, rule-based, more *amodal* nature of the learned knowledge (as suggested by our additional analyses) or due to associative, and thus more *modal*, knowledge. Thus, it would be sensible to bridge the gap to Experiments 1 – 3 at this point: Given the rather small effects obtained in Experiments 1 – 3, and considering the bimodal distribution of Experiments 1 and 3, it would be interesting to see if this distribution still remains bimodal with larger effects, as obtained in Experiment 4.

6 General discussion

6.1 Discussion of the results and their relation to the hypothesis

Our hypothesis was that the roles of *modal* and *amodal* representations in human action are not as clearly divided into action planning (*amodal*) and action control (*modal*) as presumed in past research. More specifically, and referring to TEC (Hommel et al., 2001), our hypothesis was that no abstraction of action effects in the sense of generalization occurs during action planning – at least not in R-E learning tasks following the *induction logic* (Elsner & Hommel, 2001). In relation to that this work looked at mixed evidence regarding generalization in R-E learning that was published in TEC-related research: Evidence in favor of abstraction respectively generalization of action effects, as reported by Hommel et al. (2003), and more recent evidence from REC studies contradicting these findings, as reported by Földes et al. (2018) and Koch et al. (2021). Taking these inconsistent findings as the starting point for our own research, it was first attempted to replicate the findings of Hommel et al. (2003, Exp. 1) in a pilot study. As generalization was not observed in our data (but see Section 1.4.3 for limitations), it was decided to first conceptually replicate the original experiment with a free-choice test phase and test for generalization from exemplars to their superordinate categories again. To further investigate the presence of abstract, *amodal* representations in R-E learning in a broader sense, it was then decided to conduct two follow-up experiments investigating abstraction in the sense of a semantic representation of concepts (Experiment 2) and in the sense of generalization from pictures to their corresponding semantic meaning (Experiment 3). As described in the beginning of Chapter 3, a free-choice test phase was employed in all experiments, as the individual RB was considered to be a more sensitive measure than the RTs and PEs measured in forced-choice tasks. The results of the three experiments are mixed regarding the occurrence of abstraction in R-E learning. No signs of abstraction were obtained for the hierarchical generalization from exemplars to their superordinate categories (Exp. 1) as well as for the representation of spatial concepts (Exp. 2), but such an effect was observed for the generalization from pictures to their semantic meaning (Exp. 3). The results of Experiments 1 and 2 point into the same direction: No full abstraction, respectively no abstraction at all, has occurred in the relative experimental groups. This can possibly mean that a) the R-E associations that were formed during the acquisition phase seem to be connected to stimuli that are *physically identical* to those presented as action effects during the acquisition phase, or b) that R-E associations were also formed in the relative experimental groups, but not used during the test phase task. The latter case will be discussed more thoroughly in Section 6.2. The results of Experiment 3 show that it is indeed possible to observe some kind of generalization in R-E learning, in this case from simple pictures to their corresponding semantic meaning. As described in Section 3.3.3, a possible explanation for the discrepancy of the results of Experiment 3 from the results of Experiment 1 and 2 can be the occurrence of *phonological recoding* in the moment of the presentation of the pictures as action effects (see again the lower panel of Table 2 in Chapter 3). Koch and Kunde (2002) describe this phenomenon as follows: “A second way that response effects might prime the response is that the anticipated effect stimuli could be recoded into a verbal code. For the color word, this would be structurally equivalent to “reading” an imagined word […]. This would then prime the articulatory motor system, because the compatible effect word would prime articulation of the correct response word, whereas the articulatory (or phonological) code for the anticipated incompatible color would prime the incorrect response.” (p. 1302). In our Experiment 3, participants appeared to perceive the auditory word "apple" upon being exposed to the picture of an apple. Consequently, the utilization of visual stimuli and the subsequent emergence of a semantic congruency effect during the test phase for the experimental group in Experiment 3 can be plausibly accounted for and is substantiated by the results. In this case, the preference for the acquisition-congruent response is influenced during the test phase.

The main hypothesis of this thesis was there were believed to be found no signs of generalization (in case of category words and exemplars) or abstraction (in case of pictures and concept words) in R-E learning tasks following the *induction logic* (Elsner & Hommel, 2001). Against the just summarized results, this hypothesis was only partially confirmed. Abstraction of action effects in the sense of a hierarchical generalization from exemplars to their superordinate categories as well as in the sense of an abstract representation of spatial concepts did not occur in Experiment 1 respectively Experiment 2. The results of Experiment 3 though do show that some kind of generalization seems to be possible to occur in R-E learning experiments, the generalization from pictures to the corresponding semantic content. As discussed in the preceding paragraph, a reason for this result can be the occurrence of phonological recoding during the presentation of the pictures. If this were true, employing pictures as action effects could be used to generate a baseline effect in future research on the representations in R-E learning, as an effect can be expected to be produced in any case using pictures as stimulus material.

The non-occurrence of an R-E learning effect in the experimental groups of Experiments 1 and 2 can also be due to limitations in the design, as only one exemplar was used for each category (Exp. 1), following the original design of Hommel et al. (2003, Exp. 1), respectively only one location was shown for each spatial concept (Exp. 2). First, focusing on Experiment 1, research on category learning indicates that the diversity of exemplars plays a crucial role in categorization. More stable categories seem to be built when the variability of learned exemplars is greater (e.g., Hahn et al., 2005). From linguistics it is known that a greater variety of semantic content in artificial languages enhances the identification of unchanging structures (Gómez, 2002). Lastly, research in context of Schmidt's (1975) schema theory for motor learning showed that a variety of practice items can slow down learning but the overall learning effect seems to be more reliable when compared to constant practice (e.g., McCracken & Stelmach, 1977; Wulf & Schmidt, 1997). Regarding Experiment 2, what is true for category learning can also be applied to the representation of spatial concepts. Outlined in the renewal proposal of the research unit FOR2718 are ideas to integrate a greater variability of exemplars into the experimental setup of Experiment 1 and 2: To ensure the reproduction of the absence of generalization observed with only one exemplar per category/location per spatial concept, the original experimental groups will serve as control groups in both scenarios. In a new version of Experiment 1, a fresh experimental group with a variety of exemplars will be introduced (such as “chair”, “table”, “shelf”, and “duck”, “sheep”, “lion”) during the learning phase, while adhering to category-related terms (e.g., “furniture” and ”animals”) during the subsequent testing phase, as previously conducted. In a new version of Experiment 2, a fresh experimental group will produce a visual effect in the upper or lower part of the screen, but in one of three possible locations there. The learning effect should be enhanced in both experiments compared to the outcomes of Experiment 1 and Experiment 2 of this thesis.

With regard to the main hypothesis of this thesis it is also important to mention again the work of Sun et al. (2020, Exp. 1) who hypothesized that the bimodal distribution of the data in their Experiment 1, a free-choice task, occurred due to a small number of participants with very high individual RBs driving the effect. As the results of the experiments outlined in this thesis also show a bimodal distribution of the data – except for Experiment 2 – at least in the respective control groups but also in the experimental groups of Experiments 3 and 4, the suspicion arose that the rate of congruent choices as a measure might rather reflect propositional, more *amodal* knowledge than associative and more *modal* knowledge. A free-choice task might be more sensitive towards the individual choices that were made by the participants on the basis of rule-based knowledge inferred during the test phase. RTs and PEs, on the other hand, can be considered a measure that might rather reflect associative, more *modal* knowledge, as the task is to respond as fast as possible according to certain instructions. As discussed in Section 1.4.1, Hommel et al. (2003), as well es Esser et al. (2023), did report generalization in R-E learning, measuring RTs and PEs in forced-choice test phase tasks. Individual response strategies are not needed in this type of tasks.

6.2 Discussion of the results in a larger frame

As discussed in the preceding section, the results of Experiments 1 and 2 showed that no (full) abstraction of action effects has occurred within the respective experimental groups. Considering the results of Experiment 3 as well, which show that the occurrence of abstraction can indeed be found in experiments following the induction logic, there is a growing suspicion that R-E associations were formed during the acquisition phase, though just not used during the test phase task. If this would be the case, and considering the bimodal distribution of the data in all experiments, although not statistically confirmed for Experiment 2, a rather propositional nature of the knowledge acquired in associative learning as proposed by Mitchell et al. (2009) can be assumed. The bimodally distributed data of Experiments 1 and 3 show that in all three affected groups, few participants show an almost perfect RB. According to the reasoning of Sun et al. (2020), these results could indicate that those individuals have used deliberate response strategies throughout the test phase. In fact, 63.0% of the participants in Experiment 3 reported to have used some sort of response strategy throughout the test phase (see Section 3.2.2), often in relation to assumptions regarding the instructions received during the acquisition phase. Numerous participants appear to have transferred and applied these instructions to the test phase task – although they were not explicitly asked to do so by the test phase instructions (see Appendix D for the detailed instructions). As discussed in Section 4.2, knowledge acquired through experience seems to be represented in a similar way as knowledge acquired through verbal instructions (Lovibond, 2003; Mitchell et al., 2009). Against this background, what seems to have been acquired by the participants with large RBs is propositional knowledge about rules that has been rapidly inferred when seemed to be needed – during the test phase task. The acquisition phase instructions – to press both response keys about equally often, avoiding patterns like alternating key presses – seem to have been stored as rule-based knowledge that was used later on during the test phase task. According to Mitchell et al. (2009, p. 198), learning " […] requires cognitive resources, and it is affected by verbal instructions, rules, and deductive reasoning processes" – a sentence that seems to characterize quite well what occurred in Experiment 1 – 3. At this point, the experimental approach of Sun et al. (2022), who combined acquisition phase and test phase in one trial (see also Section 4), is also noteworthy. Their results could have the following implication for R-E learning effects: Rather than being the outcome of R-E associations formed over a long time period, they could also arise from the inference of causal relations between one's actions and their consequences within the current situation (Sun et al., 2022). This seems to have occurred in Experiment 1 – 3: The acquired R-E relations were rapidly inferred during the test phase task because participants believed them to be important for the task at hand. In this case it could also be spoken of rather *propositional* knowledge based on certain (inferred) rules.

Experiment 4 was designed to test if turning the response effects in a typical R-E learning task (as in Elsner & Hommel, 2001) task-relevant would lead to larger effects (see Chapter 5). The results of this experiment showed that this is indeed the case. Considering the additional analyses performed on the data of this experiment, the rate of congruent choices was bimodally distributed in both groups, but with the most defined peak at different positions: While most participants in the control group responded at chance level, the majority of the participants in the experimental group had an almost perfect RB (see Figure 15). Thus, it is possible to conclude that the distribution of the data in this type of R-E learning experiments remains bimodal also with larger effects. This result points towards a more *amodal*, propositional nature of the knowledge learned in this experiment, again backed by the questionnaire results (see Section 5.2), rather than towards more *modal*, associative knowledge.

7 Conclusions and outlook

Based on the findings described in this thesis, the following conclusions can be drawn: 1. It is not possible to observe abstraction in the sense of generalization from exemplars to their superordinate categories (Exp. 1) and in terms of semantic concept representation (Exp. 2), in tasks following the *induction logic* (Elsner & Hommel, 2001) and presenting only one exemplar respectively one location per category/concept. The results of Experiment 3 show that it is generally possible to observe generalization in this type of tasks, but using effects/stimuli that lead to *phonological recoding*. The obtained R-E learning effect could thus be confounded. 2. The nature of the knowledge acquired during the acquisition phase tasks in this kind of experiments seems to be rather *propositional* than automatic. 3. It is possible to obtain larger R-E learning effects by turning the response effects during the acquisition phase task-relevant, as demonstrated by the results of Experiment 4.

In light of future research concerning the involvement of *modal* and *amodal* representations in R-E learning, it would be advantageous to further expand upon the series of experiments outlined in this thesis. As discussed before, employing various exemplars of a category respectively varying the exact location of the effect in relation to the screen center could be a meaningful expansion of Experiments 1 and 2. Also, it could be profitable to employ task-relevant response effects, as in Experiment 4, testing for abstraction in the sense of generalization.

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9 Appendices

9.1 Appendix A

In this appendix, design, methods and results of the online pilot experiment attempting to replicate Experiment 1 by Hommel et al. (2003) are described in detail.

Method.

Participants. Two hundred thirty-six people from the Bremen and Tübingen (Germany) area participated for course credit or without reimbursement. Fifty-seven additional participants were recruited online via Prolific and received monetary compensation. The total sample consisted of $N = 293$ participants (mean age = 27 years, 204 females, 87 males, 2 non-binary). All participants reported to be either native German speakers or to have advanced written and spoken knowledge of German and were naïve to the hypotheses.

Following one of the exclusion criteria of the original study (Hommel et al., 2003), 89 participants were excluded from further analyses because they did not press the left and the right key at least 80 times (out of a maximum of 100) each during the acquisition phase. In addition, in the original study participants were excluded when they committed more than 5.0% of errors in the test phase. Error rates in the current online experiment were generally larger though, and it was decided to apply a less strict error criterion of 20.0%. Due to this criterion, 16 participants were excluded from further analyses. The number of catch trials per participant was randomly calculated, due to a programming issue the number of catch trials ranged from 2 to 17 trials. As this variability was considered very high it was decided to exclude all participants with less than 9 catch trials from further analyses, taking the number of 10 – 11 catch trials per participant of the original study as a background. Thus, 84 participants were excluded. Due to another programming issue, the response time in catch trials was infinite instead of limited to 2,000 ms. Data showed, though, that response times in catch trials scarcely exceeded this limit, in a total of 80 trials. Finally, an analysis showed that two participants had pressed an invalid key in more than 20.0% of the test trials. These datasets were also excluded from further analyses, resulting in a final $N = 140$. In contrast to laboratory experiments, the online setup can be prone to this kind of error, therefore the invalid key presses were analyzed additionally to the anticipation and omission errors of the original study. Participants were assigned randomly to one of the four groups resulting from combining congruency (in the test phase) and effect-type group (in the learning phase). Within the exemplar group ($n = 80$), $n = 44$ and $n = 36$ participants were assigned to the incongruent and congruent mapping; within the category group ($n = 60$), $n = 29$ and $n = 31$ participants were assigned to the incongruent and congruent mapping. All participants took part in the experiment in single sessions of approximately 35 minutes.

Stimuli and Apparatus. The online study was programmed with the open-source software PsychoPy (Version 2020.2.10) (Peirce & MacAskill, 2018; Peirce et al., 2019) and run via the online platform Pavlovia. Participants could access the experiment clicking on a link, which was distributed via E-Mail and accessible on the university homepages of the psychology departments of both the University of Tübingen and the University of Bremen, leading them to the platform. Requirements for the participation were a stable internet connection, a laptop or a computer with a standard QWERTZ-keyboard (mobile devices like smartphones or tablets were not allowed), and the usage of a "common" browser (Firefox, Safari, Google Chrome, Microsoft Edge). Participants were instructed to start the experiment, if possible, in a low-stimulus environment without disruptions. Responses were given with the left and right index fingers placed on the "d" key (left) and "l" key (right) of the keyboard. In catch trials, the response was given by pressing the space bar. Stimuli and effects were the German words for "animal" and "furniture" ("Möbel" and "Tiere"; *category group*) and the German words for "chair" and "cat" ("Stuhl" and "Katze"; *exemplar group*) presented in white color against a slate grey background.

Task and Procedure. The experiment was divided into an acquisition phase and a test phase. In both groups half of the participants received a certain key-effect mapping (e.g., "d" → E1; "l" → E2) while the other half received the reversed mapping.

Acquisition phase. Each trial started with the presentation of a white fixation cross in the screen centre for 500 ms, followed by a blank interval with a randomly determined length between 200 and 400 ms. After that, the imperative stimulus (the word "START" written in green uppercase letters) was presented in the screen centre for 200 ms, indicating the participants to press the left or right key as fast as possible within 1000 ms, following the instructions.

Each keypress triggered the appearance of a white effect word (R1 → E1; R2 → E2) in the screen center for 500 ms. In the *category group*, these effect words consisted of the same category words (the German words for "furniture" and "animals") that are presented later as imperative stimuli in the test phase. In the *exemplar group*, the effect words consisted in exemplars of the same two categories (the German words for "chair" and "cat"). Participants were naïve to the R-E mapping, the response effects were considered task-irrelevant. The mapping of response keys to effect words was counterbalanced across participants. In 5.0% of the acquisition trials, the catch words "Obst" (*category group*; German for "fruit") or "Banane" (*exemplar group*; German for "Banana") appeared instead of E1 and E2, respectively. Unlike in the original experiment, where the same category word ("fruit" in Spanish) was presented to both groups as a catch word, it was decided to also present an exemplar word to the exemplar group in order to facilitate the overall learning of an R-E-association as a function of group. These catch trials were presented randomly, and participants had to respond as fast as possible by pressing the space bar within 2,000 ms.

Trials with RTs larger than 1,000 ms were considered omissions while responses faster than 100 ms were considered anticipation errors. Both were fed back to the participants by displaying an error message for 2,000 ms in the screen centre ("too fast!" and "too slow!" in German, respectively). Each trial ended with an intertrial interval of 2,000 ms before the next trial started.

Test phase. After completing the acquisition phase, participants were informed about the upcoming choice-reaction task during the test phase. Half of the participants received an S-R mapping that was compatible with the R-E mapping during the acquisition phase (e.g., acquisition phase: left key → "Möbel", right key → "Tiere"; test phase: "Möbel" → left key, "Tiere" → right key) while the other half received an incompatible S-R mapping regarding the acquisition phase mapping (e.g., acquisition phase: left key → "Stuhl", right key → "Katze"; test phase: "Möbel" → right key, "Tiere" → left key).

Each test phase trial also started with the presentation of a fixation cross for 500 ms in the screen centre, followed by a blank interval (100 ms). After that, the imperative stimulus (one of the two category words) appeared for 200 ms on the screen, demanding a left or right response following the instructed word-key-mapping. Anticipation errors and omissions were again fed back to the participants by displaying an error message for 2,000 ms. Participants completed in total 80 test trials that comprised of 40 repetitions of each category word, randomly intermixed, so that the stimulus in trial n + 1 was never predictable for the participant. As this experiment was conducted online, participants received written instructions in the beginning of the experiment and between acquisition phase and test phase. First, the division into learning phase and test phase was explained. Then, participants were informed that their task during the acquisition phase is to press - after the appearance of the fixation cross and the imperative stimulus "START" - either the "d" key or the "l" key in each trial, while each key would produce a different visual effect. They were told to choose freely between both keys but to press them about equally often and to avoid response patterns like alternating both key presses. Also, they were instructed to press the space bar as fast as possible when the catch word ("Obst" or "Apfel", respectively) appears in the catch trials. After the completion of the 200 acquisition trials, participants received the test phase instructions: Depending on the mapping, they had to press the "d" key when one category word appears, and the "l" key when the other category word appears as an imperative stimulus.

Results.

Design and Analyses. Only valid acquisition trials and correct test phase trials were considered further for RT and PE analyses. Trials with anticipations (RT < 100 ms), omissions (RT > 1,000 ms), catch trials exceeding 2,000 ms and wrong test phase responses were excluded. A 2 x 2 between-subjects ANOVA with the independent variables group (*category* vs. *exemplar*) and mapping (*compatible* vs. *incompatible*) as between-subject factors was run on acquisition phase RTs and test phase RTs and PEs.

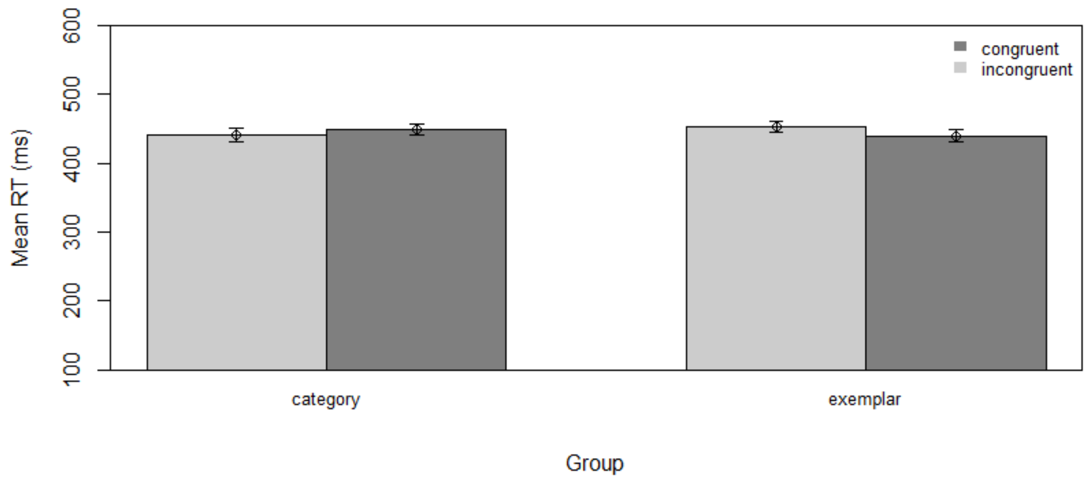
Acquisition phase. Omissions (RT > 1,000 ms) were recorded in a 2.3% and anticipations (RT < 100 ms) in a 4.8% of the trials. In the remaining trials, the mean RT was 442 ms. Both response keys were used about equally often (left key: average of 91.9 times per participant, right key: average of 92.3 times per participant). Individual response biases ranged from 0.8 to 1.2. 80 catch trials were eliminated because of an RT exceeding 2,000 ms.

The ANOVA on RTs revealed a significant main effect of group, $F(1, 136) = 9.70$, $p = .002$, $\eta_p^2 = .07$, but not of mapping, $F(1, 136) = 0.01$, $p = .935$, $\eta_p^2 < .01$. The interaction was also not significant, $F(1, 136) = 0.73$, $p = .394$, $\eta_p^2 < .01$. The ANOVA on the individual response biases revealed no significant main effects of group, $F(1, 136) = 0.05$, $p = .831$, $\eta_p^2 < .01$, and mapping, $F(1, 136) = 0.56$, $p = .457$, $\eta_p^2 < .01$, whereas the interaction of both factors approached significance: $F(1, 136) = 3.27$, $p = .073$, $\eta_p^2 = .02$.

Test phase. Trials with anticipations (0.7%), omissions (0.2%), wrong key presses (7,4%) and invalid key presses (0.02%) were excluded from further analyses. Mean correct RTs and PEs were calculated for each participant and are summarized in Table A1.

Figure A1

Mean RTs as a function of group and R-E mapping.

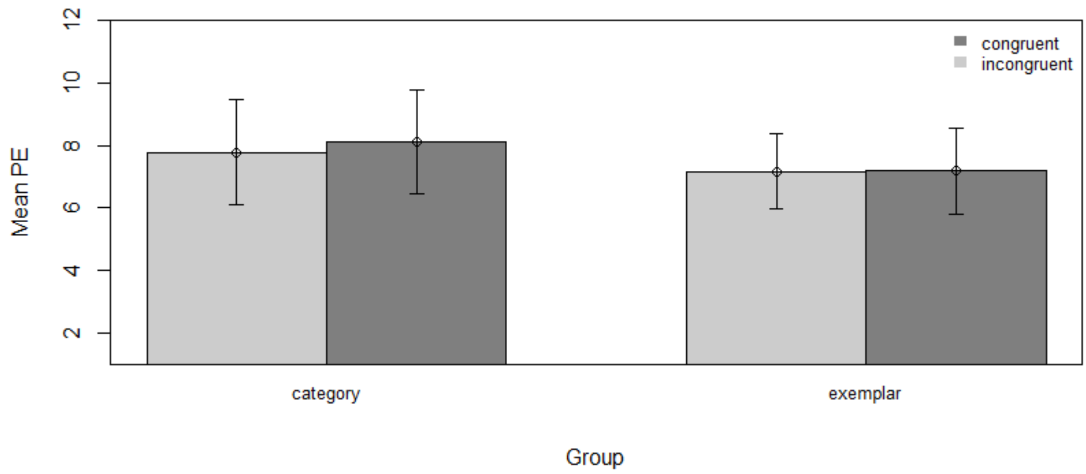


Note. The dark grey bars depict the mean RTs in the congruent condition, the light grey bars depict those in the incongruent condition. The error bars are the standard errors of the means.

As in the original study, the mean RT from the acquisition phase was used as a covariate in the RT analysis. The covariate had a significant effect, $F(1, 135) = 21.37$, $p < .001$, $\eta_p^2 = .13$. The main effects of group, $F(1, 135) = 2.22$, $p = .138$, $\eta_p^2 = .02$, and mapping, $F(1, 135) = 0.29$, $p = .590$, $\eta_p^2 < .01$, did not reach significance. The interaction was also not significant, $F(1, 135) = 0.98$, $p = .323$, $\eta_p^2 < .01$. See Figure A1 for illustration.

Figure A2.

Mean percentages of error as a function of group and R-E mapping.



Note. The dark grey bars show the mean PEs in the congruent condition whereas the light grey bars show the mean PEs in the incongruent condition. The error bars are the standard errors of the means.

A similar pattern was obtained for the percentages of error. Neither the main effect of group, $F(1, 136) = 1.09$, $p = .298$, $\eta_p^2 = .01$, nor of R-E mapping was significant, $F(1, 136) = 0.05$, $p = .829$, $\eta_p^2 < .01$. The interaction was also not significant: $F(1, 136) = 0.05$, $p = .819$, $\eta_p^2 < .01$. This is illustrated in Figure A2.

Because of the non-significant results, a Bayesian ANOVA was additionally run. The resulting BF are summarized in Table A2 and all BF provide evidence for the respective null-hypotheses.

Table A1

Mean RTs and PEs per group.

		group	
		category	exemplar
mapping	congruent	453 / 8.12	444 / 7.18
	incongruent	444 / 7.77	457 / 7.17

Note. Mean RTs (in milliseconds)/PEs as a function of group (effect words during the learning phase: *category* vs. *exemplar*) and R-E mapping (in the test phase: *congruent* vs. *incongruent*).

Table A2

Bayes factors on RTs against the intercept-only model.

model	BF
group	0.190
mapping	0.203
group + mapping	0.038
group + mapping + group:mapping	0.017

9.2 Appendix B

The post-experimental Questionnaire for Experiment 3.

Fragebogen zur Post-Evaluation

VP-Nummer (vom Experimentleiter einzutragen): ________

Liebe(r) Teilnehmer: in,

Sie haben es fast geschafft und das Experiment erfolgreich beendet! Nun haben wir noch ein paar kurze Fragen an Sie.

Zum ERSTEN TEIL des Experiments:

Bitte beantworten Sie die folgenden beiden Fragen zum ersten Teil des Experiments, indem Sie jeweils eine Antwortmöglichkeit ankreuzen! Beziehen Sie sich dabei ausschließlich auf den ERSTEN Teil des Experiments!

1. Welches **Bild** bzw. welches **Wort** erzeugte die Taste „D“ (linke Taste)?
   a) Die linke Taste erzeugte (einen) APFEL.
   b) Die linke Taste erzeugte (eine) KATZE.
   c) Die linke Taste erzeugte immer zufällig (einen) APFEL oder (eine) KATZE.
   d) Das Drücken der linken Taste hatte keinen Zusammenhang mit den Bildern/Worten.

2. Welches Bild bzw. welches Wort erzeugte die Taste „L“ (rechte Taste)?
   a) Die rechte Taste erzeugte (einen) APFEL.
   b) Die rechte Taste erzeugte (eine) KATZE.
   c) Die rechte Taste erzeugte immer zufällig (einen) APFEL oder (eine) KATZE.
   d) Das Drücken der rechten Taste hatte keinen Zusammenhang mit den Bildern/Worten.

Zum ZWEITEN TEIL des Experiments:

Bitte beschreiben Sie so knapp wie möglich (maximal 3 kurze Sätze), aber ehrlich, wie Sie im ZWEITEN TEIL des Experiments die Tasten ausgewählt haben, die Sie gedrückt haben.

Antwort:

____
____
____
____
____
____

9.3 Appendix C

The post-experimental Questionnaire for Experiment 4.

Fragebogen zur Post-Evaluation

VP-Nummer (vom Experimentleiter einzutragen): ________

Liebe(r) Teilnehmer: in,

Sie haben es fast geschafft und das Experiment erfolgreich beendet! Nun haben wir noch ein paar kurze Fragen an Sie.

Zum ERSTEN TEIL des Experiments:

Bitte beantworten Sie die folgenden beiden Fragen zum ersten Teil des Experiments, indem Sie jeweils eine Antwortmöglichkeit ankreuzen! Beziehen Sie sich dabei ausschließlich auf den ERSTEN Teil des Experiments!

1. Welchen Ton erzeugte die LINKE „Strg“ – Taste?
   e) Die linke Taste erzeugte den HOHEN Ton.
   f) Die linke Taste erzeugte den TIEFEN Ton.
   g) Die linke Taste erzeugte immer zufällig einen von beiden Tönen
   h) Das Drücken der linken Taste hatte keinen Zusammenhang mit den Tönen.

2. Welchen Ton erzeugte die RECHTE „Strg“ – Taste?
   e) Die rechte Taste erzeugte den HOHEN Ton.
   f) Die rechte Taste erzeugte den TIEFEN Ton.
   g) Die rechte Taste erzeugte immer zufällig einen von beiden Tönen.
   h) Das Drücken der rechten Taste hatte keinen Zusammenhang mit den Tönen.

Zum ZWEITEN TEIL des Experiments:

Bitte beschreiben Sie so knapp wie möglich (maximal 3 kurze Sätze), aber ehrlich, wie Sie im ZWEITEN TEIL des Experiments die Tasten ausgewählt haben, die Sie gedrückt haben.

Antwort:

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9.4 Appendix D

Instructions for Experiment 1 – 4.

Experiment 1

Acquisition phase instructions:

1. For the *control group*:

Liebe Versuchsperson!

Vielen Dank für Ihre Teilnahme an diesem Experiment. Insgesamt dauert es ca. 35 Minuten und ist in eine Lern- und eine Testphase eingeteilt.

Die Aufgabe wird Ihnen auf den folgenden Seiten erklärt. Es ist sehr wichtig, dass Sie dieser Anleitung und den Hinweisen der Versuchsleitung genau folgen und während des Experiments Ihr Bestes geben.

Vor Beginn des Experiments positionieren Sie bitte den Zeigefinger Ihrer linken Hand auf der Taste "D" und den Zeigefinger Ihrer rechten Hand auf der Taste "L".

Zu Beginn jedes Durchgangs erscheint ein weißes Kreuz in der Mitte des Bildschirms, gefolgt von "Los!".

Bitte drücken Sie entweder "D" oder "L", sobald "Los!" erscheint! Sie dürfen zwischen beiden Tasten frei wählen.

Auf jeden Tastendruck hin erscheint ein Begriff. Falls Sie zu schnell oder zu langsam reagiert haben erscheint eine Fehlermeldung. Alle fehlerhaften Durchgänge werden gespeichert und am Ende wiederholt.

Noch einmal eine kurze Zusammenfassung: Zunächst erscheint ein weißes Kreuz, daraufhin "Los!"

Daraufhin drücken Sie so schnell wie möglich die Taste "D" oder die Taste "L" - ganz wie Sie möchten!

Dann erscheint ein Begriff in der Bildschirmmitte, bevor es mit dem nächsten Durchgang weitergeht.

Achtung! Verwenden Sie beide Tasten in etwa gleich häufig und vermeiden Sie Muster, so wie z.B. die Tasten immer abwechselnd zu drücken.

Achtung! Manchmal erscheint statt den "gewohnten" Begriffen der Begriff "FRUCHT". In diesem Fall drücken Sie bitte so schnell wie möglich die Leertaste!

Wenn Sie noch Fragen haben, dann stellen Sie diese bitte jetzt. Ansonsten können wir mit dem Experiment beginnen.

2. For the *experimental group*:

Liebe Versuchsperson!

Vielen Dank für Ihre Teilnahme an diesem Experiment. Insgesamt dauert es ca. 35 Minuten und ist in eine Lern- und eine Testphase eingeteilt.

Die Aufgabe wird Ihnen auf den folgenden Seiten erklärt. Es ist sehr wichtig, dass Sie dieser Anleitung und den Hinweisen der Versuchsleitung genau folgen und während des Experiments Ihr Bestes geben.

Vor Beginn des Experiments positionieren Sie bitte den Zeigefinger Ihrer linken Hand auf der Taste "D" und den Zeigefinger Ihrer rechten Hand auf der Taste "L".

Zu Beginn jedes Durchgangs erscheint ein weißes Kreuz in der Mitte des Bildschirms, gefolgt von "Los!".

Bitte drücken Sie entweder "D" oder "L", sobald "Los!" erscheint! Sie dürfen zwischen beiden Tasten frei wählen.

Auf jeden Tastendruck hin erscheint ein Begriff. Falls Sie zu schnell oder zu langsam reagiert haben erscheint eine Fehlermeldung. Alle fehlerhaften Durchgänge werden gespeichert und am Ende wiederholt.

Noch einmal eine kurze Zusammenfassung: Zunächst erscheint ein weißes Kreuz, daraufhin "Los!"

Daraufhin drücken Sie so schnell wie möglich die Taste "D" oder die Taste "L" - ganz wie Sie möchten!

Dann erscheint ein Begriff in der Bildschirmmitte, bevor es mit dem nächsten Durchgang weitergeht.

Achtung! Verwenden Sie beide Tasten in etwa gleich häufig und vermeiden Sie Muster, so wie z.B. die Tasten immer abwechselnd zu drücken.

Achtung! Manchmal erscheint statt den "gewohnten" Begriffen der Begriff "APFEL". In diesem Fall drücken Sie bitte so schnell wie möglich die Leertaste!

Wenn Sie noch Fragen haben, dann stellen Sie diese bitte jetzt. Ansonsten können wir mit dem Experiment beginnen.

Test phase instructions:

Dies war der erste Teil des Experiments. Nun geht es weiter mit der Testphase.

Positionieren Sie hierfür wieder den linken Zeigefinger auf der Taste "D" und den rechten Zeigefinger auf der Taste "L".

Zunächst erscheint wieder ein weißes Kreuz in der Mitte des Bildschirms - Zeit, sich auf die Reaktion vorzubereiten!

Sobald daraufhin der Begriff "Tiere" oder der Begriff "Möbel" erscheint, drücken Sie entweder die Taste "D" oder die Taste "L" - ganz wie Sie möchten!

Wählen sie eine dieser beiden Tasten aus und reagieren Sie so schnell wie möglich, sobald ein Begriff erscheint!

In der Hälfte der Durchgänge wird jedoch kein Begriff erscheinen, sondern eine Folge von Zeichen ("XXXXX").

Wenn "XXXXX" erscheint, sollen Sie jegliche Reaktion zurückhalten, d.h. KEINE Taste drücken!

Nochmal eine kurze Zusammenfassung, bevor es losgeht:

Es erscheint ein weißes Kreuz in der Mitte des Bildschirms.

Daraufhin erscheint entweder "Möbel", "Tiere" oder die Zeichenfolge "XXXXX".

Erscheint ein Begriff, drücken Sie - so schnell wie möglich - entweder "D" oder "L", wobei Sie zwischen den beiden Tasten frei wählen dürfen.

Erscheint "XXXXX", drücken Sie gar keine Taste, bis es mit dem nächsten Durchgang weitergeht.

Der nächste Durchgang beginnt wieder mit einem weißen Kreuz in der Mitte des Bildschirms.

Fehler, also zu schnelle oder zu langsame Reaktionen und das Drücken einer Taste, obwohl "XXXXX" erscheint, werden zurückgemeldet. Fehlerhafte Durchgänge werden gespeichert und wiederholt.

Fertig? Dann können Sie das Experiment nun starten.

Experiment 2

Acquisition phase instructions:

1. For the *control group*:

Liebe Versuchsperson!

Vielen Dank fuer Ihre Teilnahme an diesem Experiment. Insgesamt dauert es ca. 35 Minuten und ist in eine Lern- und eine Testphase eingeteilt.

Die genaue Aufgabe wird Ihnen auf den folgenden Seiten erklaert. Es ist SEHR WICHTIG, dass Sie dieser Anleitung und den Hinweisen der Versuchsleitung genau folgen und waehrend des Experiments Ihr Bestes geben.

Vor Beginn des Experiments positionieren Sie bitte den Zeigefinger Ihrer linken Hand auf der Taste "D" und den Zeigefinger Ihrer rechten Hand auf der Taste "L".

Zu Beginn jedes Durchgangs erscheint ein weisses Kreuz in der Mitte des Bildschirms, gefolgt von der Aufforderung "Los!".

Bitte druecken Sie entweder "D" oder "L" sobald "Los!" erscheint! Sie duerfen zwischen beiden Tasten frei waehlen!

Auf jeden Tastendruck hin erscheint ein Wort. Falls Sie zu schnell oder zu langsam reagiert haben erscheint eine Fehlermeldung. Alle fehlerhaften Durchgaenge werden gespeichert und am Ende wiederholt.

Noch einmal eine kurze Zusammenfassung: Zunaechst erscheint ein weisses Kreuz, daraufhin "Los!".

Daraufhin druecken Sie so schnell wie moeglich die Taste "D" oder die Taste "L" - ganz wie Sie moechten!

Dann erscheint ein Wort auf dem Bildschirm, bevor es mit dem naechsten Durchgang weitergeht.

Achtung! Manchmal erscheint statt den "gewohnten" Worten das Wort "MITTE"! In diesem Fall druecken Sie bitte so schnell wie moeglich die LEERTASTE.

Wenn Sie noch Fragen haben, dann stellen Sie diese bitte jetzt. Ansonsten koennen wir mit dem Experiment beginnen.

2. For the *experimental group*:

Liebe Versuchsperson!

Vielen Dank fuer Ihre Teilnahme an diesem Experiment. Insgesamt dauert es ca. 35 Minuten und ist in eine Lern- und eine Testphase eingeteilt.

Die genaue Aufgabe wird Ihnen auf den folgenden Seiten erklaert. Es ist SEHR WICHTIG, dass Sie dieser Anleitung und den Hinweisen der Versuchsleitung genau folgen und waehrend des Experiments Ihr Bestes geben.

Vor Beginn des Experiments positionieren Sie bitte den Zeigefinger Ihrer linken Hand auf der Taste "D" und den Zeigefinger Ihrer rechten Hand auf der Taste "L".

Zu Beginn jedes Durchgangs erscheint ein weisses Kreuz in der Mitte des Bildschirms, gefolgt von "Los!".

Bitte druecken Sie entweder "D" oder "L", sobald "Los!" erscheint! Sie duerfen zwischen beiden Tasten frei waehlen.

Auf jeden Tastendruck hin erscheint ein Effekt im oberen oder im unteren Teil des Bildschirms. Falls Sie zu schnell oder zu langsam reagiert haben erscheint eine Fehlermeldung. Alle fehlerhaften Durchgaenge werden gespeichert und am Ende wiederholt.

Noch einmal eine kurze Zusammenfassung: Zunaechst erscheint ein weisses Kreuz, daraufhin "Los!"

Daraufhin druecken Sie so schnell wie moeglich die Taste "D" oder die Taste "L" - ganz wie Sie moechten!

Dann erscheint ein Effekt in der oberen oder der unteren Haelfte des Bildschirms, bevor es mit dem naechsten Durchgang weitergeht.

Achtung! Verwenden Sie beide Tasten in etwa gleich haeufig und vermeiden Sie Muster, so wie z.B. die Tasten immer abwechselnd zu druecken.

Achtung! Manchmal erscheint statt den "gewohnten" Effekten ein Effekt in der Mitte des Bildschirms. In diesem Fall druecken Sie bitte so schnell wie moeglich die LEERTASTE!

Wenn Sie noch Fragen haben, dann stellen Sie diese bitte jetzt. Ansonsten koennen wir mit dem Experiment beginnen.

Test phase instructions:

Dies war der erste Teil des Experiments. Nun geht es weiter mit der Testphase.

Positionieren Sie hierfür wieder den linken Zeigefinger auf der Taste "D" und den rechten Zeigefinger auf der Taste "L". Zunaechst erscheint wieder ein weisses Kreuz in der Mitte des Bildschirms - Zeit, sich auf die Reaktion vorzubereiten!

Sobald daraufhin ein Wort in der Mitte des Bildschirms erscheint, druecken Sie entweder die Taste "D" oder die Taste "L" - ganz wie Sie moechten!

Waehlen sie eine dieser beiden Tasten aus und reagieren Sie so schnell wie moeglich, sobald ein Wort erscheint!

In der Haelfte der Durchgaenge wird jedoch kein Wort erscheinen, sondern eine Folge von Zeichen ohne Bedeutung ("XXXXX").

Wenn "XXXXX" erscheint, sollen Sie jegliche Reaktion zurueckhalten, d.h. KEINE Taste druecken!

Nochmal eine kurze Zusammenfassung, bevor es losgeht:

Es erscheint ein weisses Kreuz in der Mitte des Bildschirms.

Daraufhin erscheint entweder ein Wort in der Mitte des Bildschirms, oder die Zeichenfolge "XXXXX".

Erscheint ein Wort, druecken Sie - so schnell wie moeglich - entweder "D" oder "L", wobei Sie zwischen den beiden Tasten frei waehlen duerfen.

Erscheint "XXXXX", druecken Sie gar keine Taste, bis es mit dem naechsten Durchgang weitergeht.

Der naechste Durchgang beginnt wieder mit einem weissen Kreuz in der Mitte des Bildschirms.

Fehler, also zu schnelle oder zu langsame Reaktionen und das Druecken einer Taste, obwohl "XXXXX" erscheint, werden zurueckgemeldet. Fehlerhafte Durchgaenge werden gespeichert und wiederholt.

Fertig? Dann koennen Sie das Experiment nun starten.

<u>Experiment 3</u>

Acquisition phase instructions:

1. For the *control group*:

Liebe Versuchsperson!

Vielen Dank fuer Ihre Teilnahme an diesem Experiment. Insgesamt dauert es ca. 35 Minuten und ist in eine Lern- und eine Testphase eingeteilt.

Die genaue Aufgabe wird Ihnen auf den folgenden Seiten erklaert. Es ist SEHR WICHTIG, dass Sie dieser Anleitung und den Hinweisen der Versuchsleitung genau folgen und waehrend des Experiments Ihr Bestes geben.

Vor Beginn des Experiments positionieren Sie bitte den Zeigefinger Ihrer linken Hand auf der Taste "D" und den Zeigefinger Ihrer rechten Hand auf der Taste "L".

Zu Beginn jedes Durchgangs erscheint ein weisses Kreuz in der Mitte des Bildschirms, gefolgt von der Aufforderung "Los!".

Bitte druecken Sie entweder "D" oder "L" sobald "Los!" erscheint!

Sie duerfen zwischen beiden Tasten frei waehlen!

Auf jeden Tastendruck hin erscheint ein Wort. Falls Sie zu schnell oder zu langsam reagiert haben erscheint eine Fehlermeldung. Alle fehlerhaften Durchgaenge werden gespeichert und am Ende wiederholt.

Noch einmal eine kurze Zusammenfassung: Zunaechst erscheint ein weisses Kreuz, daraufhin "Los!".

Daraufhin druecken Sie so schnell wie moeglich die Taste "D" oder die Taste "L" - ganz wie Sie moechten!

Dann erscheint ein Wort auf dem Bildschirm, bevor es mit dem naechsten Durchgang weitergeht.

Achtung! Manchmal erscheint statt den "gewohnten" Worten das Wort "HAUS"! In diesem Fall druecken Sie bitte so schnell wie moeglich die LEERTASTE.

Wenn Sie noch Fragen haben, dann stellen Sie diese bitte jetzt. Ansonsten koennen wir mit dem Experiment beginnen.

2. For the *experimental group*:

Liebe Versuchsperson!

Vielen Dank fuer Ihre Teilnahme an diesem Experiment. Insgesamt dauert es ca. 35 Minuten und ist in eine Lern- und eine Testphase eingeteilt.

Die genaue Aufgabe wird Ihnen auf den folgenden Seiten erklaert. Es ist SEHR WICHTIG, dass Sie dieser Anleitung und den Hinweisen der Versuchsleitung genau folgen und waehrend des Experiments Ihr Bestes geben.

Vor Beginn des Experiments positionieren Sie bitte den Zeigefinger Ihrer linken Hand auf der Taste "D" und den Zeigefinger Ihrer rechten Hand auf der Taste "L".

Zu Beginn jedes Durchgangs erscheint ein weisses Kreuz in der Mitte des Bildschirms, gefolgt von "Los!".

Bitte druecken Sie entweder "D" oder "L", sobald "Los!" erscheint! Sie duerfen zwischen beiden Tasten frei waehlen.

Auf jeden Tastendruck hin erscheint ein Bild in der Mitte des Bildschirms.

Falls Sie zu schnell oder zu langsam reagiert haben erscheint eine Fehlermeldung. Alle fehlerhaften Durchgaenge werden gespeichert und am Ende wiederholt.

Noch einmal eine kurze Zusammenfassung: Zunaechst erscheint ein weisses Kreuz, daraufhin "Los!"

Daraufhin druecken Sie so schnell wie moeglich die Taste "D" oder die Taste "L" - ganz wie Sie moechten!

Dann erscheint ein Bild in der Mitte des Bildschirms, bevor es mit dem naechsten Durchgang weitergeht.

Achtung! Verwenden Sie beide Tasten in etwa gleich haeufig und vermeiden Sie Muster, so wie z.B. die Tasten immer abwechselnd zu druecken.

Achtung! Manchmal erscheint ein Haus in der Mitte des Bildschirms! Sobald das Haus erscheint druecken Sie bitte so schnell wie moeglich die LEERTASTE!

Wenn Sie noch Fragen haben, dann stellen Sie diese bitte jetzt. Ansonsten koennen wir mit dem Experiment beginnen.

Test phase instructions:

Dies war der erste Teil des Experiments. Nun geht es weiter mit der Testphase.

Positionieren Sie hierfuer wieder den linken Zeigefinger auf der Taste "D" und den rechten Zeigefinger auf der Taste "L".

Zunaechst erscheint wieder ein weisses Kreuz in der Mitte des Bildschirms - Zeit, sich auf die Reaktion vorzubereiten!

Sobald daraufhin ein Wort in der Mitte des Bildschirms erscheint, druecken Sie entweder die Taste "D" oder die Taste "L" - ganz wie Sie moechten!

Waehlen sie eine dieser beiden Tasten aus und reagieren Sie so schnell wie moeglich, sobald ein Wort erscheint!

In der Haelfte der Durchgaenge wird jedoch kein Wort erscheinen, sondern eine Folge von Zeichen ohne Bedeutung ("XXXXX").

Wenn "XXXXX" erscheint, sollen Sie jegliche Reaktion zurueckhalten, d.h. KEINE Taste druecken!

Nochmal eine kurze Zusammenfassung, bevor es losgeht:

Es erscheint ein weisses Kreuz in der Mitte des Bildschirms.

Daraufhin erscheint entweder ein Wort in der Mitte des Bildschirms, oder die Zeichenfolge "XXXXX".

Erscheint ein Wort, druecken Sie - so schnell wie moeglich - entweder "D" oder "L", wobei Sie zwischen den beiden Tasten frei waehlen duerfen.

Erscheint "XXXXX", druecken Sie gar keine Taste, bis es mit dem naechsten Durchgang weitergeht.

Der naechste Durchgang beginnt wieder mit einem weissen Kreuz in der Mitte des Bildschirms.

Fehler, also zu schnelle oder zu langsame Reaktionen und das Druecken einer Taste, obwohl "XXXXX" erscheint, werden zurueckgemeldet. Fehlerhafte Durchgaenge werden gespeichert und wiederholt.

Fertig? Dann koennen Sie das Experiment nun starten.

Experiment 4

Acquisition phase instructions:

1. For the *control group*:

Liebe Versuchsperson!

Vielen Dank für Ihre Teilnahme an diesem Experiment. Dieser Teil dauert etwa 30 Minuten.

Die Aufgabe wird Ihnen auf den folgenden Seiten erklärt. Es ist sehr wichtig, dass Sie dieser Anleitung und den Hinweisen der Versuchsleitung genau folgen und während des Experiments Ihr Bestes geben.

Jeder Durchgang dieses Experiments beginnt damit, dass ein weißes Viereck auf dem Bildschirm erscheint. Sie sollen dann selber wählen, ob Sie die linke oder die rechte STRG Taste drücken.

Bitte wählen Sie die Taste zufällig aus und verwenden Sie beide Tasten in etwa gleich häufig.

Dem Tastendruck folgt dann ein tiefer oder ein hoher Ton. Die Töne sind nicht relevant für die Aufgaben und bitte ignorieren Sie die Töne.

Wenn Sie noch Fragen haben, dann stellen Sie diese bitte jetzt. Ansonsten können wir mit dem Experiment beginnen.

2. For the *experimental group*:

Liebe Versuchsperson!

Vielen Dank für Ihre Teilnahme an diesem Experiment. Der erste Teil dauert etwa 30 Minuten.

Die Aufgabe wird Ihnen auf den folgenden Seiten erklärt. Es ist sehr wichtig, dass Sie dieser Anleitung und den Hinweisen der Versuchsleitung genau folgen und während des Experiments Ihr Bestes geben.

Jeder Durchgang des Experiments beginnt damit, dass ein rotes Viereck auf dem Bildschirm erscheint. Gleichzeitig werden Sie eine Sequenz von zwei Tönen hören. Dabei vorkommen kann ein tiefer und ein hoher Ton.

Ihre Aufgabe ist es, diese Sequenz danach nachzuspielen, indem Sie die rechte und die linke "STRG"-Taste drücken. Finden Sie selbst heraus, welche Taste welchen Ton produziert!

Nachdem Sie die zu erzeugende Seuqenz gehört haben, erscheint ein "!" auf dem Bildschirm. Bereiten Sie sich nun auf Ihre Reaktion vor!

Drücken Sie die jeweilige Taste dann immer sofort, wenn - nach dem "!" - ein weißes Viereck auf dem Bildschirm erscheint!

Wenn Sie die Sequenz richtig gespielt haben, beginnt der nächste Durchgang.

Achtung: Die Schwierigkeit steigert sich! Sobald Sie dreimal eine Sequenz korrekt nachgespielt haben, wird ein weiterer Ton hinzugefügt. Machen Sie jedoch einen Fehler, reduziert sich die Sequenz wieder um einen Ton.

Bevor es losgeht, eine Zusammenfassung Ihrer Aufgabe:

Erst erscheint ein ROTES Viereck gemeinsam mit einer SEQUENZ aus zwei Tönen. Diese Sequenz sollen Sie nachspielen.

Dann erscheint ein "!" - bereiten Sie sich auf Ihre Reaktionen vor!

Danach erscheint ein WEISSES Viereck - drücken Sie nun die linke oder die rechte "STRG" - Taste, je nachdem welchen Ton Sie erzeugen möchten. Anfangs werden Sie vermutlich erst herausfinden müssen, welche Taste welchen Ton erzeugt - das ist gar kein Problem!

Für jeden weiteren Ton in der Sequenz erscheint ein weiteres weißes Viereck. Drücken Sie die jeweilige Taste so schnell wie möglich NACH dem Erscheinen des Vierecks! So erzeugen Sie die gewünschte Sequenz.

Vergessen Sie nicht: Wenn Sie dreimal erfolgreich die Sequenz nachgespielt haben, wird diese um einen Ton erweitert!

Machen Sie jedoch einen Fehler, wie z.B. den falschen Ton zu wählen oder zu langsam zu reagieren, wird die Sequenz wieder um einen Ton gekürzt.

Wenn Sie noch Fragen haben, dann stellen Sie diese bitte jetzt. Ansonsten können wir mit dem Experiment beginnen.

Test phase instructions:

Dies war der erste Teil des Experiments.

Von nun an beginnt jeder Durchgang damit, dass ein Ton erklingt. Dies kann einerseits einer der Töne sein, die im ersten Teil auf Ihren Tastendruck fogten. Wenn dies der Fall ist, drücken Sie bitte so spontan wie möglich die linke oder die rechte STRG Taste. Bitte vermeiden Sie es, immer nur die gleiche Taste zu drücken.

In anderen Durchgängen erklingt zu Beginn ein Glockenklang. Wenn dies der Fall ist, dann drücken Sie bitte keine der beiden Tasten, sondern warten bis zum Beginn des nächsten Durchganges.