Motion and Emotion: How emotional stimuli influence the motor system

Ana Carolina Saraiva

A dissertation submitted in partial fulfilment
of the requirements for the degree of
Doctor of Philosophy
of the
University College London (UCL)

Sobell Department of Motor Neuroscience and Movement Disorders

October 2016

Declaration

I, Ana Carolina Saraiva, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Abstract

This thesis examines the interaction between emotional stimuli and motor processes. Emotions are thought to be intimately linked to action, often triggering specific biases that automatically guide our behaviour for successful interaction. For example, emotional behaviour is influenced in a very specific way by two opposing appetitive and defensive motivational systems that trigger specific actions. Appetitive stimuli trigger approach, whereas aversive stimuli trigger avoidance, freezing or attack. These approach-avoidance tendencies are likely to interact with and bias various motor processes, such as action selection, planning and execution, revealing a privileged relationship between emotion and motor processes. However, this interaction remains poorly understood. Investigating how emotional tendencies influence different motor processes will further our understanding of how emotions influence actions. To this end, five experiments were conducted. Experiment One examined how approach-avoidance actions are selected. Experiment Two investigated how emotional cues in the environment bias and prepare for action to anticipated emotional stimuli. Experiment Three evaluated the effect of approach-avoidance tendencies on action execution and motor planning. Experiment Four assessed whether tendencies also influence our ability to suppress action execution. Finally, Experiment Five investigated whether updating of actions in response to emotional changes in the environment are influenced by response tendencies. Overall, this thesis found that approach-avoidance tendencies influence the selection of actions via a combination of top-down, goal-directed processes, and bottom-up, automatic processes. Predisposed tendencies did not influence any other motor process. Instead, positive and negative stimuli influenced action planning, execution and inhibition. Thus, motor processes are differentially influenced by approach-avoidance tendencies and emotional valence. This thesis demonstrates an intimate relationship between emotional stimuli and the motor system that appears to be influenced by both top-down and bottom-up mechanisms.

Acknowledgments

First and foremost, thank you to Sven for all the help, discussions, ideas, flexibility and freedom you have given me for the last 7 years. You have been a great supervisor, always supporting every idea I put on the table. Together we were able to build a project from scratch without knowing much about the field, and looking at the outcome now I think we did a very good job! As your first ever employee, I am glad I was able to see you flourish as a supervisor and I hope I also flourished as a student! Thank you for everything.

There have been other co-workers who have been very helpful in one way or another. Nick, many thanks for allowing me to sit in your office and chat about everything, including football! Marco, thanks for also being supportive of my work and most importantly for being the person who helped me code the joystick/manikin task that was the core of my entire thesis! Without it I would not have been able to do any experiments. Thanks to Paul for providing me with equipment for my experiments and who was always able to solve most of my technical difficulties.

Thanks to the Bestmann lab for all the support throughout the last 7 years. Thanks to Miriam and Friederike, who guided me through my first years in this project and taught me Matlab. Big thanks to Ale for being my lunch buddy for two years. Still hoping for the opening of Lusitalia or the writing of the “Lunchtime conversations” book. You were also the most helpful postdoc ever. Grazie per tua pazienza! Thanks to Louise and Graziella for allowing me to rant when I most needed to, and to Archy for always having great ideas. To the rest of the lab: thanks for putting up with my emotion stuff!

To the fourth floor fellows room: thanks for making our work environment so much fun, including the brief spell of “exercise” and the Friday drinks. Without having the odd interruption to work duties to talk about nothing important I would have never survived.

Thank you to all my friends: Cat, Soof, Andrew, Viki, Alex & Xica, Victoria, Geo, Tete and Janice. Without your support I would be slightly crazy right now. Massively thankful to the Ayash family who have been incredible and who have tirelessly supported me and given me everything for the last 12 years! Obrigada a minha familia Simoes-Garcia, Simoes-Assuncao e Saraiva-Lameiras, que sempre me apoiaram incondicionalmente. Voces sao os melhores e sei que sempre vao estar do meu lado. Adoro-vos.

Aos meus queridos pais, que merecem tudo o melhor neste mundo por me terem dado as melhores oportunidades possiveis. Nao posso agradecer o suficiente todo o apoio, carinho, amor, sabedoria e ajuda que me deram durante toda a minha vida. Estou muito orgulhosa de vos ter como pais. Los quiero mucho.

Last but most definitely not least, the biggest thanks of all to my husband Dani who has been through everything with me and whom without I would have never ever been able to push through with this thesis. You have been my absolute rock, my best friend and I cannot stress enough how grateful I am to you for putting up with my complaining, rants, outbursts and lack of financial means. I know you still don’t know what my thesis is about but that doesn’t matter because you have been there for me all along. Levi you are the best thing that ever happened to me and the best project I ever made (after this thesis of course!). I love you both.

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Glossary

Action execution: The execution of a selected and planned movement.

Action planning/specification: The process of specifying the spatiotemporal aspects of possible movements.

Action selection: The process of choosing an action from among many possible alternatives.

Action tendencies: States of readiness to execute specific actions that establish a particular relation with the environment, following emotional appraisal and driven by either appetitive or aversive systems.

Affective priming: The response towards, or categorisation of, a valenced stimulus that is affected by a preceding prime stimulus of the same valence.

Affordance: A potential action made possible to an agent by the environment around it.

Arousal: The intensity of the physiological response relative to an emotional stimulus.

Automatic: A process that occurs in (relative) independence from ‘top-down’ factors, such as attention and task instructions. At times, it is linked with the less strict notion of task-irrelevant or implicit processing.

Backward masking: A process whereby a visual stimulus is followed by another visual stimulus that “hides” the perceptual properties of the first stimulus thus impairing its detection or recognition.

Defensive circuit: A set of processing areas that detect danger, leading a heightened state of vigilance and which culminate in a defensive action.

Emotion: An episode of interrelated, synchronized changes in response to the evaluation of an external or internal stimulus event relevant to major concerns of the organism.

Emotional stimulus: A stimulus that is either positive or negative in its affective content.

Response facilitation: An improvement in behaviour, characterised by faster responses.

Goal directed: A behaviour that is set out to achieve desired outcomes or goals.

Implicit process: Task-irrelevant, involuntary or unintentional processing of a stimulus that leads to changes in the outcome response.

Response interference: A disruption in behaviour, characterised by slower responses.

Interhemispheric transfer: The flow of information from one hemisphere to another; e.g. information from the left eye travels to the right side of the brain which subsequently needs to transfer to back to the left side in order to influence the movement of the right arm.

Motor processes: Comprised of different motor stages such as action selection, planning and execution.

Muscle-specific: Arm movements that activate specific muscle groups. For instance, pulling triggers flexion muscles, whereas pushing activates extension muscles.

Predisposed: An action that is innate or has become automatic via repetitive behaviours.

Response inhibition/suppression: Suppression of actions that are no longer required or that are inappropriate.

Subliminal presentation: Short or weak stimulus presentations that do not elicit a conscious perception, but that result in a behavioural or physiological change.

Supraliminal presentation: Supra-threshold perceptual state in which subjects are aware of the stimulus and that result in a behavioural or physiological change.

Unconscious perception: A stimulus that is presented but is processed without any awareness of its presence or content.

Valence: Stimulus dimension that varies from ‘pleasant’ to ‘unpleasant’.

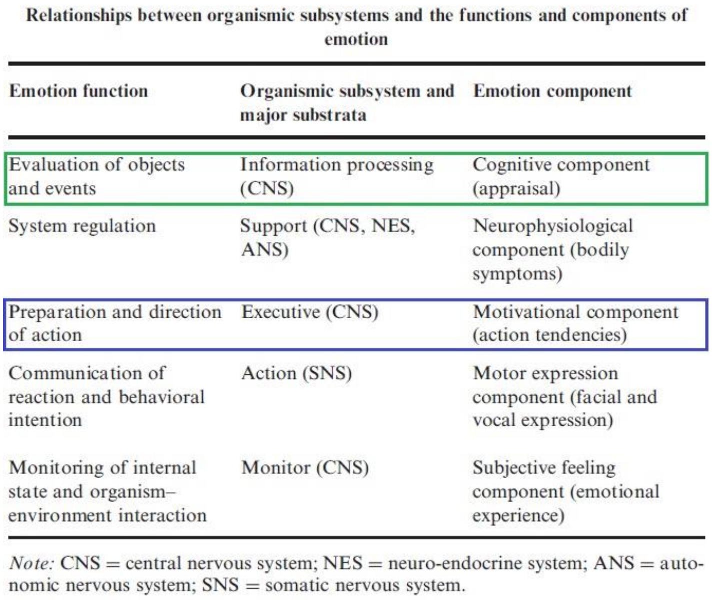
Vigour: The effort expended once an action has been initiated in order to achieve a desirable outcome. It can be characterised by variables such as movement time, acceleration or strength.

1. Introduction

"***The motor system of the brain exists to translate thought, sensation, and emotion into movement***". (Henneman, 1974)

There is no exact definition of what emotion is, but a general consensus is that emotions are a complex psychological and physiological reaction to both external and internal stimuli that are relevant to the individuals' concerns (Darwin, 1872; Frijda, 1986; James, 1884; Scherer, 2005). Emotional experience can be divided into five main components that function independently of each other yet all coordinate and contribute to the processing of emotions (**Table 1**; Eder & Rothermund, 2013; Roseman, 2014; Scherer, 2005). This framework suggests a serial processing of emotion, whereby an emotional stimulus is initially evaluated and processed (*cognitive response*), followed by physiological arousal (*somatovisceral response*) and the preparation of the body for action (*behavioural response*). Subsequently the organism communicates emotion via facial or vocal expressions (*expressive response*) which ultimately affects the internal state of the organism and results in feelings (*experiential response*).

Emotions are therefore thought to be intimately linked to action (Frijda, 1986). The word emotion itself is derived from the Latin word *movere*, which means to move. But, what is an action? Actions are the process of converting thought into overt behaviour. Here, the motor system incorporates emotional information to select, plan and execute appropriate responses. Indeed, emotions such as fear, anger, happiness and disgust, have been suggested to be fundamental predispositions for action (Damasio, 1994; Frijda, 1986; James, 1884), often triggering specific biases that automatically guide our behaviour for successful interaction (Bargh, Chaiken, Raymond, & Hymes, 1996; Lang, 1995; Lang & Bradley, 2010). Despite the intricate relationship between emotions and actions, the link between emotional processes and the motor system remains poorly understood.



Relationships between organismic subsystems and the functions and components of emotion

Emotion function	Organismic subsystem and major substrata	Emotion component
Evaluation of objects and events	Information processing (CNS)	Cognitive component (appraisal)
System regulation	Support (CNS, NES, ANS)	Neurophysiological component (bodily symptoms)
Preparation and direction of action	Executive (CNS)	Motivational component (action tendencies)
Communication of reaction and behavioral intention	Action (SNS)	Motor expression component (facial and vocal expression)
Monitoring of internal state and organism–environment interaction	Monitor (CNS)	Subjective feeling component (emotional experience)

Note: CNS = central nervous system; NES = neuro-endocrine system; ANS = autonomic nervous system; SNS = somatic nervous system.

Table 1. Relationship between emotional components and their corresponding subsystems, as well as presumed underlying substrata and functions (Scherer, 2005). This thesis will focus specifically on the preparation and direction of action (blue rectangle) and how critical the evaluation of emotional stimuli is for response tendencies to arise (green rectangle).

Emotions, motivational systems and specific action tendencies

The special relationship between emotions and actions has been demonstrated in studies investigating the influence of emotions on motor performance. Emotional stimuli can, for example, influence the speed of action initiation (Naugle, Hass, Joyner, Coombes, & Janelle, 2011), disrupt or increase the speed of suppressing actions that are no longer required (Albert, López-Martín, & Carretié, 2010; Pessoa, Padmala, Kenzer, & Bauer, 2012; Verbruggen & De Houwer, 2007), and modulate how an action is executed (Coombes, Gamble, Cauraugh, & Janelle, 2008; Esteves et al., 2016). These effects of valence on various motor processes, whereby positive and negative stimuli modulate behaviour relative to neutral stimuli, reveal an intricate relationship between emotion and motor processes.

However, these effects disregard the fact that emotional behaviour is influenced in a very specific way by two opposing motivational systems: appetitive and defensive (Lang & Bradley, 2013; Lang & Bradley, 2010; Lang, Bradley, & Cuthbert, 1990). Appetitive behaviour is guided by positive stimuli that are typically linked to approach actions, whereas defensive behaviour, such as avoidance, freezing or escape, is typically linked to negative and threatening stimuli (Lang, Davis, & Ohman, 2000; Lang, Bradley, & Cuthbert, 1997). These “primitive” motivational systems exist to promote survival in emotional situations (Darwin, 1872; LeDoux, 1996). For instance, choosing the wrong action in response to an emotional stimulus could be potentially costly: fighting off a bear might not be as successful as running away from it. It is this “survival” aspect that can make emotional stimuli and their associated action tendencies so influential on the motor system and important for appropriate behaviour. Thus, investigating the role that these motivational tendencies play in guiding action processes is fundamental for our understanding of the nature of how these “primitive” systems interact with the motor system.

Models of appetitive and defensive behaviour (Fanselow, 1994; Lang et al., 1997; LeDoux 2000) suggest that emotional stimuli lead to heightened vigilance relative to non-emotional stimuli, direct attention to the stimulus of interest and trigger actions that are selected from a wide repertoire of possibilities such as, for example, approach, avoidance or freezing. Thus, emotional behaviour occurs along a progression from an attentional state to active action through sensory-motor integration (Lang & Bradley, 2013; LeDoux, 2012). The predatory-imminence model, for instance, proposes that actions in threatening situations are selected from a “predatory imminence continuum” whereby according to the level and type of threat, behaviour will transition from increased attention and passive immobility to active fight-or-flight responses (Fanselow, 1994). This model was later extended to include appetitive approach behaviour (Lang et al., 1997). Other models propose that the detection of threat and subsequent responses occurs through learned experience, whereby associations between the evaluation of biologically relevant stimuli and specific actions serve as triggers along a sensory-motor circuit (Damasio, 1994; LeDoux, 2000).

Importantly, these models suggest that defensive actions will be faster when negative stimuli are detected, whereas approach actions will be faster in positive contexts (Bargh, 1992; Bradley, Codispoti, Cuthbert, & Lang, 2001; Lang et al., 1990). Indeed, work on humans has shown that initiating approach is faster when presented with positive stimuli, whereas initiating avoidance is faster when presented with negative stimuli (Chen & Bargh, 1999; Lavender & Hommel, 2007; Rotteveel & Phaf, 2004; Stins et al., 2011). This has been replicated numerous times using diverse stimuli (e.g. pictures, faces, words) and diverse task-settings (e.g. moving a lever, pressing buttons, moving the whole body), consolidating the idea of response tendencies that are triggered faster in certain emotional contexts as a result of appetitive and defensive systems (LeDoux, 2000).

Is there an "emotion continuum" that influences action?

While there is a clear relationship between emotional valence and approach-avoidance tendencies, there is a distinction between both. Valence refers to the positivity or negativity of a stimulus. Approach-avoidance tendencies are responses associated to the valence. It is precisely that positivity or negativity that will subsequently inform approach-avoidance tendencies. It is possible that the two work together along an "emotion continuum" in order to lead to appropriate action when we encounter an emotional stimulus. For example, specific approach-avoidance tendencies tied to positive and negative stimuli may influence what actions are selected in relation to that valence (e.g. how negative is this stimulus and what do I need to do in response to that negative stimulus [e.g. an aggressive person]?), and the negativity of that stimulus may subsequently influence motor processes after an approach or avoidance action has been selected (e.g. I need to push that very strong aggressor away very forcefully [e.g. make more effort]). However, in the latter example, both avoidance tendencies and the negativity of the stimulus may work together to influence various motor processes. At present, the interaction between both in motor processes that occur after action selection is currently unknown.

Emotion and action tendencies: influences on the motor system

The specific link between approaching positive and avoiding negative stimuli provides an ideal testbed for studying the interaction between emotion and action. This emotionally-driven action-specificity is likely to interact with various motor processes. They may, for example, bias how we select and prepare actions; influence how well we execute actions; and determine how quickly we inhibit inappropriate responses. Understanding this is important because each of these processes is guided by different underlying mechanisms. How emotional stimuli and associated tendencies influence these processes is unknown. Thus, investigating how emotional tendencies influence different motor processes will further our understanding of how emotions influence actions.

To this end, this thesis aimed to shed light on the influence that emotional stimuli and associated approach-avoidance tendencies have on different stages of motor processing. This thesis will focus specifically on how such response tendencies influence the preparation and direction of action (blue box in Table 1), and how crucial stimulus evaluation is for approach-avoidance tendencies to occur (green box in Table 1). In the section below, I address the different motor stages that may be under the influence of approach-avoidance tendencies. I will subsequently highlight the rapid conscious and unconscious processing of emotional stimuli and explain to what extent these tendencies are thought to be automatic. Finally, some methods will be highlighted, followed by a brief outline of each chapter.

1.1. The influence of emotion on action selection, planning and execution

The motor system is constituted by a functional hierarchy that is divided into several processes (Gallistel, 1980; Ghez & Krakauer, 2000; Wong, Haith, & Krakauer, 2015). Generally, movement generation can be divided into two separate phases (**Figure 1.1**): a "what" phase concerned with the selection of a motor goal (i.e. identification and intention), and a "how" phase concerned with the specification of an action (i.e. action selection and motor planning) (Cisek & Kalaska, 2010; Wong et al., 2015; Zhu & Thagard, 2002). At the highest level, the "what" phase of movement is involved in the perceptual evaluation and identification of stimuli and in forming intentions and selecting goals. This selection of goals informs the "how" phase, which serves to translate a goal into a course of action and is itself also divided into two separate processes: the high-level selection of actions and planning of movement features (e.g. selecting the effector, defining the spatiotemporal characteristics of movement). The end stage of motor processing involves "low-level" action execution and the implementation of motor commands prepared during the "how" phase.

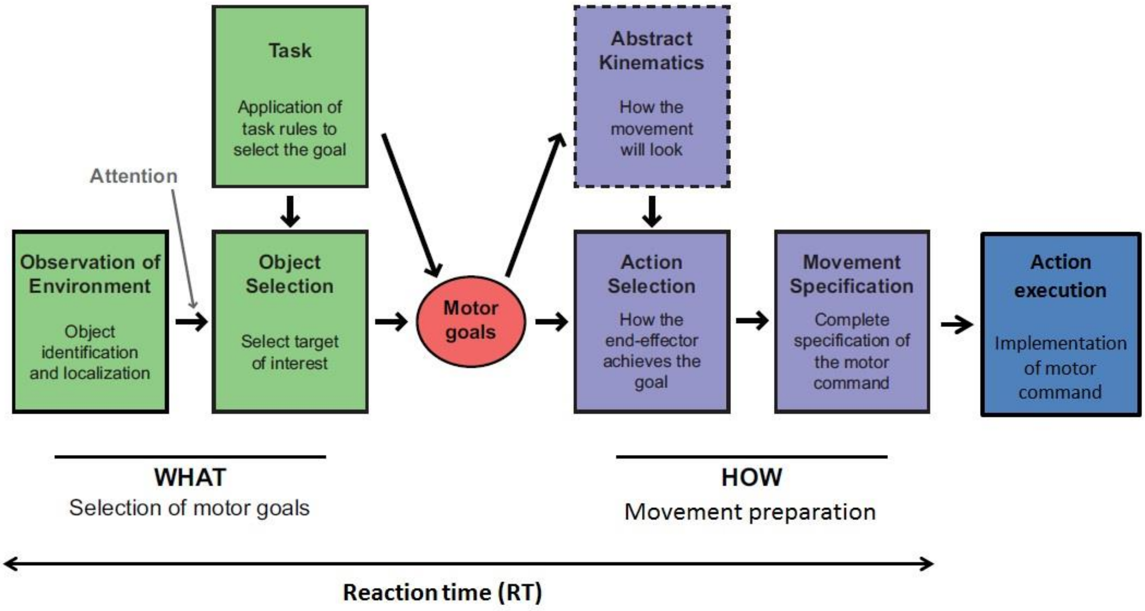


Figure 1.1. Processes concerned with movement generation. Movement generation can be divided into two separate phases: the "what" phase, concerned with the selection of a motor goal (i.e. identification, intention and goal selection), and the "how" phase, concerned with movement preparation (i.e. action selection and motor planning) (modified from Wong et al. 2015). Motor commands are implemented during execution.

The functional organisation of movement therefore allows stimuli to interact with the motor system at various stages. While it is evident that emotion influences action, we do not know which of these stages emotional stimuli and associated emotional tendencies interact with. Some evidence indicates that deciding whether to approach or avoid following stimulus evaluation is likely to occur in areas of the PFC (Damasio, 1994; Roelofs, Minelli, Mars, van Peer, & Toni, 2009; Volman, Roelofs, Koch, Verhagen, & Toni, 2011),guided by subcortical pathways that process emotion (LeDoux, 1996), whereas the planning of actions in response to emotional stimuli most likely occurs in the premotor cortex (Coombes, Corcos, Pavuluri, & Vaillancourt, 2012). Approach-avoidance tendencies may therefore interact with different motor processes guided by different underlying mechanisms.

Thus, emotional approach-avoidance tendencies may influence the "what" and "how" phases of movement generation in specific ways, but the specific details of this influence remain largely undetermined. Various key questions remain unanswered. How does action selection of approach-avoidance tendencies occur and what are the possible underlying mechanisms? Do these tendencies also influence how quickly we inhibit inappropriate movement? Do these tendencies determine the planning of movement parameters that will be sent as motor commands, thus influencing how an outcome is achieved? Do emotional changes in the environment influence and adapt action execution according to emotional tendencies? Each of these questions addresses different processes and mechanisms that emotional stimuli can interact with **(Figure 1.2)**. Importantly, they are key to understanding how emotions influence actions. In the following subsections I delve deeper into how these questions will inform of the emotion-action link.

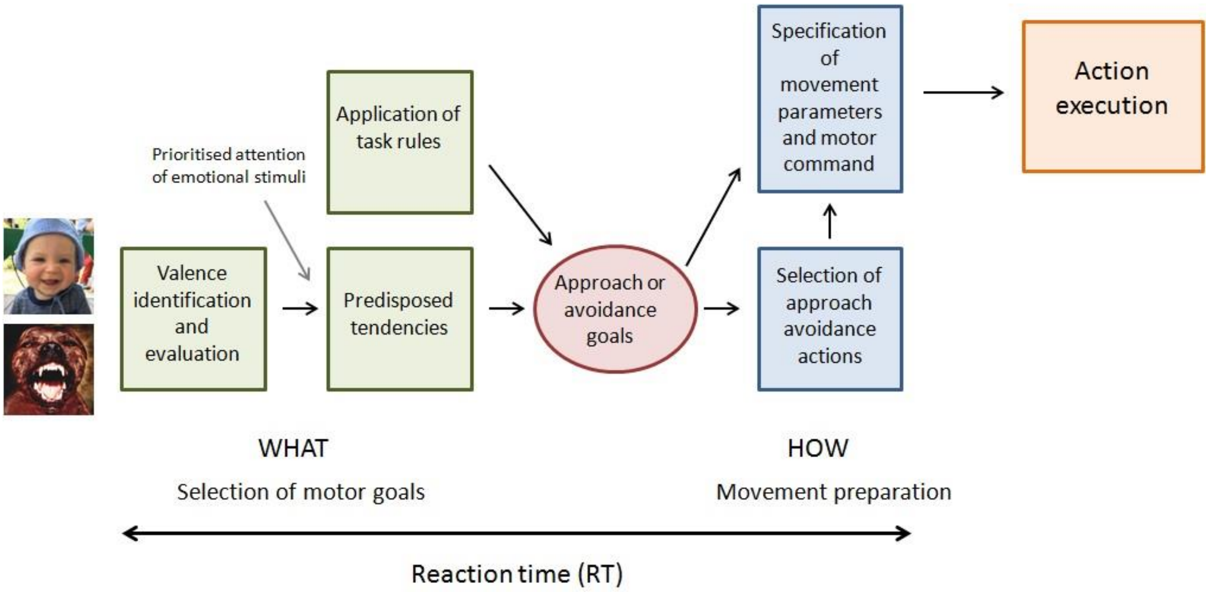


Figure 1.2. Processes concerned with movement generation in emotional situations. The selection of motor goals in the "what" phase involves the fast prioritisation of emotional stimuli which subsequently leads to the activation of predisposed approach-avoidance tendencies. Top-down influences from task instructions are likely to also influence goal selection. Approach-avoidance goals then influence the preparation of movement (selection and planning) (adapted from Wong et al. 2015). Movement parameters and motor commands are implemented during action execution.

1.1.1. Emotional stimuli and the selection and planning of actions

As explained above, the "how" phase of a movement can be divided into essentially two processes: action selection and movement planning. Here, I explain how processes involved in the structuring of an action are influenced by emotional stimuli.

1.1.1.1. Action selection

1.1.1.1.1. The affordance competition hypothesis

Classic models of action selection have always assumed that decisions are made in top-down areas and then passed down to low-level areas for execution (Pylyshyn, 1986). This idea of serial processing has been challenged by models proposing that the motor system is not just the "end-product" of cognition but rather, that it is a key influence on decision-making and biasing processes that take place prior to execution (Cisek, 2007; Cisek & Kalaska, 2010). Indeed, selecting actions involves a complex and integrated network that interacts in parallel across frontal, perceptual and motor areas and is dependent on our environment (**Figure 1.3**; Cisek & Kalaska, 2010). This idea stems from proposals that our environment is full of stimuli that "afford" the opportunity for action (Gibson, 1977). That is, some stimuli can activate several competing response alternatives that all generate their own motor plan, leading to several potential actions that would all, for example, interact with the stimulus (e.g. picking up a mug by gripping by the handle, the top rim or the whole mug) (Cisek & Kalaska, 2002). These partially prepared motor plans will eventually be biased by decision-relevant information gathered over time (Basso & Wurtz, 1998; Hanks et al., 2015; Oliveira, Diedrichsen, Verstynen, Duque, & Ivry, 2010). For instance, picking up a mug filled with freshly boiled water by holding the handle is more favourable than gripping the mug with the whole hand in order to avoid burning. This decision will be biased by gathering information related to the contents of the mug, which ultimately resolves the competition amongst response alternatives and leads to action selection. This framework has been termed the "*affordance competition hypothesis*" (**Figure 1.3;** ACH; Cisek, 2007; Cisek & Kalaska, 2010), and it suggests that action selection is biased by reciprocal and continuous influences between top-down and bottom-up levels (Bogacz, Brown, Moehlis, Holmes, & Cohen, 2006; Ratcliff & McKoon, 2008) that lead to parallel processing of decision processes and action plans. Other models of action selection support this idea by also suggesting that some degree of parallel competition between response alternatives must occur for successful behaviour (Beck et al., 2008; Redgrave, Prescott, & Gurney, 1999).

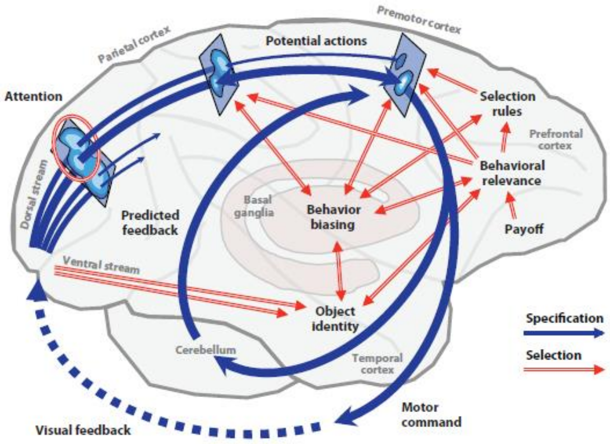


Figure 1.3. Schematic of the "affordance competition hypothesis" detailing the key structures involved in action selection and biasing responses (Cisek & Kalaska, 2010). This hypothesis implies a parallel processing of decision and action, and of several action plans, with action selection being biased by the accumulation of decision evidence determined by the environment.

Although this model has not been extended to incorporate emotional stimuli, it may serve as a blueprint for action selection in emotional situations. For instance, when encountering a negative stimulus both approach and avoidance (i.e. fight-or-flight) may be simultaneously planned as defensive actions, yet the type of negative stimulus (e.g. bear) will bias the selection of an action to what is most appropriate given the context, in this case running away. The *ACH* suggests that subcortical areas such as the basal ganglia that process selection-related information (Mink, 1996; Redgrave et al., 1999) and higher-order areas that detect context and value (Padoa-Schioppa & Assad, 2008) may bias the resolution of competition amongst various motor plans. This interaction can extend to emotional actions. The basal ganglia, for instance, also receive emotional information via limbic cortico-striatal circuits (Jahanshahi, Obeso, Rothwell, & Obeso, 2015) and other subcortical areas involved in emotion processing such as the amygdala (Cho, Ernst, & Fudge, 2013), which can bias motor output that is fed onto higher-order areas and which ultimately biases action selection (Middleton & Strick, 2000).

Similarly, top-down processing has been implicated in action selection and decision-making in emotional contexts (Damasio, 1994). For instance, the orbitofrontal cortex (OFC) has been shown to play a role in the selection of valence-related approach-avoidance actions, demonstrating that this area is essential to override predisposed response tendencies and guide the selection of actions contrary to these tendencies (Roelofs et al., 2009). The initiation of so-called "incongruent" actions (i.e. approach negative and avoid positive) leads to increased OFC activity, suggesting that this region is recruited to overcome emotional action tendencies. Further support comes from work showing that disruption to the anterior PFC using transcranial magnetic stimulation impairs the correct selection, and subsequent initiation, of approach-avoidance actions (Volman et al., 2011). This evidence suggests that action selection in approach-avoidance tasks is guided by higher-order areas involved in goal formation and action specification.

Subcortical and cortical areas may therefore bias action selection in emotional contexts. Evidence in favour of this bias comes from work showing that the midcingulate cortex receives emotion-related input from the OFC and insula and is involved in translating emotional information into actions (Pereira et al., 2010). Thus, speculatively, the *ACH* may provide a framework for action selection in emotional contexts. From the point of view of optimal behaviour, the planning of several actions simultaneously may be beneficial since emotional situations may change rapidly and require fast action to avoid detrimental behaviour. For example, approaching to hug a friend with a dog in a leash may require a rapid change from approach to avoidance if their dog suddenly became aggressive. This rapid change may rely on the simultaneous planning of multiple actions. If approach-avoidance tendencies exist, in an emotional context one planned action may be selected faster over another given their predisposition. Such approach-avoidance response tendencies should therefore influence the speed of action selection amongst competing responses.

1.1.1.1.2. The theory of event coding

Other models that explain how action selection may occur suggest an overlap between perceptual and action processing. The *theory of event coding* (TEC; Hommel, Müsseler, Aschersleben, & Prinz, 2001) based on the ideomotor and common-coding principles (Prinz, 1987, 1990; Stock & Stock, 2004), suggests that motor patterns underlying actions are represented by codes of their anticipated perceptual consequences. These perceptual codes are generated through experience and stored in memory, becoming retrieval cues that will be used in subsequent similar situations and thereby leading to the selection of the most appropriate action. This is similar to the somatic marker hypothesis (Damasio, 1994), whereby affective experiences are stored together with produced actions, becoming markers that are triggered in certain situations.

The *TEC* assumes that representations for perception and action share similar feature codes that must be co-activated and integrated for action selection to occur. Action selection occurs thus when there is an overlap between perceptual and action codes. For instance, generating the idea of an action activates codes that represent the perceivable effects of that action (i.e. goal generation) which in turn activate codes representations for that particular action (i.e. action selection). Thus, "thinking about an action" is imperative for selecting an action. Importantly, *TEC* does not consider action selection and motor planning as two sequential entities, but rather, assumes that when selection of action features activates a specific code, this code activation will also activate motor codes responsible for planning an action. Thus, it assumes that selection and planning occur in parallel, in support of the *ACH*.

Unlike the *ACH* hypothesis, the *TEC* has been adapted to account for selection in emotional situations (Eder & Klauer, 2009; Eder & Rothermund, 2008; Lavender & Hommel, 2007). For example, approaching a positive object is represented by codes for moving towards but also by codes for positive and rewarding feelings. Here, the action and perceptual codes overlap because they are both considered positive. Similarly, avoiding a negative stimulus is represented by codes for moving away but also by codes for potential costs/punishments. Both of these codes are considered negative. The overlap of affective codes is what leads to faster action selection. Furthermore, actions can be defined relative to the body or relative to an external object (Markman & Brendl, 2005). Thus, the frame of reference may also play an important role in generating affective codes. Moving towards a positive stimulus or bringing a positive stimulus towards the self will both be coded as positive, yet will activate different actions (Lavender & Hommel, 2007; Seibt, Neumann, Nussinson, & Strack, 2008). This suggests that actions that engage different effectors may be coded as having a similar affective valence depending on the type of emotional stimulus. Importantly, this framework suggests that goals and contextual evaluations of emotional situations are important determinants of the selection of approach and avoidance. Indeed, work has shown that while approach-avoidance tendencies may arise automatically, this automaticity is achieved based on the intentional implementation of approach-avoidance given the current setting (Bargh, 1989).

Different theories therefore appear to advocate similar ideas: both the *ACH* and the *TEC* suggest that action selection is a flexible, goal-directed process guided by environmental affordances. However, there are some differences. The *ACH* provides a biologically grounded framework that accommodates how interactions between cortical and subcortical regions may combine to bias actions in emotional contexts. In contrast, the *TEC* makes no formal assumption of biologically relevant processes and their anatomical underpinnings, but instead provides a psychological framework based on mental processes. Furthermore, the *ACH* bases selection on a competition of many response alternatives. Similarly, the *TEC* assumes that a stimulus can activate various perceptual and action codes simultaneously, but only codes that overlap in their affective coding will result in selection. Thus, rather than selection being biased by evidence accumulation over time like in the *ACH*, selection is biased by coding overlap. While both are integrative frameworks, they suggest different underlying mechanisms for action selection in emotional contexts.

1.1.1.1.3. Action selection in emotional contexts: flexible or rigid?

From an evolutionary perspective, actions in emotional situations would be considered to be rigidly predetermined in order to allow for fast and efficient behaviour (Darwin, 1872). Indeed, selection of approach-avoidance actions has been suggested to occur according to specific effectors in a rigid manner (Cacioppo, Priester, & Berntson, 1993; Chen & Bargh, 1999). However, this sort of hardwired behaviour is not ecologically beneficial given the numerous possibilities for action in a given environment. In threatening situations, for example, both fight-or-flight may be appropriate responses but are selected according to the affordance of the situation. A hardwired framework would not allow for this flexibility.

Despite a general consensus from the approach-avoidance literature that we are faster to initiate movements towards positive and away from negative stimuli, there is no general consensus as to how exactly approach-avoidance is triggered by emotional stimuli. Action selection in emotional contexts may be guided in a hardwired manner by specific effectors tied to predisposed tendencies or in a flexible manner by goals and contextual information **(Figure 1.4)**. This specific question was addressed in Chapter Two, with the aim to determine how different interchangeable contexts (i.e. different reference frames) and different effectors affect approach-avoidance tendencies, providing further evidence of how actions to positive and negative stimuli are selected.

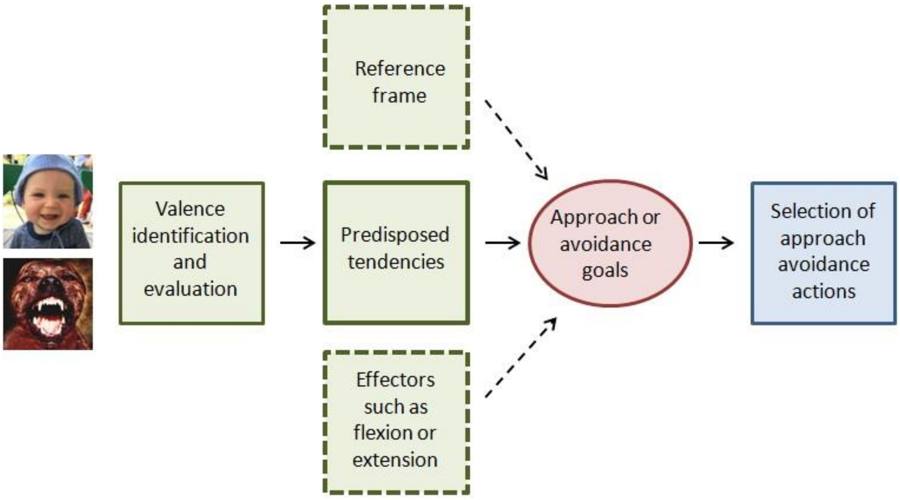


Figure 1.4. Suggested model of action selection in emotional situations. The formation of approach-avoidance goals during the "what" phase is assumed to be influenced by approach-avoidance tendencies. However, goal formation can also be biased by rigid muscle-specific tendencies (i.e. flexion/extension) or flexible contextual demands (i.e. the reference frame: am I moving to the stimulus or the stimulus moving to me?) that interact with approach-avoidance tendencies. For instance, approaching a positive stimulus by moving towards it.

1.1.1.2. Motor planning

Following the selection of actions, motor planning is the process that establishes the parameters that define how a movement is executed and a goal is achieved (Desmurget et al., 1999; Marteniuk, MacKenzie, Jeannerod, Athenes, & Dugas, 1987; Paulignan, Frak, Toni, & Jeannerod, 1997; Wong et al., 2015). Motor planning translates an abstract goal defined in the "what" phase into a concrete action. The appropriate implementation of action parameters is what determines how successful behaviour is. For instance, we may decide to pick up a mug, yet for a successful outcome, we must pick up a mug with sufficient strength so as to avoid dropping it on the floor. It has been suggested that the specification of movement parameters is a separate process to action selection (Wong et al., 2015).

While selection and planning processes may be separate entities with different underlying mechanisms, this does not mean they cannot work in parallel with each other. Indeed, the *ACH* suggests that these processes occur simultaneously during behaviour (Cisek, 2007; Cisek & Kalaska, 2005), with continuous monitoring of the environment feeding information into both selection and planning processes. Thus, the specification of action parameters, just like action selection, relies on sensory information from the environment, for example, the relation of the body to an object in space (Cisek, 2007). The parallel processing of selection and planning is important because it essentially suggests that while these processes have different underlying mechanisms, information that biases one process may also bias the other. As such, it may be possible that in emotional situations, emotional biases on action selection will also bias the planning of movement parameters for successful behaviour.

One way to explore biases on motor planning is by investigating vigour, that is, the effort expended once an action has been initiated in order to achieve a desirable outcome (Niv, Daw, & Dayan, 2005). Vigour is reflected in the spatiotemporal properties of movement such as strength or speed, which are presumably determined during motor planning. Recent work has revealed that vigour is biased by the value of a predicted outcome, whereby a rewarding stimulus leads to more vigorous action, and a punishment leads to less vigorous action (Guitart-Masip, Beierholm, Dolan, Duzel, & Dayan, 2011; Guitart-Masip, Duzel, Dolan, & Dayan, 2014; Niv et al., 2005). Similar work has revealed that the effort one must produce during execution informs individuals about the value of a reward, with increasing amounts of perceivable effort seeming less rewarding and leading to less vigorous actions (Klein-Flügge, Kennerley, Saraiva, Penny, & Bestmann, 2015). Similarly, uncertainty about an outcome is incorporated into movement plans in order to maximise rewards and minimise costs (Hudson, Maloney, & Landy, 2008; Zhang, Morvan, & Maloney, 2010). The more uncertain the environment, the more variable and less rewarding the movement. The parameters of vigour established during motor planning therefore reflect the opportunity cost of an action: the more rewarding a stimulus is, the more vigorous an action is, while the more aversive a stimulus is, the less vigorous an action will be.

How is this relevant to emotional situations? Emotional stimuli can be assigned positive or negative values: positive stimuli can be rewarding, whereas negative stimuli can be considered punishments (Lang & Bradley, 2008; Rolls, 2000). If non-emotional rewards and punishments, which are classified as positive and negative in value, bias the vigour of actions, then it is possible that positive and negative emotional stimuli also bias motor planning and vigour. More specifically, this bias may arise from approach-avoidance tendencies that lead to certain outcomes. For example, approaching a positive stimulus could be seen as rewarding, but approaching a negative stimulus may be seen as potentially costly. The same action is assigned a different value depending on the emotional stimulus. Similarly, in emotional situations some actions may lead to more certain outcomes than others. Approaching a threatening stimulus, for instance, will cause a higher degree of uncertainty about the outcome, whereas avoidance will cause greater certainty that the outcome will be positive. Approach-avoidance tendencies may therefore influence the degree of uncertainty of an action. Vigour thus allows to assess and assay the extent of this uncertainty.

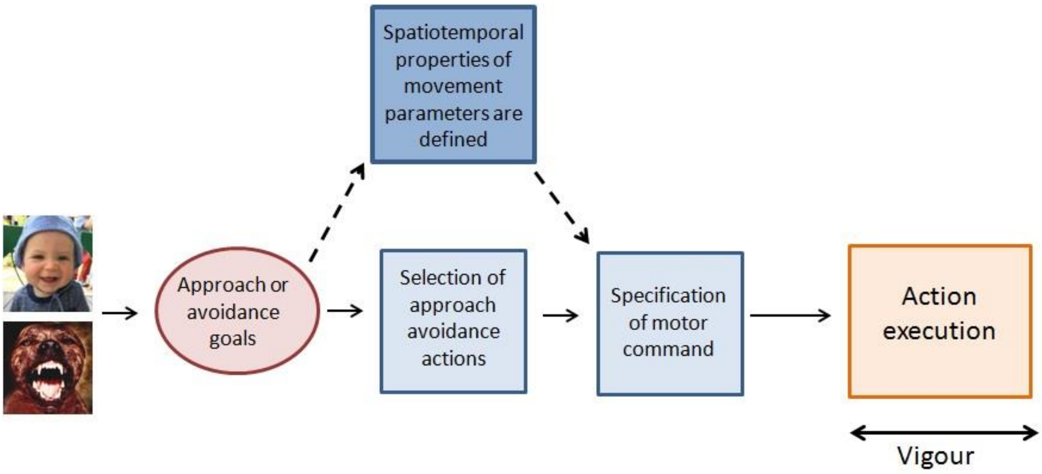


Figure 1.5. Model of how approach-avoidance tendencies may influence motor planning. Once goals have been selected, these goals are expected to bias selection and planning of movement parameters in parallel. These parameters specify the motor command which is implemented during execution. The vigour of an action should reflect these biases.

It is currently poorly understood whether approach-avoidance tendencies have an influence on vigour. Some recent evidence has shown an influence of these tendencies on the spatial (Stins, van Gelder, Oudenhoven, & Beek, 2015), and temporal (Esteves et al. 2016) properties of execution, giving some indication of an influence on movement planning. However, other evidence suggests that vigour is not modulated by emotional stimuli or associated tendencies (Coombes, Cauraugh, & Janelle, 2007, 2007; Stins, Roelofs, et al., 2011; Stins & Beek, 2011).

Taking into account the *ACH*, if approach-avoidance tendencies influence action selection, then such tendencies should also influence the specification of movement parameters **(Figure 1.5)**. This should be the backbone of successful emotional behaviour: selecting to run away should be complemented by running away more vigorously. To this end, Chapter Four investigated the influence of approach-avoidance tendencies on motor planning and vigour, giving further insight into the link between emotions and actions.

1.1.1.3. *<u>The suppression of actions</u>*

Suppressing actions that are no longer appropriate or advantageous is a fundamental requirement of flexible and successful behaviour (Aron, 2007; Aron et al., 2007; Verbruggen & Logan, 2008). In emotional situations, failure to inhibit inappropriate responses may lead to potentially costly outcomes. In everyday life stimuli lead us to prepare and execute actions (“go” stimuli), but occasionally, a stimulus signalling us to stop us from executing a prepared action may arise (“stop” stimulus). For instance, in a crossing a green light may signal us to start walking, but an unexpected passing car may signal us to inhibit walking. Response inhibition is therefore a fundamental influence on motor processing.

The success of inhibition is dependent on competition between the preparation of a response following the “go” stimulus and the preparation of stopping processes following the appearance of the “stop” stimulus. This competition between two processes has been described in the “*Horse Race Model*” (Logan & Cowan, 1984; Verbruggen & Logan, 2009). In situations where one is required to stop their actions, if the “go” process is completed before the “stop” process (i.e. if action preparation was sufficiently fast), then inhibition would be difficult and a response will be executed. In contrast, if the “stop” process is completed before the “go” process (i.e. if action preparation was slow), inhibition is successful. The speed of action suppression is therefore an indication of how quickly preparation to respond occurred (De Jong, Coles, Logan, & Gratton, 1990; Verbruggen & Logan, 2009). Some actions may be easier to prepare than others making them harder to inhibit, whereas unprepared responses will be easier to inhibit.

The speed of inhibition relies on competition between preparatory processes, and the inhibition itself requires the immediate suppression of an effector. How is this achieved? Two mechanisms have been proposed for this. The first one involves a global stopping mechanism, whereby the prepared response and other response alternatives are suppressed simultaneously (Badry et al., 2009; Coxon, Stinear, & Byblow, 2007; Majid, Cai, George, Verbruggen, & Aron, 2012). For instance, when suppressing a finger movement, there was also suppression of neural excitability of the leg despite the leg being task-irrelevant (Badry et al., 2009). This type of inhibition is therefore nonselective in that all motor output is suppressed and it may be beneficial in situations that require the avoidance of potential danger. The second mechanism is more selective in that specific, rather than all, tendencies are suppressed (Aron, 2011; Aron & Verbruggen, 2008). That is, one specific action may be inhibited but other effectors may still be active. Selective inhibition may be important in situations where, for instance, one needs to inhibit a prepared approach response towards an animal that turned aggressive while simultaneously initiating an avoidance movement. In this situation inhibiting both approach and avoidance would not be beneficial.

Why is response inhibition relevant to the link between emotions and actions? Inhibition in the motor system can be deployed in two separate ways through distinct pathways. Inhibition of competing response alternatives during action selection, for instance, occurs prior to response initiation and is mediated via dorsal premotor areas, biased by cortical and subcortical structures (Cisek, 2007; Cisek & Kalaska, 2005). Response inhibition, in contrast, aims to inhibit an already selected action plan (Aron et al., 2007), and is mediated by the activation of the right inferior frontal cortex which projects to the subthalamic nucleus and suppresses motor output already prepared by the “go” process (Aron & Poldrack, 2006; Aron, Robbins, & Poldrack, 2014; Temel, Blokland, Steinbusch, & Visser-Vandewalle, 2005). In emotional situations, these inhibition networks extend to involve the orbitofrontal cortex and the anterior cingulate cortex (Goldstein et al., 2007;

Schulz et al., 2009; Shafritz, Collins, & Blumberg, 2006). The existence of specialised response inhibition networks during emotional situations further suggests the possibility that emotional approach-avoidance tendencies may selectively influence the speed of stopping.

In sum, response inhibition depends on a competition between “go” and “stop” processes, and can be implemented via global or selective mechanisms that target all or individual motor processes, respectively. Importantly, response inhibition is driven by different mechanisms than those observed in selection, demonstrating than inhibition is a separate yet critical process for successful interaction. The influence of emotional response tendencies on the speed and implementation of inhibition remains unknown. If action preparation influences how well inhibition can be deployed, then it follows that approach-avoidance tendencies that result in faster actions may consequently influence how quickly we stop our movements. For example, preparing an approach to a positive stimulus may occur faster than the preparation to inhibit, “winning” the competition and thus delaying inhibition. While this link may seem obvious, there is surprisingly little evidence showing an influence of approach-avoidance tendencies on inhibition. Some evidence suggests that inhibition is harder when subjects need to initiate responses in positive contexts and easier when initiating responses in negative contexts (Albert et al., 2010; Chiu, Cools, & Aron, 2014). Initiation in this case might be considered an “approach” action. Thus, in positive contexts “approach” was prepared faster whereas in negative contexts “approach” was prepared slower, leading to differences in inhibition. This is supported by evidence showing that threatening stimuli lead to immobility and faster inhibition (Facchinetti, Imbiriba, Azevedo, Vargas, & Volchan, 2006; Stins, Roerdink, & Beek, 2011).

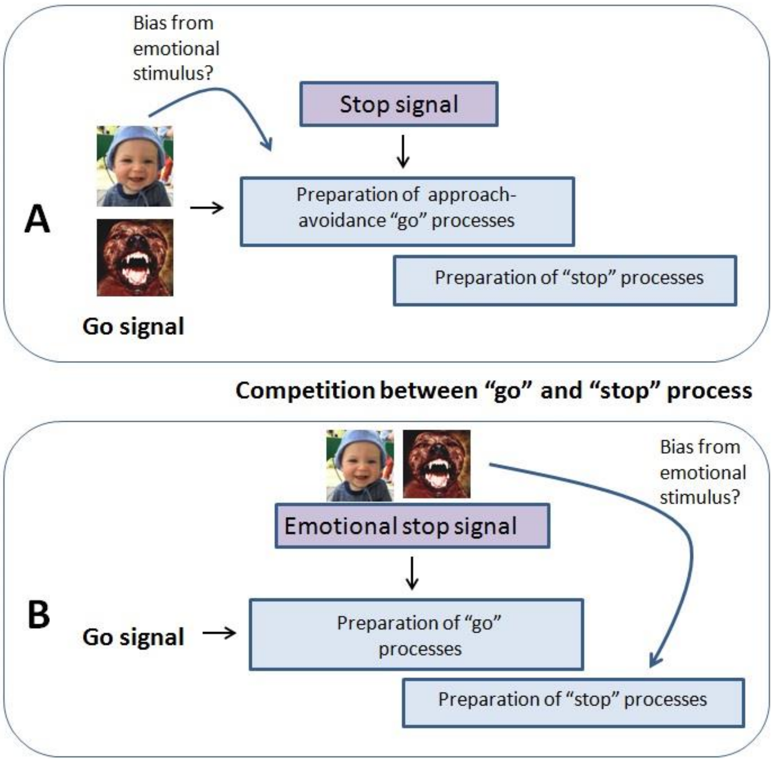


Figure 1.6. Model of how approach-avoidance may bias response inhibition. A) Emotional go signals should influence the preparation of "go" processes. Approach-avoidance tendencies should be prepared faster. When a stop signal is presented, this bias should influence the resolution between competing go and stop processes. **B)** Emotional stop signals and associated predisposed tendencies should bias "stop" processes. Inhibiting predisposed tendencies should be harder.

To the best of my knowledge, no work has investigated response inhibition in situations where individuals are required to actively approach or avoid a stimulus. An influence of emotional tendencies on inhibition would suggest that these tendencies can influence different processes and mechanisms **(Figure 1.6)**. The speed of response inhibition of approach-avoidance responses to positive and negative stimuli should reveal further insight into the state of preparation of such tendencies. Chapter Five investigates action preparation of approach-avoidance tendencies by looking at the speed of response inhibition.

1.1.1.4. The re-planning of actions during execution

Action execution is the implementation of the parameters defined during motor planning. In the face of ever-changing environments, these parameters may sometimes need to be updated in real time to accommodate new goals and ensure successful behaviour occurs (Desmurget et al., 1999; Goodale, Pelisson, & Prablanc, 1986). The *ACH* (Cisek, 2007; Cisek & Kalaska, 2010) predicts that this quick re-planning most likely occurs via the parallel processing between motor planning and movement execution, whereby feedback mechanisms update motor plans which in turn update outgoing motor commands (Kalaska & Crammond, 1992; Sabes, 2000). Neural data has supported this hypothesis, demonstrating that the same regions involved in movement planning are also active during action execution (Crammond & Kalaska, 2000; Kalaska, Scott, Cisek, & Sergio, 1997). Recent behavioural data show that errors performed during action execution inform decision-making processes which subsequently modify the motor representation of reward and update motor commands (McDougle et al., 2016). Parallel processing of execution and motor plans during ongoing movement therefore allows for flexibility and adaptation even after an action has been committed.

How does movement re-planning during execution occur? Parallel processing is likely to reflect a combination of feedforward and feedback mechanisms (Desmurget & Grafton, 2000). When a stimulus is identified, visual information allows for the planning and specification of potential actions (feedforward specification). Throughout execution, a forward model of the movement dynamics is generated based on continuous input into the visual system, which informs feedback loops to update these movement dynamics **(see Figure 1.7)**. The speed of feedback mechanisms is dependent on the speed of sensory processing during ongoing movement (Striemer, Yukovsky, & Goodale, 2010).

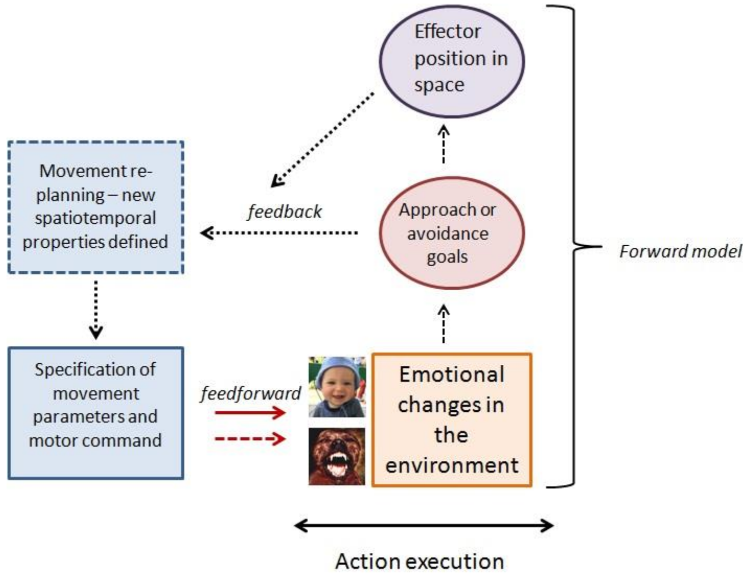


Figure 1.7. Tentantive schematic of feedforward and feedback mechanisms during motor re-planning as a consequence of emotional changes in the environment. Solid red arrow representing the original motor command. The presentation of an emotional stimulus updates motor plans according to its predisposed tendency (e.g. positive – approach) through feedback mechanisms. The position of the effector in space also contributes to this feedback. Dotted red line represents the updated motor command.

Visuomotor adaptation studies, in which participants are required to respond to environmental changes during execution with a movement correction, have been critical for our understanding of mechanisms involved in visually-guided movement corrections (Day & Lyon, 2000; Desmurget, Prablanc, Jordan, & Jeannerod, 1999; Kalaska & Crammond, 1992; Nijhof, 2003; Paulignan, MacKenzie, Marteniuk, & Jeannerod, 1991; Prablanc & Martin, 1992). Evidence suggests that visuomotor corrections occur very rapidly, even when participants are unaware of the change (Goodale et al., 1986; Prablanc & Martin, 1992). Rapid corrections are subsequently followed by more intentional control of the movement. Indeed, two classes of responses appear to guide visuomotor corrections: a fast response guided by an automatic pathway and a slow response guided by a less automatic pathway (Day & Lyon, 2000a; Pisella et al., 2000). This automatic continuum allows for a gradual shift from “more automatic” to “less automatic” and is likely influenced by the speed of feedback (Striemer et al. 2010).

In the example above, fast corrections are thought to be guided by subcortical structures. This view is supported by work on split-brain patients, who were able to make early limb adjustments despite not being able to transfer information between hemispheres (Day & Brown, 2001). In contrast, slow corrections are thought to be guided by top-down influences (Day & Lyon, 2000). Alternatively, both fast and slow responses may be guided by a single pathway, whereby top-down attentional engagement (or disengagement) determines the speed of visuomotor corrections (Tipper, Howard, & Houghton, 1998; Tipper, Howard, & Jackson, 1997).

Changes in emotional environments may have specific consequences on motor updating and action execution. Neural evidence supports this assumption. For example, areas involved in motor planning, such as the dorsolateral prefrontal cortex and the premotor cortex, are also active while executing actions in emotional contexts (Coombes et al., 2012). Can approach-avoidance tendencies associated to emotional stimuli influence the speed at which fast or slow pathways are engaged during visuomotor correction of movements? For instance, correcting a movement towards a positive target might occur faster than correcting towards a negative target. Similarly, correcting away from a negative target might be faster than correcting away from a positive target. This is because a positive stimulus predisposes approach whereas a negative stimulus predisposes avoidance (Chen &

Bargh, 1999). In essence, there may be two automatic systems at play: one related to the speed of visuomotor corrections (fast vs. slow responses) and another related to approach-avoidance tendencies.

The influence of emotional approach-avoidance tendencies on fast and slow pathways remains unexplored, yet is critical for our understanding of how emotional information may bias action execution. Importantly, any influence of emotional stimuli would indicate that approach-avoidance tendencies are able to influence motor processing at different stages, and bias different underlying mechanisms. To assess whether rapid emotional changes in the environment bias and influence action execution, three experiments were conducted in Chapter Six.

1.1.1.5. *Summary*

In sum, movement generation is divided into two phases: the “what” and the “how”, each composed of different processes that all contribute to guide appropriate behaviour given the environment. These different processes interact with each other to translate thought into action, often operating in parallel, yet are guided by different underlying mechanisms. This is key to successful behaviour in emotional situations. Investigating the influence of emotional stimuli and their associated tendencies on each of these different components of movement generation is crucial for our understanding of the mechanisms that translate emotions into actions. A link between approach-avoidance tendencies and different processing stages would demonstrate that emotional stimuli have a privileged status when it comes to the motor system that may be crucial for optimising behaviour.

1.2. Forming action goals: an automatic process?

Given how crucial emotional approach-avoidance tendencies are deemed for optimal behaviour, the fast detection and recognition of emotional stimuli must first occur. Above, we saw that movement generation is divided into the “what” and the “how”. The “what” phase is concerned with how a motor goal is created, whereby stimulus identification and evaluation determine the value of a stimulus (e.g. good or bad) and what needs to be done to the stimulus (e.g. approach or avoid). The goals formed during the "what" phase will inform the "how" processes involved in converting a goal into an action. Furthermore, the deployment of attentional resources plays a fundamental role in forming goals by selecting the object of interest and excluding the surrounding environment, thereby increasing the availability of resources necessary for action. Thus, rapid stimulus processing and attentional allocation of resources to the stimulus is a necessity for action preparation (Wong et al., 2015).

In emotional environments the fast allocation of attentional resources to, for example, a threatening stimulus is a prerequisite for fast action. Indeed, the processing of emotional information is considered to be prioritised in a fast and automatic manner, via a subcortical network involving the amygdala and brainstem areas, and presumably bypassing consciousness (**Figure 1.8**; LeDoux, 1995; Méndez-Bértolo et al., 2016; Mobbs et al., 2009; Tamietto & Gelder, 2010). The processing of emotional information is assumed to require less attentional resources than non-emotional stimuli (Ohman, Flykt, & Esteves, 2001; Vuilleumier, Armony, Driver, & Dolan, 2001; Vuilleumier et al., 2001). For instance, emotion processing areas are activated by the appearance of emotional faces even when participants are engaged in another task (Anderson & Phelps, 2001; Vuilleumier et al., 2001; Williams, McGlone, Abbott, & Mattingley, 2005). This is supported by evidence showing that even when emotional information is masked (i.e. a visual stimulus that hides the perception of another visual stimulus) processing areas are still activated without the participants' awareness of the emotional stimulus (Morris et al., 1998; Whalen et al., 1998). Furthermore, the presence of task-irrelevant emotional stimuli can disrupt task performance (Hartikainen, Ogawa, & Knight, 2000; Pereira et al., 2006). Overall, the evidence suggests that participants process emotional information independently of attention (Anderson, Christoff, Panitz, De Rosa, & Gabrieli, 2003). Thus, in emotional situations, the formation of goals during movement generation may be guided by the rapid and unconscious processing of emotional information.

This contrasts with evidence showing that the processing of emotional stimuli is dependent on attentional resources and awareness of the emotional stimulus (Pessoa, McKenna, Gutierrez, & Ungerleider, 2002; Pessoa & Adolphs, 2010; Pessoa, Japee, & Ungerleider, 2005). For instance, studies in which highly demanding attentional tasks were performed while showing task-irrelevant emotional stimuli, demonstrated no amygdala activation, presumably because the majority of attentional resources were devoted to the highly demanding task (Pessoa, 2005; Pessoa, Kastner, & Ungerleider, 2002; Schupp, Flaisch, Stockburger, & Junghöfer, 2006). The formation of goals during movement generation may therefore be dependent on awareness and on consciously directing attention to an emotional stimulus.

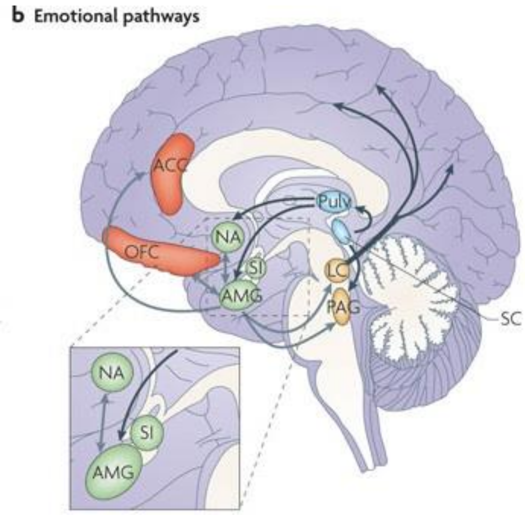


Figure 1.8. Key subcortical and cortical emotion structures in the brain, including the amygdala, basal ganglia, brainstem nuclei and orbitofrontal and anterior cingulate cortices (from Tamietto & de Gelder, 2010). Projections from subcortical to cortical structures may underlie the automatic triggering of response tendencies in goal-directed situations. For instance, fast detection of emotional content in the amygdala (AMG) may inform prefrontal areas such as the OFC, which may subsequently influence selection of goals and actions, depending on the context.

The mixed evidence presented above suggests that processing of emotional stimuli can occur with and without awareness and is dependent on the availability of attentional resources. Speculatively, the processing of emotional stimuli may be guided by interactions between top-down and bottom-up processes. For instance, the amygdala is widely connected to other subcortical structures and to cortical areas (Amaral, 1992). The facilitation of attention in emotional situations has been suggested to occur through amygdala modulation of cortico-sensory areas (Morris, Öhman, & Dolan, 1999), whereby the amygdala influences further attentional and perceptual processing of the emotional stimulus (Vuilleumier, Richardson, Armony, Driver, & Dolan, 2004). Furthermore, reciprocal connections between higher-order areas and the amygdala exist (Cardinal, Parkinson, Hall, & Everitt, 2002; Everitt & Robbins, 1992; Young, Scannell, Burns, & Blakemore, 1994), suggesting that these structures work together to rapidly detect and evaluate emotional stimuli, form goals and intentions and direct appropriate actions given the context. For instance, while emotional processing may rely on initial bottom-up processing via the amygdala, the medial prefrontal cortex has been shown to be involved in directing defensive behaviour (Fanselow, 1994). Furthermore, top-down influences gather information related to the context and subsequently project to the amygdala to trigger appetitive or defensive actions (LeDoux, 1996; Mobbs et al., 2009).

If the “how” phase is dependent on the formation of goals during the “what” phase, then the fast prioritisation of emotional information, the allocation of attention with or without awareness, and reciprocal interactions between top-down and bottom-up areas during processing may all play a role in the formation of approach-avoidance goals. Although the current thesis is not primarily concerned with the processing of emotional stimuli, an additional goal was to investigate to what extent stimulus evaluation and awareness are necessary to form approach-avoidance goals. To this end, two chapters presented emotional information in a task-unrelated way (i.e. they are not directly relevant to task).

Chapter Three investigates if action preparation of approach-avoidance tendencies is influenced by task-irrelevant emotional information presented for durations deemed too low but sufficiently high for the detection and discrimination of emotional content. Previous work has shown that briefly presenting task-irrelevant emotional information prior to an emotional target influences the speed of responses, with matching emotional information facilitating responses (Eder, Leuthold, Rothermund, & Schweinberger, 2012; Klauer, 1997), presumably via the prioritisation of emotional stimuli. This suggests that task-irrelevant emotional information unintentionally influences the preparation of subsequent responses. Tendencies triggered by task-irrelevant emotional information may therefore also unintentionally bias response preparation. If the tendency prepared by the task-irrelevant stimulus (e.g. approach) matches that of the target, then responses will be faster. This suggests that irrelevant information in the environment may be prioritised and help predict and prepare for upcoming emotional stimuli. This specific hypothesis was addressed in a series of experiments with the aim of understanding whether approach-avoidance tendencies can implicitly influence action preparation.

Similarly, Chapter Six investigated whether action execution is influenced by task-irrelevant emotional distractors (see section 1.1.1.4). Thus, both chapters assume that due to attentional prioritisation, participants will unintentionally process task-unrelated emotional information that should consequently impact different motor stages.

1.2.1. Automatic approach-avoidance tendencies

Approach-avoidance tendencies are assumed to occur automatically and unintentionally (Chen & Bargh, 1999; Duckworth, Bargh, Garcia, & Chaiken, 2002). However, what does automatically mean? Automaticity is difficult to define, but generally it can be described as a process occurring independently of the availability of resources, not affected by intentions, and not necessarily tied to consciousness (Moors & De Houwer, 2006). Indeed, automatic processes require very little attention, depleting minimal resources from the task at hand yet allowing to maximise behaviour (Moors & De Houwer, 2006, 2010). Some have even suggested that visual processes can flow automatically into actions such that actions can be triggered with little or no conscious intention (Tipper, 2001). The automaticity of emotional tendencies is in line with the fact that emotional stimuli are prioritised when attentional resources are limited (Vuilleumier et al., 2005) and even when individuals are seemingly unaware of the presence of the stimuli (Whalen et al., 1998). In this thesis automaticity refers to an unintentional effect that occurs faster than others with and without awareness of the emotional stimulus. I do not attempt to give a detailed overview of automaticity here as this is beyond the scope of the current thesis (see Moors & De Houwer, 2006 for a review).

Despite much of the approach-avoidance literature describing predisposed tendencies as occurring automatically and unconsciously (Bargh & Morsella, 2008; Krieglmeyer, Houwer, & Deutsch, 2013; Moors & De Houwer, 2006), there is conflicting evidence regarding the extent to which these actions are automatic. Much evidence has demonstrated a direct link between the immediate and unintended evaluation of emotional stimuli and approach-avoidance tendencies (Chen & Bargh, 1999; Neumann, Förster, & Strack, 2003). For instance, we are faster to approach positive and avoid negative stimuli even when instructions do not explicitly mention approach and avoidance (Chen & Bargh, 1999), when we are required to approach and avoid a non-emotional feature such as the colour or gender of the emotional stimulus (Krieglmeyer, Deutsch, Houwer, & Raedt, 2010) and even when they are presented so briefly they are deemed unconscious (i.e. without awareness) (Duckworth et al., 2002). Moreover, even when participants are explicitly told to move towards positive and negative stimuli and away from both stimuli (Roelofs et al., 2009; Volman et al., 2011), they are still faster to approach positive and avoid negative, showing that response tendencies still automatically arise. One would assume that if such tendencies were not automatic, intentionally approaching positive and negative stimuli as dictated by task instructions should not differ from each other. However, this is not the case when explicit instructions are given. Thus, approach-avoidance tendencies appear to automatically and unconsciously generate motor goals, suggesting a strong predisposition to act in specific ways in emotional situations. Accordingly, motor processes should be automatically biased.

Despite strong evidence for automatic tendencies, other work has shown that approach-avoidance may not be completely independent of goals and context (Eder & Klauer, 2009; Eder & Rothermund, 2008; Lang & Bradley, 2013; Lavender & Hommel, 2007). Task instructions and contextual evaluation, for instance, have been shown to dictate whether an approach or avoidance is required (Eder & Rothermund, 2008; Markman & Brendl, 2005). Similarly, approach-avoidance tendencies are not triggered when participants are instructed to respond to a non-affective component of an affective stimulus (Rotteveel & Phaf, 2004). Furthermore, such tendencies may not just be triggered by the presence of an emotional stimulus, but also by the anticipated consequences of the action (e.g. if I approach a cute puppy then I may be able to play with it) (Eder & Rothermund, 2013; Eder & Hommel, 2013). Evaluating a context and anticipating the consequences of an action according to that context suggests a top-down mechanism involved in generating approach-avoidance goals that will subsequently bias motor processes. Accordingly, approach-avoidance tendencies may be goal-directed (Lang & Bradley, 2013).

To summarise, the above evidence suggests that while some degree of automaticity exists, approach-avoidance tendencies still interact with environmental demands in order to lead successful behaviour. This is supportive of an interaction between top-down and bottom-up processes, mentioned previous in sections 1.1.1.1 and 1.2. Speculatively, bottom-up processes may prioritise the processing of emotional stimuli, plan competing responses upon stimulus evaluation, and interact with top-down areas to establish what the most appropriate action is given the current context, biasing behaviour towards approach or avoidance. Approach-avoidance is therefore likely to be a combination of automatic and goal-directed processes.

1.3. A brief introduction to methods

To answer the research questions in this thesis, a variety of behavioural techniques were used. Here, I briefly outline the emotional stimuli used to evoke approach-avoidance actions and highlight a couple of important measurements necessary to assess the effect of emotional stimuli on motor processes.

1.3.1. Presenting emotional stimuli: emotional pictures and affective faces

Emotions are subjective and emotional stimuli may evoke emotions in very different ways depending on the individual (Bradley & Lang, 2007). For example, someone might strongly dislike babies yet the majority of people love them. For this reason, when studying emotion and their respective approach-avoidance tendencies it is necessary to use a standardised, validated and established set of emotional stimuli that are confirmed to evoke specific emotions. Moreover, there is a range of emotional stimuli that can be used to evoke approach-avoidance tendencies. We can use, for instance, auditory or pictorial stimuli of emotional scenes, emotional words and affective faces. In this thesis I opted to present participants with emotional pictures and affective faces. These were chosen for the following reasons: pictures of emotional scenes and faces are static (i.e. unchanging) meaning that they are easily interpretable and their content does not change throughout a trial (Bradley & Lang, 2007), they are ecologically valid (Garvert, Friston, Dolan, & Garrido, 2014), they are clearly evocative, and their features – image size, duration, brightness, luminance and colour – can be easily controlled for and manipulated to make standardisation better.

The most widely employed database of emotional pictures is the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008). This database comprises of more than a thousand pictures depicting content showcasing everyday human experience – relationships, babies, families, erotica, attack, threat, wars, death, plants and flowers, and many others. In the current thesis only emotional pictures depicting humans or animals were included as they represent what most humans interact with emotionally on a daily basis. Neutral pictures contained inanimate objects such as chairs and tables. To standardise and validate the database, each picture has been rated on a scale of 1 – 9 on their valence (e.g. pleasant, neutral, and unpleasant) and their arousal (e.g. not very arousing, neutral, and very arousing) by a large group of naive participants. A comprehensive review of the standardisation and validation procedure of the IAPS can be read in Bradley & Lang (2007).

Contrary to emotional pictures, there are many standardised databases that contain emotional faces – the NimStim Face Stimulus Set (NimStim; Tottenham et al., 2009), the Karolinska Directed Emotional Faces (KDEF; Lundqvist, Flykt, & Öhman, 1998), Radboud Faces Databases (RFD; Langner et al., 2010), and others. The most widely used database is the KDEF, which comprises of 4900 pictures of human emotional expressions taken from 70 male and female individuals. Similarly, the RFD comprises of 536 emotional expressions taken from 67 individuals. Given the large amount of emotional faces provided and because these databases have been validated (Goeleven, Raedt, Leyman, & Verschuere, 2008; Langner et al., 2010), the KDEF and RFD were the preferred choice for this thesis. Importantly, in all the experiments conducted here, participants rated all of the stimuli presented on their valence and arousal ratings.

1.3.2. Measuring approach-avoidance: the joystick/manikin task

The main goal of this thesis was to investigate how approach-avoidance tendencies influence motor processes, and as such, it was imperative to use a task that readily evokes approach-avoidance. Two prominent tasks have been used separately in the approach-avoidance literature: the joystick and the manikin tasks.

The joystick task **(Figure 1.9A)** was originally devised in the prominent Chen & Bargh (1999) paper and has been used by others (Eder & Klauer, 2009; Roelofs et al., 2009; Seibt et al., 2008). The premise is rather simple: participants are required to pull or push the joystick in order to approach or avoid emotional stimuli on a computer screen. Some studies do not provide task instructions related to valence (Chen & Bargh, 1999), while others give explicit movement instructions related to valence (Eder & Rothermund, 2008; Eder & Klauer, 2009). The majority of joystick studies do not provide visual feedback (i.e. the movement they make does not cause any changes to the stimulus), but a few have provided the illusion that the emotional stimulus does approach or avoid the participant (Rinck & Becker, 2007; Seibt et al., 2008; van Dantzig, Pecher, & Zwaan, 2008). Providing feedback on the screen adds a realistic touch to the joystick task and is advantageous in that participants can see the consequences of their actions which might provide feedback to the motor system.

The manikin task **(Figure 1.9B)** was devised by De Houwer and colleagues (2001) as an alternative to the joystick task. A small stick figure (i.e. manikin) on the screen was moved up or down using a keyboard in order to approach or avoid an emotional word presented on the centre of the screen. Crucially, depending on the position of the manikin (i.e. above or below the word), an upward movement could mean approach or avoidance, meaning that for each trial participants must decide which movement means approach and which means avoidance. This task is advantageous over the joystick task in two ways: participants can see the change in distance between the "self" (i.e. manikin) and the object by means of visual feedback, and there is less chance of re-categorisation of movements (e.g. in joystick tasks pulling a joystick to bring a positive stimulus towards may also be interpreted as pulling the joystick away from negative pictures, whereas in manikin tasks participants only press a button and explicitly see the consequence on the screen). Re-categorisation of movements can introduce error variance (some participants may re-categorise, others may not), which reduces the sensitivity of the measure.

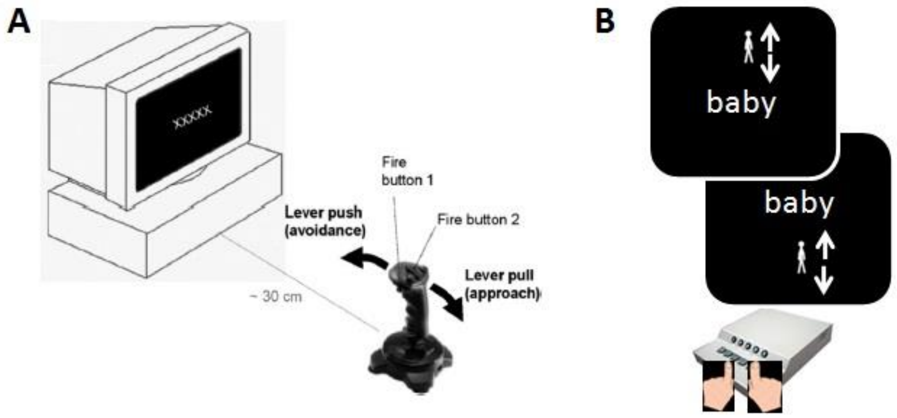


Figure 1.9. Schematics of the joystick and manikin tasks. A) A joystick is used to push or pull when an emotional stimulus is presented on the screen. Typically, pulling is considered an approach and pushing an avoidance response, although the opposite can be true as well (taken from Eder & Klauer). **B)** In the manikin task, a stick figure representing the self is moved on the screen via button presses, either towards or away from the emotionl stimulus.

A recent comparison between the tasks (Krieglmeyer & Deutsch, 2010) demonstrated that the manikin task had greater sensitivity over the joystick task in depicting approach and avoidance. This result was also true only when the joystick task provided visual feedback of the consequences of arm movement. Thus, this suggests that approach-avoidance tendencies are more strongly evoked when participants can observe the consequences of their actions on the screen and when there is no chance of re-categorisation of the movement. This helps generate goals as participants know what they can expect from their movements.

Taking this into consideration, for the current thesis I devised a novel task that combined the feedback joystick and manikin tasks. Essentially the manikin is moved on the screen by participants pulling or pushing a joystick. For example, when the manikin is located above the picture participants need to pull the manikin to approach and push to avoid the stimulus, whereas when the manikin is located below the picture participants must push to approach and pull to avoid. It combines the strengths of both the manikin and feedback joystick tasks and moreover, allows participants to physically make approach-avoidance movements rather than pressing buttons. This task was used in Chapters Two, Three and Five, whereas a modified version using button presses was used in Chapter Four.

1.4. Quantifying approach-avoidance

Quantifying approach and avoidance can involve a number of dependent variables that will not all be discussed here. All variables are explained in their respective chapters. However, a special note is given to the two most featured variables of the entire thesis: the reaction and movement time. Both of these comprise what is known as the response time (Welford, 1980).

1.4.1. Reaction Times

The reaction time (RT) is the time taken from stimulus onset to the initiation of a motor response, and it is estimated to last approximately 200 ms (Welford, 1980), although this varies with the type of stimulus presented and the type of response that needs to be executed. A series of events occur during the RT: a stimulus is perceived and identified, a goal is formed, the action required is determined and a motor command is implemented that will subsequently mobilise the respective group of muscles (Wong et al., 2015). The RT therefore encompasses many different processes, namely the “what” and “how” phases of movement generation that were described in section 1.1. Thus, RT comprises perceptual and motor processing.

What does the RT mean and why is it important? It is difficult to truly define what the RT means. A broad definition is that the RT is a determinant of processing speed, giving an indication of how fast an individual can carry out mental operations required by the task (Welford, 1980). Indeed, the RT has been found to increase proportionately with the amount of information needed to be processed (Jensen, 1987). However, because it presumably encompasses a variety of processes, it is difficult to accurately determine from an RT if detection and identification consumed more resources than action selection. For example, from an RT of 300 ms, one cannot be sure that the “what” phase consumed 150 ms and the “how” phase consumed the remaining 150 ms. A recent review suggests that the “what” phase consumes the majority of the RT, whereas the “how” only consumes a small fraction (Haith et al. 2016), demonstrating how quickly motor processes occur in the brain. Irrespective of this, the RT is essential for determining the speed of evaluation, action selection and response inhibition. For instance, faster RTs give an indication that a specific stimulus was processed more easily than another stimulus or that an action was selected faster than a competing alternative. This is evident in approach-avoidance studies, in which approaching positive and avoiding negative stimuli has a faster RT than the opposite actions. Throughout this thesis, the RT is measured and reported as an indication of the speed of processing and action selection, as well as being used to determine the speed of response inhibition.

1.4.2. Movement times

The movement time (MT) is the time taken from response initiation to reaching the target and thus reflects the total time of action execution. Unlike the RT, MT is unaffected by increases in the amount of stimulus information (Jensen, 1987), suggesting that it does not reflect processes that occur prior to action initiation. However, some work has suggested that MT is also sensitive to stimulus evaluation processes (Houlihan, Campbell, & Stelmack, 1994). The MT may be relatively unaffected by what happens prior to the initiation of movement, but it might be affected by unexpected changes that occur once a movement has been initiated, thereby reflecting evaluation processes that occur while a movement is ongoing. Thus, the MT may not only reflect the speed of action execution but may also be a reflection of the speed of motor planning.

With respect to approach-avoidance tendencies, we may not only be faster at initiating such responses, but the rate at which we move towards or away from an emotional stimulus may also be affected. That is, our speed may increase at a faster rate as time progresses if we are approaching a positive stimulus relative to a negative stimulus. MT is therefore an important measure of how motor planning and action execution are influenced by approach-avoidance tendencies.

1.5. Outline of the thesis

This thesis is about how emotional stimuli and their related action tendencies impact different motor processes. I address my research questions by using a variety of behavioural techniques including psychophysical testing and movement tracking. Thus, I focus largely on behavioural measures, which can only lead me to speculate on the anatomical regions involved in translating emotions to actions. The anatomical, functional and behavioural relationship between emotion and the motor system outlined above has led me to ask several unanswered, yet important, questions related to the preparation, execution and inhibition of actions in emotional contexts. Below I outline the relevant question each chapter attempts to answer.

Chapter Two is concerned with how approach-avoidance actions are selected. Some studies have demonstrated that approach-avoidance actions are linked to specific muscle activation (Caccioppo et al., 1993; Chen & Bargh, 1999) whereas others have suggested that approach-avoidance tendencies are flexibly determined by the reference-frame (Lavender & Hommel, 2007; Seibt et al., 2008) or task instructions (Eder & Rothermund, 2008). While the former implies that action selection occurs in a rigid and muscle-specific way, the latter implies that action selection is flexibly influenced by the environment. Given that previous work has demonstrated that action selection relies on the simultaneous planning of several competing responses until the more appropriate one is chosen (Cisek & Kalaska, 2010), it is less likely that emotionally-guided behaviour is muscle-specific, but is instead flexibly guided by contextual requirements. However, no study has previously pitted these two lines of evidence against each other. This chapter aims to shed light on the “how” phase of movement generation in emotional contexts and further understand in what manner actions in response to emotional stimuli are selected.

Chapter Three investigates how actions in response to emotional stimuli are prepared. Emotional cues in the environment may serve as “warning” signals that may predict upcoming emotional stimuli, leading to fast and efficient behaviour. These emotional cues in the environment are not task-relevant yet may be unconsciously prioritised, biasing goal formation towards automatic response tendencies which will subsequently prepare the motor system for appropriate action and maximise the efficiency of our behaviour. Alternatively, in goal-directed situations whereby task instructions dictate approach and avoidance, instructions may be unconsciously applied to task-irrelevant emotional cues. Thus, is preparation determined by unintentional automatic tendencies or goal-related task-instructions? And can this biasing still occur when emotional cues are presented under the threshold for conscious detection? To this end, three experiments were conducted using affective primes to determine how action preparation occurs and establish the extent to which processing of emotional information is unconscious.

In **Chapter Four**, the effect of approach-avoidance tendencies on action execution was investigated. While selecting the appropriate action is important for behaviour, the correct implementation of action parameters in order to achieve the desired outcome is as important. The planning of spatiotemporal parameters during the "how" phase of movement generation may be biased by approach-avoidance tendencies. Deciding to fight off an attacker is not enough for successful behaviour. The vigour with which we fight off the attacker will determine the success of the outcome. Indeed, emotional approach-avoidance tendencies may affect the vigour with which execute our actions. No work has previously addressed whether vigour is influenced by response tendencies. If vigour is biased it would demonstrate that such tendencies do not only bias action selection, but also influence the planning of the spatiotemporal parameters, thus suggesting that such tendencies have the capacity to influence distinct motor stages.

A fundamental property of behaviour is not only to execute accurate responses to emotional stimuli, but to also suppress inappropriate actions that may be detrimental. In **Chapter Five**, two experiments were conducted to examine whether our tendencies to approach and avoid emotional stimuli also influence our ability to inhibit our actions. Inhibiting a planned approach action to pet a friendly dog, for example, is necessary in order to avoid getting bitten if the dog has turned aggressive. Response inhibition is influenced by the competing "go" and "stop" processes. These processes are in turn influenced by the speed of action preparation. Thus, inhibition is a measure of movement preparation. Because approach-avoidance tendencies are assumed to be prepared faster than other response alternatives, inhibiting such tendencies may be harder. Whether this is the case is currently unknown.

Lastly, **Chapter Six** further explores the effect of approach-avoidance tendencies on action execution, but focuses on their ability to influence the re-planning of actions in the face of changing environments to accommodate new goals and ensure successful behaviour (Goodale et al., 1986; Desmurget et al., 1999). The updating of motor plans as actions are executed may rely on two mechanisms: a fast and a slow pathway. The fast pathway allows for the early and automatic adjustment of an effector, whereas the slow pathway allows for later and less automatic adjustments that under top-down control (Day & Lyon, 2000). The interaction of these pathways with emotional stimuli remains undetermined. To this end three experiments investigated the influence of emotional stimuli and approach-avoidance tendencies on reaching trajectories.

Chapter Two. Emotional valence and contextual affordances flexibly shape approach-avoidance movements

This chapter is a modified version of Saraiva, A.C, Schuur, F & Bestmann, S. (2013) *Emotional valence and contextual affordances flexibly shape approach-avoidance movements.* Frontiers in Psychology: Emotion Science.

2.1. Abstract

Behaviour is influenced by the emotional content – or valence – of stimuli in our environment. Positive stimuli facilitate approach, whereas negative stimuli facilitate defensive actions such as avoidance (flight) and attack (fight). Facilitation of approach or avoidance movements may also be influenced by whether it is the self that moves relative to a stimulus (self-reference) or the stimulus that moves relative to the self (object-reference), adding flexibility and context-dependence to behaviour. Alternatively, facilitation of approach avoidance movements may happen in a predefined and muscle-specific way, whereby arm flexion is faster to approach positive (e.g. flexing the arm brings a stimulus closer) and arm extension faster to avoid negative stimuli (e.g. extending the arm moves the stimulus away). While this allows for relatively fast responses, it may compromise the flexibility offered by contextual influences. This experiment investigates under which conditions approach-avoidance actions are influenced by contextual factors (i.e. reference-frame). The reference-frame in which actions occurred was manipulated by asking participants to move a symbolic manikin (representing the self) towards or away from a positive or negative stimulus, and move a stimulus towards or away from the manikin. The type of movements used to approach or avoid in each reference were also controlled for. The results show that the reference-frame influences approach-avoidance actions to emotional stimuli, and additionally show muscle-specificity for negative stimuli in self-reference contexts. Speculatively, this muscle-specificity may be a fast and adaptive response to threatening stimuli. The results confirm that approach-avoidance behaviour is flexible and reference-frame dependent, but can be muscle-specific depending on the context and valence of the stimulus. Reference-frame and stimulus-evaluation are key factors in guiding approach-avoidance behaviour towards emotional stimuli in our environment, and are determinants of how action selection occurs in emotional environments.

2.2. Introduction

Selecting appropriate actions in response to emotional stimuli is crucial for successful social and emotional interaction. For example, while it seems safe to approach and sit next to a smiling stranger on the bus, one should avoid a potentially dangerous scene of disturbance on the street. Indeed, emotions are thought to be fundamental predispositions for action (Damasio, 1994; Frijda, 1986; James, 1884): positive stimuli facilitate approach, whereas negative stimuli facilitate avoidance (e.g. withdrawal and escape) (Bradley et al., 2001; Lang & Bradley, 2010).

Approach and avoidance behaviour may not be only shaped by the valence of the stimulus, but also by the context in which behaviour occurs (common-coding account; Eder & Klauer, 2009; Eder & Rothermund, 2008). More specifically, behaviour may be influenced by whether the environment requires us to move *ourselves* towards or away from an emotional stimulus (self-reference) or whether it requires us to move the emotional stimulus towards or away from *ourselves* (object-reference). Moreover, both arm extension *and* flexion can be used to approach or avoid: we can *extend* our arm to pet a puppy, or alternatively *flex* our arm to bring the puppy closer to us. Similarly, we can *flex* our arm to move away from a spider but also *extend* our arm to chip that spider away from us. Thus, to achieve the same behavioural goal, actions conducted in a self-reference frame are opposite to the ones conducted in an object-reference frame. This suggests that the reference-frame may determine which actions are coded as “approach” and “avoidance”. In the self-reference frame, for example, arm flexion may be coded as an avoidance action and would subsequently be facilitated upon *negative* stimulus evaluation. In the object-reference frame, by contrast, arm flexion may be coded as an approach action and, following stimulus evaluation, would be facilitated by a *positive* stimulus. Viewed in this way, the reference-frame may determine the “affordance of an action” (Gibson, 1977): flexion can elicit avoidance in a self-reference frame, whereas in an object-reference frame the same movement allows for approach.

An alternative suggestion is that *specific* movements may automatically be facilitated to approach or avoid emotional stimuli upon (conscious or non-conscious) stimulus evaluation (Chen & Bargh, 1999; Duckworth et al., 2002). This suggestion will be referred to as the “muscle-specific” account. Accordingly, we should be faster at *flexing* our arm to bring a positive stimulus closer to us (e.g., a puppy) and faster at *extending* our arm to push away a negative stimulus (e.g., a spider; Caccioppo et al., 1993; Chen & Bargh, 1999) independently of the context. Such automaticity would suggest a close but rigid relationship between emotional stimuli, selective muscle recruitment, and approach-avoidance behaviour, which may be a hard-wired process that bypasses conscious awareness of the encountered stimuli (Lang & Bradley, 2010). This may allow for faster responses, but compromises the flexibility offered by contextual influences. To understand how contextual factors may allow for flexible actions therefore requires controlling for the presence of muscle-specificity within each reference-frame.

Evidence for the common-coding account has been substantial (Bamford & Ward, 2008; Eder & Rothermund, 2008; Lavender & Hommel, 2007; Proctor & Zhang, 2010; Seibt et al., 2008; **see Table 2.1**). To demonstrate movement flexibility, studies have varied either the reference-frame (Lavender & Hommel, 2007; Seibt et al., 2008) or the arm movements required to approach and avoid (e.g. flexion vs. extension to approach; Markman & Brendl, 2005; Proctor & Zhang, 2010), but never both. Similarly, other work supporting the common-coding account suggested that when the self approaches and avoids, behaviour is a goal-dependent mechanism rather than muscle-specific (Bamford & Ward, 2008), but in this work there was no manipulation of neither the reference-frame nor movement type. Manipulation of both factors, however, is required to test for movement flexibility within each reference-frame. Studies in support of the muscle-specific account (Duckworth et al., 2002; Roelofs et al., 2009) did not manipulate the reference-frame or movement type either (for an overview of studies on approach and avoidance and the experimental factors included in their designs, **see Table 2.1**) and could not reveal muscle-specificity in different contexts.

To investigate the extent of flexible movement facilitation for approach-avoidance within each reference-frame and how this may explain action selection in emotional situations, one needs to demonstrate that within each reference-frame there is facilitation of a variety of movements and that one type of movement (e.g. flexion) is not *per se* faster than another (e.g. extension) when approaching and avoiding stimuli. Studies showing that approach and avoidance of emotional stimuli is influenced by the reference-frame, for example, only included specific subsets of flexion and extension movements to approach or avoid emotional stimuli. In Lavender & Hommel (2007), subjects always made an extension when the self moved towards (approached) and always made a flexion when the self moved away from (avoided) emotional stimuli. Similarly, in Seibt et al. (2008), in the self-reference frame condition subjects pushed (extended) a joystick to move towards and pulled (flexed) to move away from a stimulus. Essentially, both studies assumed that specific arm movements are naturally facilitated in self-reference situations, namely arm extension when the self approaches, and flexion when the self avoids. No direct comparison was made with flexion movements for approach and extension movements for avoidance within a self-reference frame, which is essential to eliminate any potential confounds with the biophysical properties of the arm.

The direct comparison of movements to approach and avoid emotional stimuli has only been conducted in an object-reference frame, in which both flexion and extension movements were facilitated when moving a stimulus closer to and away from a reference on the screen (Markman & Brendl, 2005; Proctor & Zhang, 2010; van Dantzig, Zeelenberg, & Pecher, 2009). It remains undetermined whether this flexible facilitation of flexion and extension movements extends to the self-reference frame (i.e. when the *self* moves towards or away from stimuli). Directly comparing different reference-frames allows one to distinguish how different interchangeable contexts affect approach-avoidance. This crucial manipulation is essential to reveal the extent of movement flexibility within different contexts and to determine how action selection in emotional contexts occurs.

In contrast to previous studies (Chen & Bargh, 1999; Krieglmeyer et al., 2010; Lavender & Hommel, 2007; van Dantzig et al., 2008), the current study looked at participants' reaction times for positive and negative stimuli separately. Approach-avoidance behaviour occurs in response to the valence of the stimuli in our environment. That is, approach is typically linked to positive and avoidance is typically linked to negative valences. However, negative stimuli are known to facilitate various defensive actions such as escape or attack (Lang & Bradley, 2010), which are not necessarily linked to avoidance (i.e. moving *away* from the stimulus). Thus, given that negative stimuli can trigger a variety of defensive actions, it may be possible that negative stimuli do not only facilitate avoidance. To demonstrate the how approach and avoidance is influenced by emotional stimuli, reaction times were analysed for both valences separately. Questionnaires were also administered that would help determine any subjective influences on our reaction times. Factors such as personality and motivational traits may influence the subjective interpretation of various emotional stimuli, and consequently determine approach and avoidance behaviour (Elliot & Thrash, 2010).

Paper	**Manipulation type**		
	Reference-frame	**Movement type (flex/ext)**	**Valence RT**
Chen & Bargh, 1999	**No** – object-reference only	**No –** Flexion to approach, extension to avoid	**No** – averages RTs across valences
Markman & Brendl 2005	**No** – object-reference only	**Yes** – Both flexion and extension movements were made for approaching and avoiding	**Yes**
Lavender & Hommel 2007	**No** – self-reference only	**No** – Flexion to approach, extension to avoid	**No**
Eder & Rothermund 2008	**No**	**Yes** – Both flexion and extension movements made for approaching and avoiding - not directly compared within the same experiment	**No**
Seibt et al. 2008	**Yes** – both reference-frames	**No** – Flexion to approach, extension to avoid in the object-reference; extension to approach and flexion to avoid in the self-reference	**Yes**
Bamford & Ward, 2008	**Yes –** self-reference only	**No –** extension to approach and avoid	**Yes**
Van Dantzig, Zeelenberg & Pecher, 2009	**No – Object-reference only**	**Yes -** Both flexion and extension movements were made for approaching and avoiding	**Yes**
Krielgmeyer et al. 2010	**No** – self-reference only	**No** – No flexion or extension was executed	**No**
Proctor & Zhang 2010	**No –** object-reference only	**Yes -** Both flexion and extension movements were made for approaching and avoiding	**Yes**
Current experiment	**Yes –** both reference-frames	**Yes -** Both flexion and extension movements were made for approaching and avoiding	**Yes**

Table 2.1. Overview of studies supporting the muscle-specific vs. common-coding accounts. The table summarises the experimental factors included in previous approach-avoidance studies. Studies included depict *situations* in which the self moves towards or away from a stimulus, or a stimulus is moved towards or away from the self, irrespective of the requirement to move a symbolic self/object on a screen. **Reference-frame**: Was a manipulation of reference-frame included? In the self-reference frame, the self always moves towards or away from an emotional stimulus. In the object-reference frame, an emotional object is always moved towards or away from the self. **Movement type**: Were flexion movements made to approach *and* avoid, and extension movements made to approach *and* avoid emotional stimuli, or was a predefined set of movements used? **Valence influences on RT**: Was the relative influence of positive and negative valences on RTs assessed?

No study, to the best of my knowledge, has directly compared the effects of different movement types within different reference-frames on approach-avoidance behaviour to investigate the influence of approach-avoidance tendencies on the speed of action selection and initiation (**see Table 2.1**; current experiment). Combining these three factors within the same experimental design is key for understanding the individual contributions of reference-frame, movement type and valence and, of any interactions between them, to the selection of approach and avoidance actions. The manipulation of reference-frame allows for observing contextual influences on the speed of selection and initiation of approach-avoidance actions. Similarly, the manipulation of movement type controls for the potential presence of muscle-specificity within different reference-frames. And the manipulation of valence allows us to demonstrate the individual contribution of each valence to approach-avoidance. This design therefore allows us to uncover interactions other work has not been able to show, for example, muscle specificity within one reference-frame for one type of valence only; only full factorial designs can uncover interaction effects.

A design that incorporated two different arm movements (flexion/extension) used to approach or avoid, varied the reference-frame in which these movements occurred, and balanced the valence of the emotional stimuli that had to be approached or avoided was employed. To this end, a novel paradigm was devised which combined two tasks commonly used to study approach-avoidance behaviour: the manikin task (De Houwer et al. 2001) and the joystick task (Chen & Bargh, 1999). This combination improves previous versions of the manikin task (De Houwer et al., 2001; Krieglmeyer et al., 2010) in that the movement of the symbolic manikin on the screen is actually linked to arm flexion and extension, which is crucial for the goal of this study. This allows participants to see the behavioural consequences of their actions, as either a decrease or increase in the distance between the self and the emotional stimulus. Furthermore, it controls for the possibility that apparent movement facilitation can be due to the specific biophysical constraints of different arm movements: some movements may be more difficult to execute than others. Finally, the reference-frame was manipulated by moving the symbolic manikin towards or away from a stimulus or a stimulus towards or away from the manikin. This design allowed manipulating the reference-frame (self vs. object) and movement type (extension vs. flexion) *independently*.

If the common-coding account holds true, reference-frame should flexibly influence facilitation of approach-avoidance movements (i.e. the consequences of stimulus evaluation determines whether we approach or avoid) *and* the specific movements that are facilitated (i.e. both flexion and extension can be used to approach and avoidance within the particular context). That is, the common-coding account predicts an interaction of the reference-frame, stimulus valence and approach-avoidance actions. In contrast, the muscle-specific account predicts an interaction of movement type with stimulus valence (i.e. specific actions will be activated by emotional stimuli to achieve faster approach or avoidance). That is, participants should pull faster to approach positive and push faster to avoid negative stimuli, irrespective of the reference-frame. Possible interaction effects occurring between the reference-frame, movement type and valence were predicted, which previous work had not been able to reveal.

In brief, the current work aimed to determine how actions to approach and avoid emotional stimuli are selected, and whether automatic approach-avoidance tendencies influence the speed of action selection and initiation in emotional contexts. The data shows that the reference-frame influences which actions are facilitated to approach and avoid, and also determine the speed at which we approach and avoid emotional stimuli, in line with previous findings. There was no evidence of muscle-specificity in object-reference conditions. In contrast, in the self-reference evidence of movement flexibility for positive stimuli and muscle-specificity for negative stimuli was found. Novel, albeit speculative, evidence that negative (threatening) stimuli have the capacity of triggering a variety of defensive actions in a fast and efficient manner is provided. Flexible selection of approach-avoidance actions is dependent on the reference-frame.

2.3. Methods

2.3.1. *Participants*

28 healthy volunteers (mean age = 25.7 ± 5.95 S.D. years; 17 female) were recruited from the University College London Psychology database, with local ethics approval (UCL).

All participants had normal or corrected-to-normal vision. Subjects gave written informed consent to participate in the study, and received monetary compensation for their time and travel (10£/h). Two participants were excluded from the analysis for having a total number of errors above 2 S.D.'s from the population mean for self and object references. Picture ratings from one subject were missing and the subject was excluded from the questionnaire correlation analysis. Overall, 26 subjects were included in the main analysis and 25 subjects were used in the picture ratings analysis and questionnaire correlations analysis.

2.3.2. *Stimuli and Apparatus*

220 pictures were selected from the International Affective Picture System (IAPS; Lang et al., 2008): 110 negative pictures (e.g. gang violence, mutilated bodies) with valences 1.8-3.8 (1.8 = most negative), and 110 positive pictures (e.g. babies, families) with valences 6.2-8.2 (8.2 = most positive). All pictures (maximum 240 x 180 pixels) were matched for luminance. Pictures differed in their arousal ratings, which was addressed in the analyses. Pictures depicting only humans or animals were included as they are believed to represent what most humans interact with on a daily basis. The assignment of pictures in each of the 8 blocks and order of presentation was randomised for each subject. Block order was randomised per subject such that no two subjects had the same sequence of block instructions or same sequence of pictures in each block. Each block comprised of 110 trials (55 positive/negative). In total, for each reference-frame, there were 110 repetitions for each experimental condition.

All stimuli were presented on an 19 inch LCD monitor of a Dell Optiplex-780 computer (refresh rate: 60 Hz), using the Cogent 2000 toolbox (University College London, http://www.vislab.ucl.ac.uk/Cogent2000/index.html) and MATLAB (v.7.9.1.705; The MathWorks Inc., Natick, MA). A white manikin (2.8 x 1.9 cm) represented the self. A small yellow circle (1.3 x 1.2 cm) representing the "away" target was presented at the edge of the screen on the same side as manikin presentation. This "away" target was presented purely for guidance purposes when subjects had to move away. The manikin or picture stimuli were moved smoothly on the screen using a home-made analogue joystick connected to a CED1401 (Cambridge Electronic Design) machine. Joystick data were recorded using a

CED1401-MATLAB interface (matced32; Cambridge Electronic Design) between MATLAB and the data acquisition device.

2.3.3. *Experimental Procedure & Design*

One experimental session was conducted for each reference-frame, in a counter-balanced order, and each session was separated by at least one day. At the start of the experiment, participants completed 3 questionnaires: the Big Five Personality Inventory (BFI; John, Donahue, & Kentle, 1991), the Behavioural Activation and Inhibition Scales (BIS/BAS; Carver & White, 1994) and the Fear Survey Schedule (FSS-III; Wolpe & Lang, 1964). Participants then sat in front of a computer at a distance of approximately 50 cm with the joystick fixed to the table on the right-hand side. They were instructed to imagine that the manikin represented themselves on the screen.

In the *self-reference* condition, participants moved a manikin (the self) on the screen towards or away from an emotional picture. Previous work has shown that participants can represent themselves on a computer screen when moving positive or negative stimuli towards or away from their own names (Markman & Brendl, 2005). Here, the subject is represented on the screen by means of a symbolic manikin, which has produced reliable approach-avoidance effects (De Houwer et al. 2001; Krieglmeyer et al. 2010; Krieglmeyer & Deutsch, 2010). Trials started with a fixation cross presented in the centre of the screen (500 ms), followed by both the fixation cross and the manikin (500 ms), which was presented pseudo-randomly either above or below fixation (**Figure 2.1A**). Central fixation was then replaced by a picture (max. 2000 ms, or until the respective target was reached). The inter-trial-interval was 500 ms. Within this condition, two types of blocks occurred, each repeated four times. In *congruent* blocks (approach-positive, avoid-negative) participants were instructed to move the manikin towards positive pictures and away from negative pictures, as fast and as accurately as possible upon picture presentation. In *incongruent* blocks (approach-negative, avoid-positive) participants had to move towards negative and away from positive pictures. The starting position of the manikin (above or below) determined the type of movement that was executed to approach and avoid. When the manikin was located above, subjects had to pull to approach and push to avoid. When the manikin was located below, subjects had to push to approach and pull to avoid. Therefore, both approach and avoidance could be achieved by either pulling or pushing, depending on the starting position of the manikin.

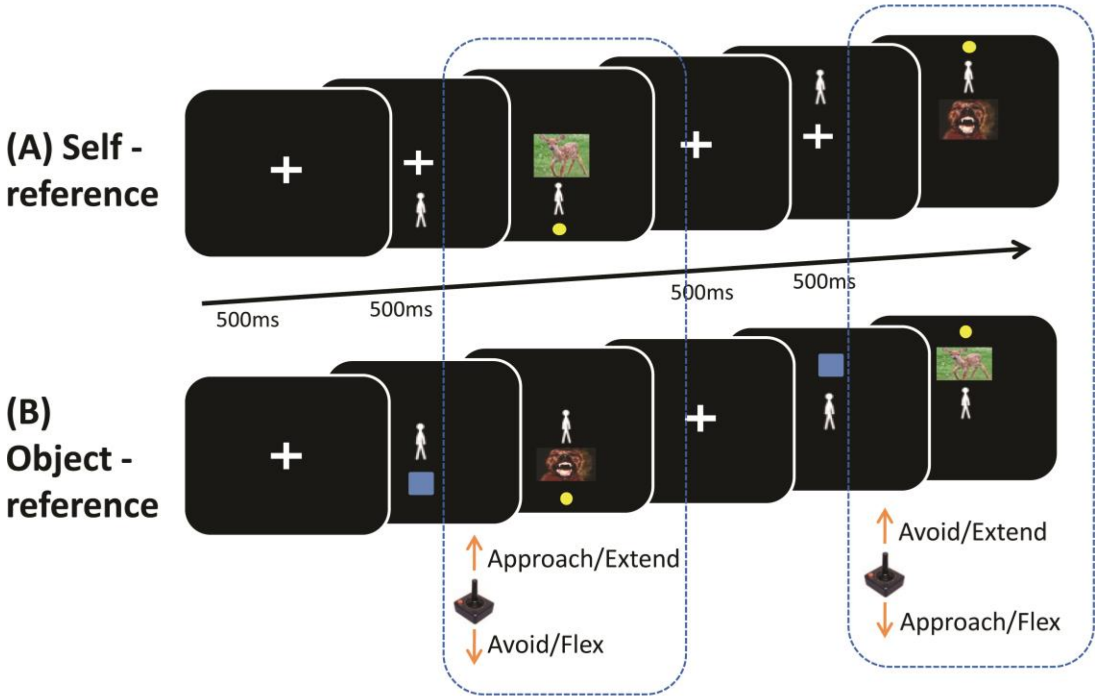


Figure 2.1. Illustration of the task. A) Self-reference condition: A manikin was presented either above or below an emotional picture. Participants moved the manikin towards or away from the picture depending on the block. In *congruent* blocks (approach-positive, avoid-negative) participants were instructed to move the manikin with a joystick towards positive pictures and away from negative pictures, as fast as possible upon picture presentation. In *incongruent* blocks (approach-negative, avoid-positive) participants had to move towards negative and away from positive pictures. **B)** Object-reference condition: An emotional picture was presented either above or below a manikin. Participants moved the emotional picture towards or away from the manikin depending on the block. Participants were instructed to move positive pictures towards and negative pictures away from the manikin (*congruent* blocks), or move negative pictures towards and positive pictures away from the manikin (*incongruent* blocks). For both reference-frames, the direction of movement determined whether subjects had to make a pull or a push to approach and avoid.

In the *object-reference* condition, participants moved an emotional picture (object) towards or away from a centrally presented manikin. Trials started with the central fixation cross (500 ms), followed by both the fixation and a blue square that was pseudo-randomly presented above or below fixation (500 ms; **Figure 2.1B**). Subsequently, the central fixation was replaced by the manikin and the blue square was replaced by the picture (max. 2000 ms, or until the target was reached). Participants were instructed to move positive pictures towards and negative pictures away from the manikin (*congruent* blocks), or move negative pictures towards and positive pictures away from the manikin (*incongruent* blocks). Here, the starting position of the picture also determined the type of movement that subjects had to execute to approach or avoid.

Congruency thus refers to whether the goal of approaching or avoiding was congruent with the valence (i.e. approach positive and avoid negative pictures). *Movement type* refers to whether a pull or a push was executed to approach and avoid the emotional stimulus.

For *each* reference-frame session, participants completed two training blocks of 30 trials each, one for congruent and one for incongruent movements, before the main experiment to familiarise themselves with the task. For training, a different set of 60 pictures (30 negative/positive) was used. Participants rated the valence of all the pictures at the end of the second experimental session on a scale of 1 to 9 (1 = most negative; 9 = most positive). They did not provide arousal ratings.

2.3.4. <u>*Data Analyses*</u>

Reaction times (RT; time from picture onset to joystick movement onset) and movement times (MT; time from movement onset to completion of the movement, i.e. reaching the target area) were measured as dependent variables. Joystick data were recorded in XY-coordinates and RTs were calculated based on vertical y-axis coordinate deviations (over 10 coordinates) from trial baseline. The baseline was recorded while the manikin remained stationary prior to the appearance of the picture.

RTs determine the timing of action initiation and give an idea of how quickly processing takes place. Thus, it should reveal the speed of selection of approach-avoidance actions. In contrast, MTs determine the speed of action execution and therefore informs us of any effects of approach-avoidance tendencies on online motor planning and action execution.

All trials in which the movement did not match the instructions (e.g., avoiding when instructed to approach negative images; 10.2% of trials), with RTs below 100 ms (0.6%) or exceeding 2000 ms (3.8%) were excluded from analyses. Outlier RTs (2.5%) were calculated per block for each subject using Grubb's test ($\alpha = 0.05$) and were excluded. Across both experimental sessions, 17.1% of trials were excluded.

A 2x2x2x2 within-subjects repeated measures ANOVA (rm-ANOVA) with factors *Reference-Frame* (self vs. object) x *Movement type* (pull vs. push) x *Congruency* (congruent vs. incongruent) x *Valence* (positive vs. negative) for both RT and MT analyses was conducted. For all analyses, partial η^2 is reported as a measure of effect size. For all significant results, statistical threshold was fixed at 0.05. Significant interactions were followed-up using two-tailed paired-sample t-tests. Mean RTs are reported in brackets, ±1 standard error of the mean (SEM). For questionnaire correlations, a 2-tailed bivariate Pearson correlation was used and corrected for multiple comparisons. All RTs and MTs are in milliseconds.

To analyse the effect of arousal on RTs, a multiple regression was conducted for each condition with dependent variable RT and independent variables *valence* and *arousal* for each participant separately. A 4-way RM-ANOVA was subsequently computed on the beta coefficients obtained from the multiple regression with factors *Reference-Frame* (self vs. object) x *Variable type* (valence vs. arousal) x *Movement direction* (approach vs. avoid) x *Movement type* (pull vs. push). The beta coefficients were taken as an indication of which of the independent variables (valence or arousal) had a greater impact on the RTs.

2.4. Results

2.4.1. Speed of movement initiation: Reaction times

The 4-way RM-ANOVA yielded a 4-way interaction across all four factor types (*Ref.-Frame*Congruency*Valence*Movement type*, $F_{(1,25)} = 33.31$, $p < 0.001$, $\eta_p^2 = 0.57$). All other interactions were qualified by this 4-way interaction, and therefore only follow-up statistics are reported for the breakdown of this 4-way interaction. The 4-way interaction was split and analysed separately for each *Reference-Frame* **(Figure 2.2)**.

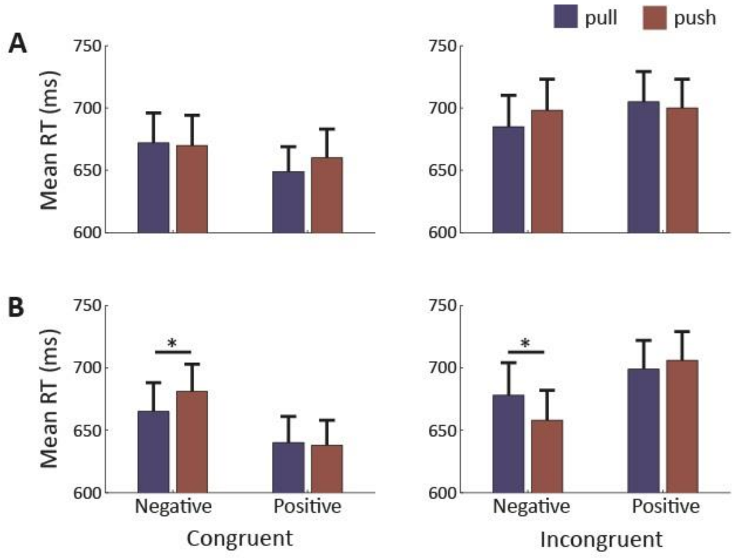


Figure 2.2. Mean reaction times (RTs) for each reference-frame. A) Object-reference condition: RTs did not differ when pulling or pushing to approach and avoid. **B)** Self-reference condition: RTs were significantly faster for pulling to avoid and pushing to approach negative pictures. Error bars (+1 S.E.M.); blue bars = pull; red bars = push. * = significant at $p < 0.05$ level.

Follow-up analyses for the *object-reference* yielded a 3-way interaction (*Congruency*Valence*Movement type,* $F_{(1,25)} = 5.62$, p = 0.026, $\eta_p^2 = 0.18$). Paired t-tests did not reveal any significant differences between making push and pull movements when avoiding and approaching emotional pictures **(Figure 2.2A)**. The 3-way interaction was mainly driven by a *Congruency*Valence* interaction ($F_{(1,25)} = 10.09$, p = 0.004, $\eta_p^2 = 0.29$) which revealed a congruency effect for positive and negative valence, regardless of the type of movement made to achieve the required behaviour **(Figure 2.3B)**. Reaction times were faster when approaching (655 ± 21 ms) compared to avoiding (703 ± 23 ms) positive pictures ($t_{(25)} = -5.18$, $p < 0.001$, Cohen's d = -1.05), and were marginally faster at avoiding (671 ± 24 ms) compared to approaching (692 ± 24 ms) negative pictures ($t_{(25)} = -1.78$, p = 0.087, Cohen's d = -0.35). Furthermore, approaching was faster for positive compared to negative pictures ($t_{(25)} = -3.38$, p = 0.002, Cohen's d = -0.69), and avoidance was faster for negative relative to positive pictures ($t_{(25)} = -2.62$, p = 0.015, Cohen's d = -0.52).

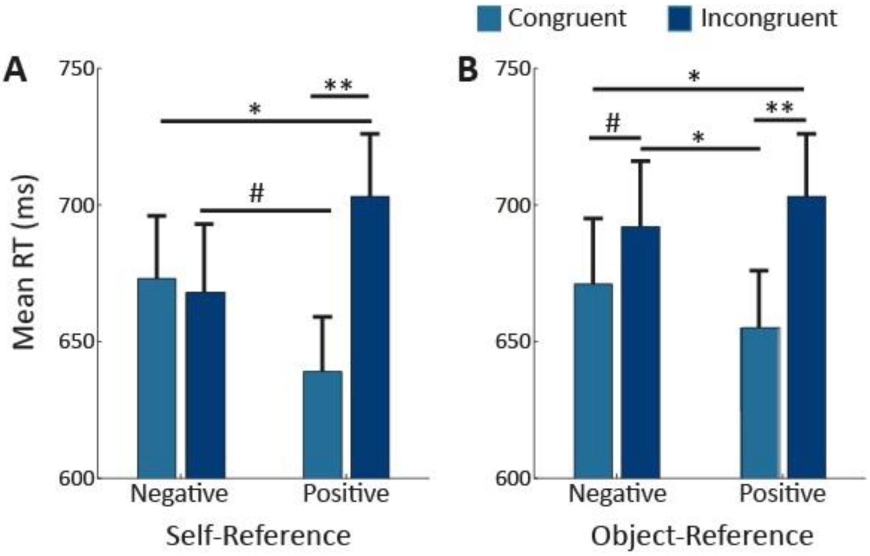


Figure 2.3. Mean reaction times (RTs) for each reference-frame collapsed across pull and push movements. A) Self-reference condition: RTs were significantly faster when participants approached compared to avoiding positive pictures. Avoidance was faster for negative relative to positive pictures. **B)** Object-reference condition: RTs were significantly faster for approaching than avoiding positive pictures and marginally significantly faster when avoiding compared to approaching negative pictures. Approach was faster for positive relative to negative pictures and avoidance was faster for negative relative to positive pictures. Error bars (+1 S.E.M.); light blue bars = congruent; dark blue bars = incongruent. ** = significant at p < 0.001 level, * = = significant at p < 0.001 level; # = marginally significant.

Follow-up analyses for the *self-reference* **(Figure 2.2B)** also yielded a 3-way interaction (*Congruency*Valence*Movement type,* $F_{(1,25)}$ = 52.00, p < 0.001, η_p^2 = 0.42). In contrast to the *object-reference*, paired t-tests revealed differences between push and pull movements for negative pictures only. Avoidance was faster when subjects pulled (665 ± 23 ms) than pushed negative pictures (681 ± 22 ms) ($t_{(25)}$ = -2.26, p = 0.032, Cohen's d = -0.46). Similarly, approach was faster when subjects pushed (658 ± 23 ms) than pulled negative pictures (678 ± 26 ms) ($t_{(25)}$ = 3.61, p = 0.001, Cohen's d = 0.76). No other significant differences were found. Therefore, this interaction was mainly driven by differences between the valences, but also by differences between pushing and pulling negative pictures.

For the *self-reference* there was also a significant 2-way interaction between *Congruency*Valence*, $F_{(1,25)}$ = 61.79, p < 0.001, η_p^2 = 0.71) which showed a congruency effect for positive pictures **(Fig 2.3A).** Approaching was faster (639 ± 20 ms) compared to avoiding (703 ± 23 ms) positive stimuli, irrespective of the required action ($t_{(25)}$ = -4.81, p < 0.001, Cohen's d = -0.97). A congruency effect for negative pictures was not observed (avoid: 673 ± 23 ms, approach: 668 ± 25 ms, n.s). Thus, participants were equally fast in approaching or avoiding negative pictures, independently of the required movement. Additionally, avoiding was faster for negative than positive pictures ($t_{(25)}$ = -2.26, p = 0.032, Cohen's d = -0.52). Approach was marginally faster for positive than negative ($t_{(25)}$ = -2.01, p = 0.055, Cohen's d = -0.42).

Overall, the speed of action selection and initiation appeared to be influenced by valence-related approach-avoidance tendencies. Importantly, action selection of response tendencies was influenced by whether it was the self moving towards the emotional stimulus, or the emotional stimulus moving towards the self, indicating an effect of context on action selection.

2.4.2. Speed of action execution: Movement times

Action execution was also influenced by the reference-frame and the type of movement made. Analysis of the MTs revealed a 4-way interaction (*Ref.-Frame*Congruency*Valence*Movement type*, $F_{(1,25)}$ = 10.76, p = 0.003, η_p^2 = 0.30). This interaction was analysed separately for each *Reference-Frame*.

In the *object-reference* **(Figure 2.4A)**, the 3-way rm-ANOVA (with factors *Congruency, Valence and Movement type*) revealed a 2-way interaction *Congruency*Valence* ($F_{(1,25)}$ = 12.12, p = 0.002, η_p^2 = 0.33). MTs were faster when avoiding (185 ± 12 ms) compared to approaching (219 ± 16 ms) negative pictures ($t_{(25)}$ = -3.84, p = 0.001, Cohen's d = -0.85). Similarly, MTs for avoiding positive pictures (190 ± 13 ms) were faster than approaching (210 ± 16 ms), ($t_{(25)}$ = 2.08, p = 0.048, Cohen's d = 0.41). Importantly, these effects occurred independently of the type of movement made. Thus, subjects were not only faster to initiate avoidance compared to approach when negative pictures were presented (as seen in the RTs) but they were also faster to move the picture away once the movement had been initiated. However, the result for positive pictures is difficult to interpret since RTs were faster for approach compared to avoidance, but subjects were faster at moving a positive picture away than towards.

In the *self-reference* **(Figure 2.4B)**, follow-up analyses revealed a 3-way interaction (*Congruency*Valence*Movement type*, $F_{(1,25)}$ = 23.10, $p < 0.000$, $\eta_p^2 = 0.48$). This interaction was split into each *Congruency*. For *Congruent* trials, pulling to approach positive pictures was faster than pushing (pull: 152 ± 14 ms; push: 165 ± 13 ms; $t_{(25)} = -2.44$, $p = 0.022$, Cohen's d = -0.47). Differences between pushing and pulling to avoid negative pictures were not significant. For *Incongruent* trials, pulling to approach negative pictures was faster than pushing (pull: 154 ± 12 ms; push: 174 ± 14 ms; $t_{(25)} = -3.30$, $p = 0.003$, Cohen's d = -0.74). Differences between pushing and pulling to avoid positive pictures were not significant. Thus, in situations where participants had to approach valenced stimuli, pulling was always faster than pushing. However, these differences for pulling or pushing movements to approach were the same for both valences, as revealed by paired sample t-tests. In contrast, when participants had to avoid both valences, there were no differences between movements. This highlights that without appropriate control, MTs can potentially be explained by the biophysical properties of the arm rather than by the content of the stimulus. In sum, valence did not affect action execution when the self was approaching or avoiding (see also (Rotteveel & Phaf, 2004).

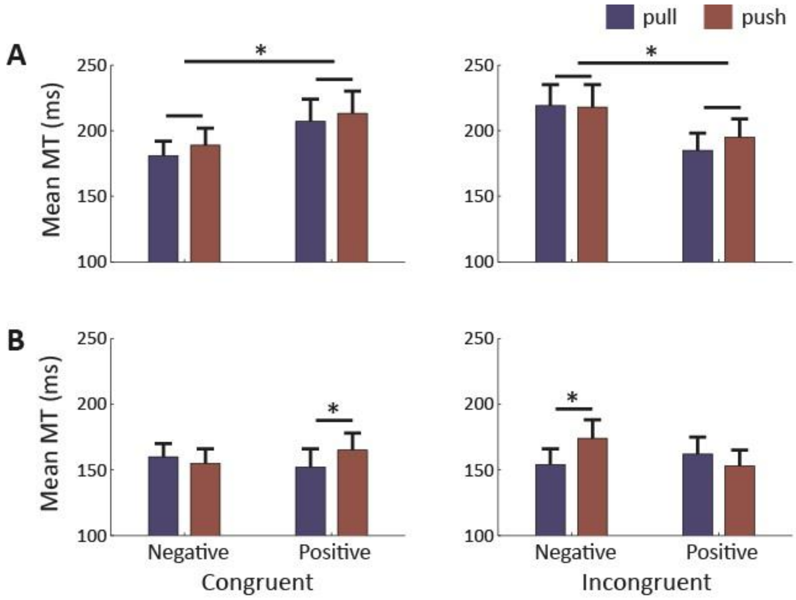


Figure 2.4. Mean movement times (MTs) for each reference-frame. A) Object-reference condition: MTs did not differ when pulling or pushing to approach and avoid albeit MTs to avoid were faster than to approach both valences. **B)** Self-reference condition: MTs were significantly faster for pulling to approach both positive and negative pictures. There were no significant differences in MT to approach or avoid both valences. Error bars (+1 S.E.M.); blue bars = pull; red bars = push. * = significant at < 0.05 level.

Overall, context appeared to influence the speed of action execution. When the emotional stimulus moved towards or away from the self, execution was faster when avoiding than approaching, irrespective of valence. When participants moved the self towards or away from the emotional stimulus, approaching was faster than avoiding irrespective of valence. Thus, it appears as though context influenced the execution of actions but approach-avoidance tendencies did not.

2.4.3. *Individual picture ratings and arousal*

Subjects may differ in their perception of emotional stimuli, which may affect individual RTs. For this reason, the data was re-analysed using participants' subjective picture ratings instead of the IAPS ratings. A 4-way rm-ANOVA identical to that computed for the main RT analysis above revealed the same 3-way interaction (*Ref.-Frame*Congruency*Valence*, $F_{(1,24)} = 28.89$, $p < 0.001$, $\eta_p^2 = 0.55$). Follow-up ANOVA's yielded the same results as the main analysis above. Therefore, results were no different from the IAPS ratings.

Similarly, because emotional pictures also elicit arousal (i.e. intensity of activation; Lang & Bradley, 2010) the analysis examined whether RT effects could be explained by arousal rather than valence. Arousal ratings were taken from the IAPS. Average arousal rating for positive pictures was 5 and for negative pictures 5.7. The 4-way rm-ANOVA revealed an effect of the variable type (valence vs. arousal) on approach and avoidance (2-way interaction *Variable type*Movement direction*, $F_{(1,25)} = 10.80$, $p = 0.003$, $\eta_p^2 = 0.30$). A positive correlation between valence and avoidance and a negative correlation between valence and approach was expected. Indeed, it was found that beta coefficients were significantly higher in the valence-avoidance (0.13 ± 0.03) compared to the valence-approach (-0.09 ± 0.06) conditions ($t_{(25)} = 3.002$, $p = 0.006$, Cohen's $d = 0.19$). Arousal-avoidance was not significantly higher than arousal-approach. Thus, the arousal associated with the emotional stimuli did not influence the results.

2.4.4. *Questionnaire correlations*

Some research has suggested that approach-avoidance tendencies may be influenced by motivation and personality traits (Elliot, 2006; Elliot & Thrash, 2010). As such, the analysis tested whether personality traits, motivational states, and fear levels correlate with participants' individual picture ratings and RTs for approach-avoidance. Positive questionnaire items (BAS *drive*, *fun seeking*, *reward responsiveness*; BFI factor *Extraversion*) were correlated with ratings and RTs for positive pictures. Positive picture ratings and *Extraversion* correlated with each other (r = 0.54, n = 25, p = 0.005) indicating that more extroverted individuals rate stimuli more positively compared to those with low extraversion. Thus, more optimism is related to increased positive evaluation of emotional stimuli, compared to participants with a more pessimistic outlook. No other questionnaire ratings correlated with RTs for approaching positive stimuli. This may be because extraversion relates to affective experience (e.g. being outgoing or sociable), whereas approach is related to a broader range of biologically relevant emotional stimuli. Similarly, no correlations were found for BAS items because they are mainly elicited by reward associated social situations (Elliot & Thrash, 2010). Negative questionnaire items (*BIS*; BFI factor *Neuroticism*; FSS-III (*fear*) items were correlated with ratings and RTs for negative pictures. There was a correlation trend between *Neuroticism* and *Fear*, (r = 0.46, n = 25, p = 0.021), but was not significant after correcting for multiple comparisons. No other correlations were observed. Overall, personality traits, social motivational states and fear levels did not impact on approach-avoidance behaviour.

2.5. Discussion

The selection of approach-avoidance actions to emotional stimuli may be flexibly influenced by the context in which behaviour occurs or be rigidly determined by the activation of specific movements. To investigate how action selection in emotional situations occurs, an experiment was conducted comparing two different reference-frames and by manipulating the type of movements executed within each reference-frame. The results are supportive of evaluative-coding models of action selection (Lavender & Hommel, 2007; Eder & Rothermund, 2008), whereby the context and the frame of reference determine approach-avoidance goals that will subsequently influence action selection.

Reference-frame facilitates different actions for approach and avoidance

Results show that the reference-frame influences the facilitation of flexion and extension movements to approach or avoid emotional stimuli, indicating an effect on action selection. When the self had to move towards or away from a positive stimulus (self-reference), results were incompatible with a muscle-specific account: when approaching positive pictures, pulling was not faster than pushing, and vice versa. Thus, this work shows support for the common-coding account and confirms previous studies (Bamford & Ward, 2008; Eder & Rothermund, 2008; Lavender & Hommel, 2007; Markman & Brendl, 2005a; Proctor & Zhang, 2010; Rotteveel & Phaf, 2004; Seibt et al., 2008).

In contrast, novel evidence of muscle-specificity for negative pictures was found. When the self avoided negative pictures, pulling was faster than pushing, and when the self approached negative pictures, pushing was faster than pulling. Thus, defensive behaviour facilitated specific movements when the self moved either towards or away from a negative stimulus. This supports previous work that push movements are faster when the self approaches a stimulus (e.g. a puppy), whereas pulling is faster for avoidance of a stimulus (e.g. a spider) (Lavender & Hommel, 2007; Seibt et al., 2008; Wentura, Rothermund, & Bak, 2000). Importantly, this effect is opposite to that proposed by the muscle-specific account, namely that flexion is faster for approach and extension is faster for avoidance. It is therefore the context that determines which actions are facilitated. The muscle-specificity of approaching and avoiding negative pictures supports the existence of a fast-acting and automatic response mechanism to threat. Responding quicker to negative stimuli in our environment when the self needs to withdraw from a stimulus may have evolutionary advantages, and it is speculated that this muscle-specificity arises from a hard-wired, possibly subcortical, process (LeDoux, 2000).

In the object-reference condition, the facilitation of actions to approach and avoid positive and negative stimuli was not pre-defined and muscle-specific. That is, when participants were required to move a stimulus towards or away from the self, there were no differences in initiating (RTs) and making (MTs) approach or avoidance movements, suggesting no influence on the selection or execution of actions. Thus, contrary to the predictions of the muscle-specific account, pulling was not faster than pushing to approach, and pushing was not faster than pulling to avoid. The results replicate and confirm those of

Markman & Brendl (2005) who had previously manipulated movement direction in an object-reference frame and demonstrated the actions to approach and avoid were not muscle-specific. Rotteveel & Phaf (2004) had also previously shown that although approach and avoidance were faster for positive and negative faces, respectively, such behaviour was not automatically dependent on flexion or extension movements. Similarly, Eder & Rothermund (2008) suggested that it is not the pull or push action made that drives approach-avoidance behaviour but rather the instruction that is assigned to the responses.

The results therefore advocate the flexibility of pull and push actions to approach and avoid in both reference-frames, but also demonstrate a degree of muscle-specificity present only in situations when the self has to respond to threat. Thus, the results confirm that actions to approach and avoid are not rigidly determined, as previously speculated (Bamford & Ward, 2008; Eder & Rothermund, 2008; Rotteveel & Phaf, 2004; Seibt et al., 2008). That is, when we want to chip a spider away extension is not faster than flexion and we want to pet a puppy or when we want to bring a puppy closer to us, extension is not faster than flexion. However, results also show that in some instances of threat, muscle-specific actions can be facilitated, supporting the existence of a fast-acting defensive circuitry. Importantly, these effects could not be attributed to arousal or personality traits, confirming that approach and avoidance are valence-driven behavioural effects. Importantly, the results demonstrate an influence of context on the selection of approach-avoidance actions.

Reference-frame determines the affective coding of approach-avoidance actions

In the current experiment, approach and avoidance behaviour is shown to be influenced by whether it is the self that moves relative to an object or whether it is an object that is moved relative to the self. Thus, context determines how to approach or avoid emotional stimuli, and suggests an influence of context on action selection and initiation. While in the self-reference condition participants were faster to approach than avoid positive pictures, there was no difference between approaching and avoiding negative pictures (see also Gawronski, Deutsch, & Strack, 2005; Stins, Roelofs, et al., 2011). In contrast, in the object-reference condition, participants were also faster to approach than avoid positive stimuli but avoidance was now faster than approach for negative pictures. Whereas the object-reference showed the typical avoidance pattern for negative stimuli, the self-reference did not. These differences indicate that, through the experimental set up, subjects viewed both reference-frames as being different and therefore both tasks could be used interchangeably. Previous studies had shown that movements made to approach and avoid can occur to a salient reference on the screen (Proctor & Zhang, 2010; van Dantzig et al., 2009). In line with previous work (Markman & Brendl, 2005), the results show that a symbolic self on the screen is capable of eliciting different approach-avoidance results for different reference-frames. It is demonstrated that directly looking at interchangeable approach-avoidance contexts is important to determine context-dependent approach-avoidance effects.

It has been previously shown that negative stimuli can trigger a variety of defensive actions including escape (i.e. avoidance) and attack (i.e. approach) (Lang et al. 1997; Lang & Bradley, 2010). The current findings reinforce this hypothesis by showing that the self can facilitate movements either towards or away from a negative picture with equal speed. This tendency may result from the fact that the set of pictures contained both fearful and violent scenarios, which have been classified as being the most threatening from a survival perspective (Bradley et al., 2001). *Speculatively*, the former may predominantly facilitate “flight” responses (i.e. the self moving away), whereas the latter may trigger “fight” responses (i.e. the self moving towards), which may be coded as appropriate responses to negative stimuli. Previous work had suggested that approach-avoidance is faster when there is a correspondence between the affective content and associated approach-avoidance response codes (e.g. positive-move towards, negative-move away; Proctor & Zhang, 2010). However, there is no evidence of such correspondence for negative stimuli, as moving towards was also coded as a negative response.

To speculate, the specific content of the negative stimulus (e.g., fearful vs. attack) may determine which behaviour is facilitated (approach or avoid) and in self-reference contexts, the evaluation of negative stimuli may not necessarily result in avoidance. Indeed, recent work using whole-body movements suggests that the body approaches negative (attack) stimuli faster than it avoids such stimuli (Naugle et al., 2011). Similarly, faster avoidance has been linked to fearful faces (Seidel, Habel, Kirschner, Gur, & Derntl, 2010a), and faster approach to angry faces (Carver & Harmon-Jones, 2009; Wilkowski & Meier, 2010; though see Stins et al. 2011). Furthermore, in the self-reference frame there was no difference in approach or avoidance speed once the movement was initiated (MTs). This reinforces the crucial role of stimulus evaluation in dictating differences in approach and avoidance, rather than any subsequent perceptual or cognitive mechanisms that may take place once the movement has been initiated, supporting studies that have shown an "evaluative-dependency" of approach-avoidance behaviour (Eder & Rothermund, 2008; Lavender & Hommel, 2007; Rotteveel & Phaf, 2004). However, this result is at odds with previous work which has suggested that negative stimuli automatically trigger avoidance, both with and without conscious evaluation of the stimulus (Chen & Bargh, 1999; Krieglmeyer et al., 2010; Rotteveel & Phaf, 2004).

Crucially, in the self-reference frame, pulling (flexing) was faster to avoid and pushing (extending) was faster to approach negative stimuli, consistent with previous suggestions (Lavender & Hommel, 2007; Wentura et al., 2000). Thus, we may not only have a tendency to approach and avoid negative pictures depending on their level of threat, but for each tendency, specific movements are facilitated in a fast and efficient manner, suggesting a fast-acting context-dependent defensive circuitry (LeDoux, 2000).

Lastly, results highlight the importance of looking at approach and avoidance effects for positive and negative stimuli separately. Thus, previously reported approach-avoidance effects (Chen & Bargh, 1999; Krieglmeyer et al., 2010; Lavender & Hommel, 2007; van Dantzig et al., 2008) may mask important differences in reactions to valenced stimuli due to the practice of averaging RTs across positive and negative valences for congruent (i.e. approach-positive/avoid-negative) and incongruent (i.e. avoid-positive/approach-negative) conditions. Although previous work attempted to eliminate any confounding effect of stimulus evaluation on RTs by averaging across valences, the results highlight that a combination of stimulus evaluation and movement facilitation drive differences in RTs. This work raises the interesting question whether avoidance effects can be further subdivided according to the specific requirement for flight or fight actions in response to negative stimuli. Given the current results, future studies could directly address this by comparing approach and avoidance to pictures that have been classified as containing violent/attack scenarios and pictures depicting fearful stimuli.

In sum, the data suggest that emotional approach-avoidance tendencies influence the speed of action selection and initiation, and this selection is dependent on the context. Furthermore, the results highlight the existence of automatic (i.e. faster) approach tendencies when encountering a positive stimulus, and suggest the existence of automatic defensive actions to negative stimuli, which may involve both approach and avoidance depending on the type of negative stimulus encountered.

Movement execution is not influenced by valence-related approach-avoidance tendencies

The results demonstrated an influence of emotional tendencies on the speed of selection of approach-avoidance actions. However, such response tendencies did not appear to influence the speed of action execution. There was no influence of approach and avoidance on how quickly actions were executed, but there was an influence of context. When the emotional stimulus moved relative to the self, action execution was faster when avoiding than approaching, whereas when the self moved relative to the stimulus the opposite was true. This shows an influence of context and movement type on movement planning and action execution. Importantly, it demonstrates a dissociation in the effect of approach-avoidance tendencies on action preparation and action execution, with approach-avoidance tendencies only influencing the former.

Alternative explanations

An alternative explanation suggests that approach and avoidance is dictated by the subjective outcome of the action (a decrease or an increase in the distance between the self and the emotional stimulus), rather than by stimulus evaluations (distance regulation account; Strack & Deutsch, 2004). The current design allowed participants to directly observe the outcome of their actions, and therefore show whether there was an actual increase or decrease in distance between the self and the stimulus. The results for negative pictures in the self-reference condition do not support the distance regulation account because in this condition the self both increased and decreased the distance This provides additional evidence for the evaluative nature of approach-avoidance, showing that the evaluation of the content of the picture dictates the facilitated action and that this occurs independently of the distance change involved.

Conclusions

To conclude, the current work has shown that the reference-frame influences the speed of selection of approach and avoidance actions, and flexibly determines the facilitation of actions to approach and avoid emotional stimuli. Thus, the data support the common-coding account by showing that action facilitation to approach and avoid emotional stimuli is not pre-determined and muscle-specific. Only when the self moves relative to a negative (threatening) stimulus, specific movements are triggered to either approach or avoid, similar to a "fight or flight" response, depending on whether stimulus evaluation elicits attack or escape. Results therefore confirm that approach-avoidance behaviour is flexible and reference-frame dependent, but can be muscle-specific depending on the context and valence of the stimulus. Valence-related approach-avoidance tendencies and the context therefore are key influences on the speed of action selection and initiation. Importantly, such valence-related tendencies do not influence the speed of action execution, demonstrating a dissociation in the influence of approach-avoidance tendencies on different motor stages. The reference-frame and stimulus-evaluation are key factors in guiding approach and avoidance behaviour towards emotional stimuli in our environment.

Chapter Three. Facilitation and interference of approach-avoidance responses through affective primes

3.1. Abstract

The faster preparation of action should benefit humans by allowing for the anticipation of potential threats or advantages in the environment. Emotional tendencies associated to affective cues in the environment may influence how fast action preparation occurs, subsequently speeding up the initiation of actions to impending affective stimuli (*valence-trigger account*). Alternatively, affective cues may bias responses according to task-defined stimulus-response (S-R) associations, irrespective of any pre-established valence-action mappings (*action-trigger account*). Here, these two accounts were directly contrasted to investigate how task-irrelevant primes influence action preparation, and whether this influence can occur implicitly. In Experiment 1, supraliminal positive and negative face primes preceded task-relevant affective face targets that required approach-avoid responses. Results showed that task-irrelevant affective primes influenced target responses according to task-specific instructions. In Experiment 2, the specificity of facilitation and interference effects was further assessed. Results showed that when compared to a baseline, the same prime-target valence pairings resulted in faster responses, whereas different prime-target pairings slowed down responses. Using the same task, Experiment 3 presented affective primes subliminally and supraliminally to assess for implicit effects on preparation. There was no evidence for implicit effects of subliminal primes. In sum, affective primes bias the preparation of approach-avoidance actions through the task-defined context in which these actions occur, rather than by response tendencies. The results therefore lend support to the *action-trigger account.* Importantly, this influence does not occur implicitly without conscious stimulus evaluation.

3.2. Introduction

Chapter Two demonstrated that action selection and initiation is influenced by approach-avoidance tendencies and the reference frame. Valence-related approach-avoidance tendencies and the emotional context therefore have an impact on the preparation of actions prior to the initiation of movement. This influence on preparation should benefit humans by allowing for the anticipation of potential threats or advantages in the environment. That is, affective stimuli may act as warning cues that signal, for example, upcoming danger (LeDoux, 1996), and may allow individuals to prepare appropriate responses in expectation of forthcoming emotional events (Damasio, 1994; Fijda, 1986; James, 1884). Upon hearing scary music in a movie, for example, one may anticipate a scary scene and consequently prepare to cover one's eyes to avoid the expected negative movie scene. Given that valence-related response tendencies influence how quickly we select approach and avoidance actions prior to the initiation of movement, responses to impending positive or negative stimuli may occur faster if these target stimuli are preceded by affective cues (or primes) of the same valence (Eder & Klauer, 2009; Eder & Rothermund, 2008; Hommel, 1998). Seemingly, a positive affective cue would prepare for approach and subsequently lead to a faster approach response if a positive target follows, whereas a negative cue would allow for faster avoidance.

Importantly, these emotional cues may be unintentionally processed via the prioritisation of emotional information (Ohman et al., 2001; Vuilleumier, 2005; Vuilleumier et al., 2001). It is currently unknown whether task-irrelevant emotional cues are unintentionally processed such that they trigger approach-avoidance tendencies to help prepare responses to upcoming emotional stimuli. In this chapter, preparation refers to the ability to anticipate the selection of actions. This anticipation of action selection would suggest that irrelevant emotional information in the environment may sometimes become relevant in order to guide appropriate and successful behaviour, demonstrating the ability for emotional information to have privileged access to motor processes.

This chapter investigated how approach-avoidance tendencies influence action preparation using an approach-avoidance task in which affective primes preceded affective target stimuli. Affective primes are stimuli that are task-irrelevant and presented briefly before an imperative target stimulus (i.e. a stimulus that requires a behavioural response), and can influence the processing of these targets (Eder et al., 2012; Klauer, 1997). Indeed, previous work has suggested that primes are used to predict an outcome and influence expected upcoming responses (Klauer, 1997). A positive prime may lead to faster responses to an expected positive target stimulus, whilst a negative prime may decrease the time needed to respond to an expected negative target stimulus. Thus, if the response tendency associated with the prime and the target match (stimulus-response (S-R) validity), responses will be faster (Kunde, 2004; Kunde, Kiesel, & Hoffmann, 2003; Moors & De Houwer, 2010; Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach, 2003).

There are two ways in which affective primes may bias response preparation to affective targets **(Figure 3.1)**. Firstly, primes may be biased by predisposed, and presumed automatic, tendencies (Bargh, 1992; Bradley et al., 2001; Chen & Bargh, 1999; Lang et al., 1990). As such, positive primes may bias towards approach while negative primes may bias towards avoidance action preparation (Bradley et al., 2001; Chen & Bargh, 1999). Accordingly, valence biases actions, and this will be referred to as the "*valence-trigger account*". Indeed, previous work (Eder & Klauer 2009; Experiment 3) showed that approach movements are faster when preceded by a briefly presented positive word cue, and avoidance is faster when preceded by a negative word cue. Importantly, the influence of affective primes on action preparation may occur in an unconscious manner, in accordance with evidence suggesting that goals do not need to be consciously set in order to influence subsequent responses (Custers & Aarts, 2010).

Secondly, affective primes may prepare responses depending on context-dependent top-down influences set up through task instructions, as has been shown previously (Kiesel, Kunde, & Hoffmann, 2007; Liefooghe, Houwer, & Wenke, 2013; Waszak, Pfister, & Kiesel, 2013). For example, instructions may be given to approach positive and avoid negative target faces. Assuming a predisposed tendency to approach positive and avoid negative faces, instructions are congruent with this response tendency. By contrast, one may be given incongruent instructions to avoid positive and approach negative target faces. If task instructions determine the influence of primes on responses, presenting a positive prime during an incongruent block, for example, might result in faster avoidance of a subsequent positive target, even if participants are instructed to ignore primes. Indeed, "*subjects unconsciously apply the task instructions to the prime*" and consequently prepare an action in response to the prime despite being told to ignore the prime (Dehaene et al., 1998; p598). This is further supported by common-coding models, whereby a prime will lead to faster responses to a target if both the prime and the target share similar coding features (Hommel, 1997). This *"action-trigger account"* (Kiesel et al., 2007; Kunde et al., 2003) is in contrast to the *valence-trigger account*, and suggests that movement preparation is guided via top-down influences that override possible automatic S-R tendencies (Waszak et al. 2013).

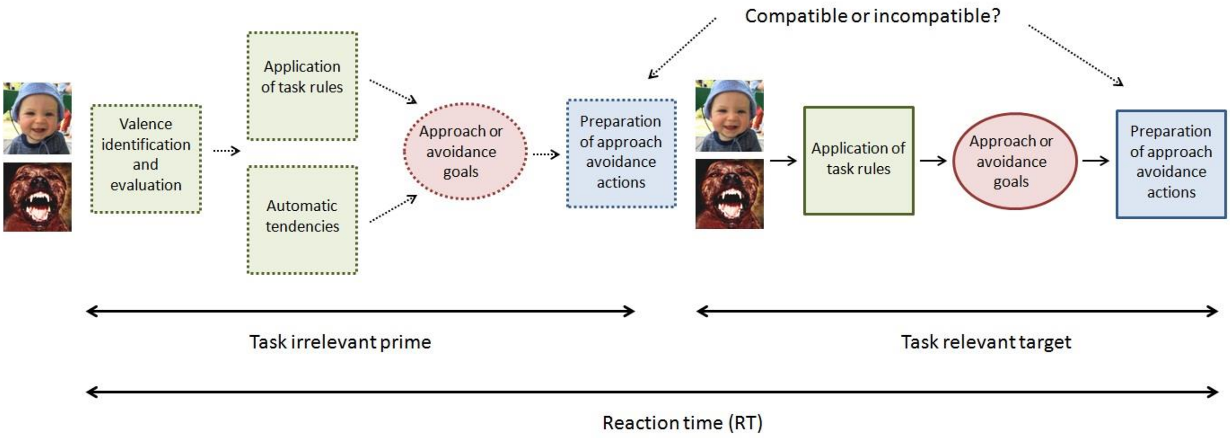


Figure 3.1. Model of how a task-irrelevant prime may prepare for upcoming action. Actions may be prepared via predisposed automatic tendencies, whereby positive triggers approach and negative triggers avoidance irrespective of task instructions, or by the application of task rules that override automatic tendencies. The task-relevant target is expected to trigger approach and avoidance by the application of task rules. If the action prepared by the task-irrelevant prime matches the response prepared by the task-relevant target, then these responses will be compatible and faster than if they do not match. For schematic purposes some steps are left out but for clarification, valence identification and evaluation occurs for both the prime and target.

Previous work has shed light on how actions to approach and avoid are selected (Eder & Klauer, 2009; Lavender & Hommel, 2007), yet no work has directly addressed how task-irrelevant emotional cues are unintentionally processed such that they trigger approach-avoidance goals to help prepare responses to upcoming emotional stimuli. As such, two experiments were conducted to investigate whether and how affective primes bias the preparation of approach-avoidance responses to subsequently presented affective targets. A third experiment was conducted to assess if this bias occurs in situations where the prime is subliminally presented such that it does not reach consciousness. This third experiment was expected to give insight into any unconscious effects on preparation.

Experiment 1 sought to determine if the influence of affective primes on approach-avoidance responses to subsequent affective targets is mediated via predisposed (i.e. *valence-trigger account*) or task-related response associations (i.e. *action-trigger account*). An adapted manikin and joystick task was used (see Chapter One for details), where participants moved a manikin on the screen with a joystick either towards or away from an affective target face that was always preceded by a briefly presented prime face. Participants moved depending on whether the block had congruent (i.e. approach-positive, avoid-negative) or incongruent (i.e. avoid-positive, approach-negative) instructions. Affective primes had either the same valence as the target face or not. Emotional faces were used because these are ecologically valid stimuli that have been shown to be processed fast and reliably (Garvert et al., 2014).

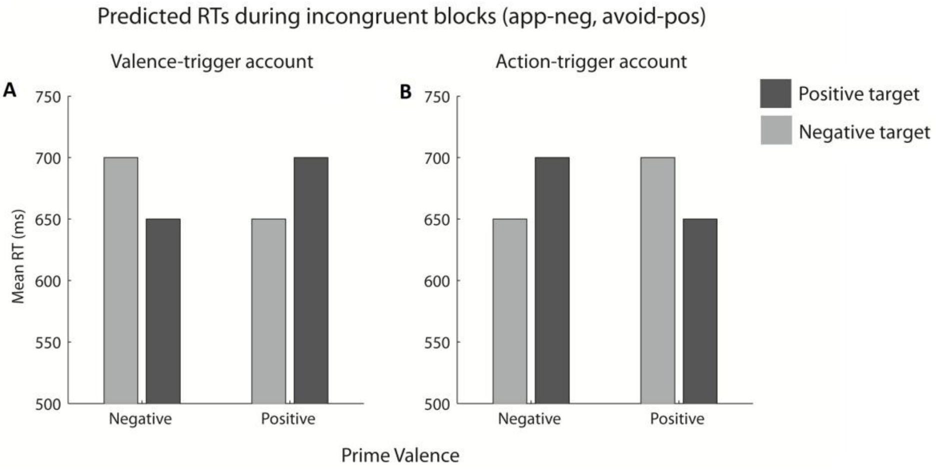


Figure 3.2. Predicted RTs for each account during blocks when participants need to approach negative and avoid positive faces only (incongruent blocks). This condition was expected to reveal differences in the preparation of approach-avoidance actions. **A)** Expected RTs for the *valence-trigger account*, which predicts that when negative primes are presented, which presumably automatically trigger the preparation of avoidance, approaching negative target faces should take longer than avoiding positive target faces. Equally, when positive faces are presented, which presumably trigger the preparation of approach, approaching negative target faces should be faster than avoiding positive target faces. **B)** Expected RTs for the *action-trigger account* which predicts that primes activate actions according to the task-instructions. In incongruent cases, negative primes therefore presumably trigger the preparation of approach and should subsequently lead to faster RTs when negative targets are presented relative to positive targets. Similarly, positive targets that presumably trigger avoidance should lead to faster responses to positive target faces than to negative target faces due to the fact that primes and targets activate the same responses according to the task instructions.

Under a valence-trigger account, positive primes should always lead to the preparation of approach, whereas negative primes should always lead to the preparation of avoidance of subsequent affective targets, irrespective of task instructions (Eder & Klauer, 2009). Thus, approach-avoidance tendencies should override context-determined actions. By contrast, if preparation is guided by top-down influences, primes should lead to the preparation of the response as determined by the current context, and thus task instructions should hold a stronger influence on how actions are prepared by affective primes (Waszak et al., 2013). To determine which of the two proposed accounts is more fitting, it was expected that the reaction times of the incongruent condition compared to the congruent condition would be key in revealing how primes influence action preparation (see **Figure 3.2** for predicted RTs). Furthermore, responses should be initiated faster (i.e. facilitation) for the same prime-target pairings and response initiation should be slower (i.e. interference) for different prime-target pairings.

Both facilitation and interference effects are ways of determining that a response was prepared. However, the results of Experiment 1 only demonstrated an interference arising from the S-R mismatch between the primes and the targets. It remained unknown whether a S-R match between the primes and the targets can also speed up responses. To determine this, a comparison was necessary between situations when affective and non-affective information is available prior to response initiation. Presumably, when primes are not emotional, there should be no interference or facilitation of approach-avoidance responses, whereas when emotional primes are presented their associated approach-avoidance tendencies should interfere or facilitate subsequent response initiation.

As such, in Experiment 2 a neutral face prime condition was introduced as a baseline control that allowed for distinguishing the changes in reaction times in terms of a decrease or increase from this non-affective condition. Importantly, if neutral primes have no effects on the initiation of target responses, then it would show that affective valence is an important feature of action preparation that serves to anticipate emotional outcomes.

Based on the results of Experiment 1, it was predicted that, in comparison to neutral primes, affective primes would slow down responses to affective targets when prime-target pairings were invalid. Similarly, it was expected that affective primes would speed up the selection of responses during valid prime-target pairings. However, if neutral primes have the capacity to elicit their learned associated responses, there should be no difference between the neutral and affective primes in interfering or speeding up action initiation to affective targets. Therefore, the aim of Experiment 2 was two-fold: firstly, to further determine if primes are capable of biasing towards predisposed S-R approach-avoidance associations by applying a different experimental method, and secondly, to demonstrate both facilitatory and inhibitory effects of affective primes.

Irrespective of the type of mechanisms underlying preparation, the prioritisation of task-irrelevant emotional information presented as the prime is expected to drive preparation. This prioritisation may occur unconsciously, whereby participants have no awareness of the existence of the prime (Whalen et al., 1998). Indeed, because work has shown that primes have the capacity of biasing responses, even without participant's awareness of the prime valence (Greenwald, Draine, & Abrams, 1996; Hermans, Spruyt, De Houwer, & Eelen, 2003; Sweeny, Grabowecky, Suzuki, & Paller, 2009) it was hypothesised that accurate detection and discrimination of the affective content of primes may not be required for priming effects. Furthermore, previous work suggests that approach-avoidance responses are unconsciously triggered by affective stimuli (Duckworth et al., 2002) and that goals as determined by the environment can be set without awareness of the stimulus influence (Custers & Aarts, 2010).

The current study also examines whether correct discrimination of the prime is essential to influence the preparation of approach-avoidance responses. If this is the case, it would demonstrate an implicit effect of approach-avoidance tendencies on response preparation. To test for this, in Experiment 1 affective face primes were presented prior to the appearance of the target in an upright or inverted orientation, with the latter orientation known to reduce valence discrimination (Eimer, 2000; Rieth & Huber, 2010). Inverted faces were presented for design purposes, in order to maintain primes at a supraliminal threshold yet impair discrimination. It was predicted that if correct discrimination of the affective prime was necessary for priming effects, priming effects with inverted face primes should be reduced or absent. In Experiment 3 face primes were presented in a supraliminal and subliminal manner and participants approached or avoided affective target faces. Previous studies claiming that conscious evaluation is not necessary for approach-avoidance typically display the emotional content but instead require a different property of the stimulus to be evaluated. For example, presenting a positive or negative face and asking subjects to approach and avoid based on gender and not valence (Krieglmeyer et al. 2010). Thus, the stimulus is still perceivable and may allow for 'affective leaks'. To overcome this, the stimulus was presented subliminally. Work has shown that non-consciously perceived emotional stimuli can increase activity in areas responsible for emotional processing (Anderson et al., 2003) and can elicit electrophysiological activity (Liddell, Williams, Rathjen, Shevrin, & Gordon, 2004). Thus, it is possible for subliminal stimuli to be unconsciously detected and influence the preparation of responses. It was predicted that both supraliminal and subliminal prime faces should influence the initiation of responses to affective targets, albeit subliminal effects should be more subtle. If subliminal primes have the capacity to impact response preparation despite being unconsciously processed, it would suggest that in emotional information is prioritised without the participants' awareness in order to improve the success of emotional behaviour.

3.3. Experiment 1

3.3.1. Methods

3.3.1.1. Participants

32 healthy volunteers (mean age = 25.6 years [± 5.95 S.D.]; 11 female) were recruited from the University College London Psychology database, with local ethics approval (UCL). All participants had normal or corrected-to-normal vision. Participants gave written informed consent to participate in the study, and received monetary compensation for their time and travel (10£/h). Two participants were excluded from the analysis for having a total number of errors above 2 S.D.'s from the population mean.

3.3.1.2. *Stimuli and apparatus*

264 male and female faces were selected from the Karolinska Directed Emotional Faces (KDEF; Lundqvist et al., 1998) and from the Radboud Faces Database (Langner et al., 2010): 132 fearful (negative) faces and 132 smiling (positive) faces. All faces (178 x 241 pixels) were presented in black and white and the ears, neck and hair were excluded. Assignment of faces to blocks and trials was randomised per subject. Each block comprised of 132 trials (66 positive/negative faces). A high contrast pixelated black and white mask (178 x 241 pixels) created in Matlab (v.7.9.1.705; The MathWorks Inc.) was used. The mask was not intended to make the prime subliminal or impair discrimination, but was used instead to eliminate any after images of the prime. The same faces were used as primes and targets but the same face never repeated within a trial.

All stimuli were presented on an LCD screen of a Dell Optiplex 780 computer (refresh rate of 60 Hz), using the Cogent 2000 toolbox (University College London, http://www.vislab.ucl.ac.uk/Cogent2000/index.html) and MATLAB. A white manikin (2.8 x 1.9 cm) was used to represent the subject on the screen. A small yellow circle (1.3 x 1.2 cm) representing the “away” target was presented at the edge of the screen on the same side and at the same time as the manikin. This “away” target was presented on all trials and it was purely for guidance purposes when participants had to move away. The manikin was moved using an analogue joystick connected to a CED1401 (Cambridge Electronic Design) machine. Joystick data were recorded using a CED1401-MATLAB interface (matced32; Cambridge Electronic Design) between MATLAB and the data acquisition device. This allowed for the joystick to move the manikin smoothly on the screen.

3.3.1.3. *Speed of action preparation: Priming task procedure*

Participants were seated in front of a computer at a distance of approximately 40cm with their heads fixated on a chin rest. The joystick was fixed to the table on their right-hand side. Participants were instructed to imagine that the manikin represented them on the screen. Previous work has demonstrated that participants have the ability to represent themselves on a screen, a form of disembodied cognition (Van Dantzig et al., 2009).

Congruency was determined by the approach or avoidance movements made in relation to each valence. 4 blocks (2 congruent/incongruent) were presented in random order. In *congruent* blocks (approach-positive, avoid-negative), participants were instructed to evaluate *target valence* and subsequently move the manikin towards positive faces and away from negative target faces (Fig 2A). In *incongruent* blocks (approach-negative, avoid-positive), participants were instructed to approach negative and avoid positive target faces. In *valid* trials, prime faces had the same valence. In *invalid* trials, the prime faces did not have the same valence as the target. Thus, *prime validity* was determined by whether the valence of the prime and the target were the same or different. Participants were told that a stimulus would briefly appear prior to the presentation of the faces and were instructed to ignore it. Participants were not informed of the content of this stimulus. The *presentation* of the prime face was either inverted (50% of trials) or upright (50%), in random order.

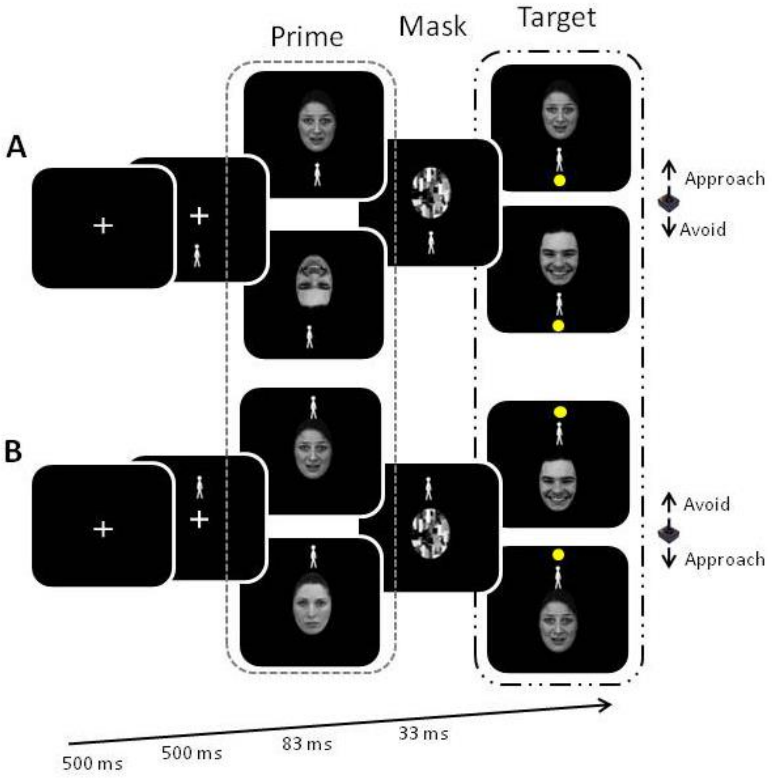


Figure 3.3. Illustration of two trial sequences for Experiment 1 and 2. A) Experiment 1 task: An upright or inverted prime face was presented for 83 ms followed by a high contrast black and white mask displayed for 33 ms. Subsequently, the target was presented and participants had to move the manikin towards positive and away from negative faces (congruent block) or had to move the manikin away from positive and towards negative faces (incongruent block). **B)** Experiment 2 task: An upright affective or neutral face prime was presented for 83 ms followed by a high contrast black and white mask displayed for 33 ms. Subsequently, the target was presented and participants had to move the manikin towards positive and away from negative faces (congruent block) or had to move the manikin away from positive and towards negative faces (incongruent block).

Trials started with a central fixation cross (500 ms), followed by the appearance of the prime and the manikin (5 frame displays of 16.6s; 83 ms), backwardly masked for 33 ms (2 frame displays). Subsequently, the target face was presented (max. 1500 ms or until the respective target was reached). The inter-trial-interval was 500 ms. Previous work has shown good subjective and objective discrimination at displays of around 90 ms (Hsu, Hetrick, & Pessoa, 2008), therefore rendering the prime supraliminal. As such, prime faces were displayed for the duration closest to this value (83 ms). To avoid confounds with the biophysical properties of the arm (e.g. pull vs. push), the manikin was pseudo-randomly presented either above or below the face. If participants moved before the presentation of the target, the trial was aborted and was added to the trial sequence at a randomised location. Error feedback was provided when subjects made a wrong movement. All target faces were presented upright (only primes were either upright or inverted). Before the experiment, participants completed two short training blocks, one congruent and one incongruent, of 30 trials each with faces to familiarise participants with the task. The faces used for training were different to those used in the experiment.

3.3.1.4. <u>Awareness of emotional content: Discrimination task procedure</u>

After completion of the priming task, participants discriminated the valence of each face, to test for participants' awareness of affective valence. In two blocks, faces were presented in the upright or inverted orientation, respectively. Order and duration of presentation were identical to the priming task. The only difference was that no target face was presented after the prime face. After presentation of the prime face participants had to indicate the valence of the stimulus, by pressing one of two indicated keys. Immediately after they made their judgement participants rated via a key press how confident (high or low) they were of their decision. If they were very sure they had made the correct discrimination, their confidence was *high*, if they were unsure about their judgement, their confidence was *low*.

3.3.1.5. Data analyses

Reaction times

Reaction times (RT) were determined from the time of target onset to the initiation of joystick movement. Joystick data were recorded in XY-coordinates and joystick onset was calculated based on vertical y-axis coordinate deviations (±10 y-coordinates) from trial baseline. The baseline was recorded while the manikin was stationary prior to the appearance of the target. All trials in which the movement did not match the instructions (e.g., avoiding when instructed to approach negative faces; 6.3% of trials), with RTs below 100 ms (1.0%) or exceeding 2000 ms (2.4%) were excluded from the analyses. Outlier RTs (1.2%) were calculated per block for each subject using a Grubb's test, $\alpha = 0.05$. In total, 10.9% of trials were excluded.

A 2x2x2x2 within-subjects repeated measures ANOVA (RM-ANOVA) was conducted with factors *Presentation* (upright vs. inverted), *Congruency* (congruent vs. incongruent), *Target-Valence* (positive vs. negative) and *Prime-Validity* (valid vs. invalid). For all analyses, partial-η^2 is reported as a measure of effect size. Statistical threshold was fixed at 0.05. Significant interactions were followed up using two-tailed paired-sample t-tests and Cohen's *d* is reported. RT means and standard error of the mean (SEM) are also reported.

Discrimination task

For discrimination both *subjective* and *objective* d' were measured. Subjective d' was calculated from individual confidence ratings (see Hsu et al., 2008) using *Signal Detection* (Wickens, 2001). Trials were classified as hits if participants answered correctly and reported high confidence, as misses if participants answered correctly but reported low confidence, as false alarms if participants gave an incorrect answer with high confidence, and as correct rejections if participants gave an incorrect answer with low confidence. *Objective* d' (see Hsu et al., 2008) was based on participants' actual correct responses and was determined by taking the proportion of total hits for both negative and positive faces for each presentation and calculating their z-scores. These z-scores were then added to give a combined *objective* d’ across both valences. Paired-sample t-tests were used to determine significant differences from chance level (d’ = 0).

3.3.2. Results

3.3.2.1. Priming task

3.3.2.1.1. Speed of response initiation: Reaction times

The influence of prime validity on target responses was demonstrated by a 3-way interaction between the prime presentation, valence of the target and the validity of the prime with respect to the target (**Figure 3.4A & B**; *Presentation*Target-Valence*Prime-Validity:* $F_{(1,29)} = 7.91$, $p = 0.009$, $\eta_p^2 = 0.21$). This interaction revealed that when the prime was presented upright or inverted, the effect of prime validity was different for each target valence. A follow-up of this interaction was conducted separately for each level of *Presentation* (2 x 2 ANOVA’s with factors *Target-Valence* and *Prime-Validity*, collapsed across *Congruency*).

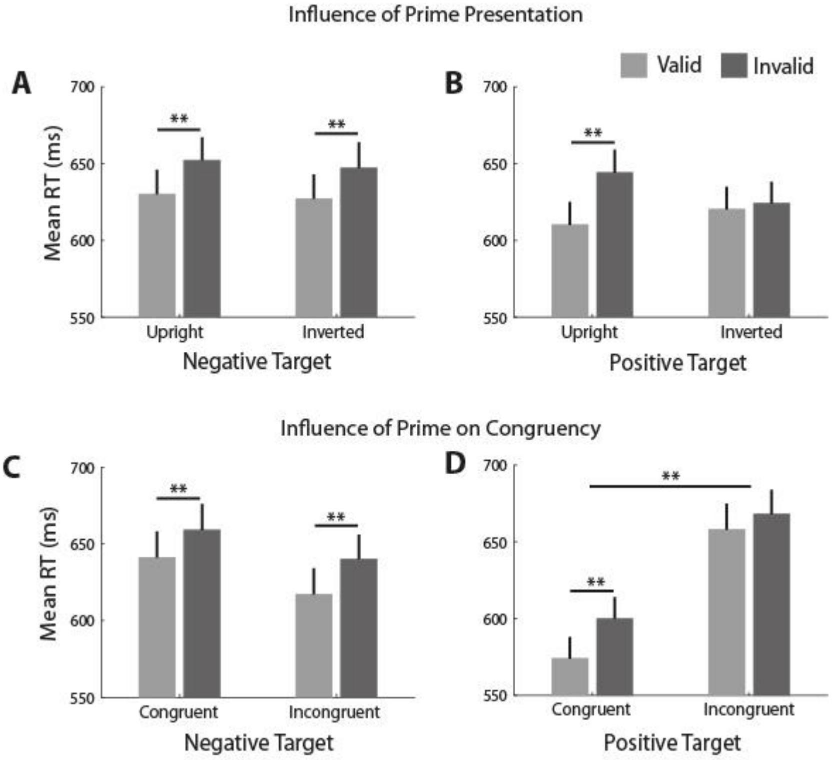


Figure 3.4. The influence of affective primes on the speed of response initiation to affective targets. Upper panels: Mean RTs for valid and invalid trials for the interaction between *Presentation*Target-Valence*Prime-Validity* **(A)** Negative targets: RTs were significantly faster when negative targets were primed by negative upright and inverted primes. Validly primed trials were therefore significantly faster than invalidly primed trials. **(B)** Positive targets: RTs were significantly faster when positive targets were primed by positive upright primes. There was no difference in RTs when positive targets were primed by inverted positive or negative faces. **Lower panels:** Mean reaction times (RTs) for valid and invalid trials for the interaction between *Congruency*Target-Valence*Prime-Validity* **(C)** Negative target faces: Avoidance and approach were faster in valid compared to invalid trials **(D)** Positive target faces: Approach was faster in valid compared to invalid trials. No significant difference between valid and invalid trials when avoiding positive faces. Approach was significantly faster than avoidance for positive target faces. Error bars (+1 S.E.M.); light bars = valid; dark bars = invalid. ** significant at $p < 0.001$ level

When upright prime faces were presented, the effect of *Prime-Validity* was the same for both target valences (*Target-Valence*Prime-Validity*, n.s.). Thus, valid trials were faster than invalid trials for both positive (valid: 610 ± 15 ms; invalid: 644 ± 15 ms; $t_{(29)} = -5.42$, $p < 0.001$, Cohen's $d = -0.98$) and negative (valid: 630 ± 16 ms; invalid: 652 ± 15 ms; $t_{(29)} = -4.86$, $p < 0.001$, Cohen's $d = -0.84$) upright prime faces. In contrast, for inverted prime faces (Fig 3B), the effect of *Prime-Validity* was affected by the valence of the prime face (*Target-Valence*Prime-Validity*, $F_{(1,29)} = 9.73$, $p = 0.004$, $\eta_p^2 = 0.25$). This interaction revealed that, for negative target faces, valid trials were faster than invalid trials (valid: 627 ± 16 ms; invalid:

647 ± 17; $t_{(29)} = -4.63$, $p < 0.001$, Cohen's d = -0.85), but for positive target faces, valid trials (620 ± 15 ms) were not significantly different from invalid trials (624 ± 14 ms).

The influence of affective primes on approach-avoidance responses made in response to affective targets was demonstrated by a 3-way interaction (**Figure 3.4C & D**; *Congruency*Target-Valence*Prime-Validity*, $F_{(1,29)} = 4.73$, $p = 0.038$, $\eta_p^2 = 0.14$). This interaction showed that the initiation speed of approaching and avoiding positive and negative target faces was influenced by the validity of the prime).

A follow-up of this interaction was conducted separately for *Target-Valence* (2 x 2 RM-ANOVA with factors *Congruency* and *Prime-Validity* collapsed across *Presentation*). Both 2-way ANOVA's for negative and positive targets yielded significant *Congruency*Prime-Validity* interactions. For negative target faces, avoidance was faster in valid compared to invalid trials (valid: 641 ± 17 ms; invalid: 659 ± 17 ms; $t_{(29)} = -3.683$, $p = 0.001$, Cohen's d = -0.68) and approach was faster for valid compared to invalid trials (valid: 617 ± 17 ms; invalid: 640 ± 17 ms; $t_{(29)} = -4.62$, $p < 0.001$, Cohen's d = -0.80). In contrast, for positive target faces (**Figure 3D**), approach was faster for valid compared to invalid trials (valid: 574 ± 14 ms; invalid: 600 ± 14 ms; $t_{(29)} = -5.71$, $p < 0.001$, Cohen's d = -1.05). Avoidance was not significantly faster for valid compared to invalid trials (valid: 658 ± 17 ms; invalid: 668 ± 16 ms; n.s). Therefore, both for congruent and incongruent movements, invalid trials were slower than valid trials.

Additionally, for both valences, there was a main effect of congruency. Pairwise comparisons revealed that for negative targets, approaching was significantly faster than avoiding (avoid: 650 ± 16 ms; approach: 628 ± 16 ms; $t_{(29)} = 2.58$, $p = 0.042$, Cohen's d = 0.44). Similarly, for positive targets, approach was faster than avoidance (avoid: 663 ± 16 ms; approach: 587 ± 14 ms; $t_{(29)} = -6.81$, $p < 0.001$, Cohen's d = -1.58). Approaching was therefore faster than avoidance for both valences.

3.3.2.1.2. Awareness of emotional content: Discrimination task

Subjective d’

To show whether the correct discrimination of the primes was necessary for priming effects both subjective and objective discrimination was calculated. Subjective discrimination was above chance (i.e. zero) for both upright and inverted faces (d’upright: 1.72 ± 0.31, $t_{(28)}$ = -5.48, $p < 0.001$; d’inverted: 0.92 ± 0.13, $t_{(29)}$ = -7.09, $p < 0.001$) when combined across valences. Furthermore, subjective d’ was higher when faces were upright compared to when they were inverted ($t_{(28)}$ = 2.52, $p = 0.018$).

When subjective discrimination was split into individual valences for upright faces, discrimination for both valences was above chance (d’positive: 2.02 ± 0.43, $t_{(28)}$ = -4.49, $p < 0.001$; d’negative: 1.42 ± 0.41, $t_{(25)}$ = -3.12, $p = 0.005$), therefore showing participants confidently discriminated both positive and negative upright faces. For inverted faces, subjective discrimination was above chance level for positive faces (d’positive 1.87 ± 0.34: $t_{(27)}$ = -5.38, $p < 0.001$) but discrimination was not significantly different from chance level for negative faces (d’negative: 0.30 ± 0.26, n.s.). The lack of a difference from chance level for negative inverted faces resulted from a combination of high proportion of misses (i.e. correct responses but low confidence) and false alarms (i.e. incorrect responses with high confidence). Thus, participants had low confidence despite being accurate and had high confidence despite being inaccurate.

Objective d’

Objective discrimination was above chance level (i.e. 0.5) for both upright and inverted faces (d’upright: 3.48 ± 0.03; $t_{(29)}$ = -23.68, $p < 0.001$; d’inverted: 2.07 ± 0.03, $t_{(29)}$ = -12.44, $p < 0.001$). Furthermore, objective discrimination was higher for upright than inverted faces ($t_{(29)}$ = 10.62, $p < 0.001$). The z-scores for each individual valence are shown, which were all significantly above chance (d’positive upright: 1.69 ± 0.08; d’ positive inverted: 1.32 ± 0.1; d’negative upright: 1.79 ± 0.08; d’ negative inverted: 0.77 ± 0.09).

3.3.3. Discussion

Experiment 1 was concerned with determining *how* action preparation to approach and avoid occurs. The results show that affective primes help prepare actions according to their contextual (i.e. task-related) S-R associations. This is supportive of the *action-trigger account* (Kiesel et al., 2007): when participants were instructed to approach positive and avoid negative targets, positive primes facilitated responses for approaching positive targets, but slowed down responses for avoiding negative targets. Similarly, in approach-negative/avoid-positive blocks, positive primes biased responses towards avoidance, subsequently making it easier to avoid positive targets but interfering with approaching negative targets. This demonstrates that the instructed link between the response and the valence of a target stimulus is also applied to the task-irrelevant prime. Primes do not bias according to the predisposed action-valence associations as predicted by the *valence-trigger account*. Action preparation to approach and avoid emotional stimuli appears to occur in a top-down manner, whereby goals established by task instructions bias response preparation.

When primes were presented in the upright orientation, validly cued trials were initiated faster than invalidly cued trials for both positive and negative target faces, irrespective of whether an approach or avoidance movement was required. In contrast, when negative inverted prime faces were presented, there was no difference in reaction times to positive target faces between valid and invalid trials. As inverted negative prime faces were not subjectively discriminated above chance, it is speculated that their influence on subsequent responses was minimal and therefore valid trials did not differ from invalid trials in this condition. In contrast, positive inverted faces were discriminated above chance and therefore did influence responses in invalid trials. Indeed, responses for valid trials in all conditions were similar, while responses for invalid trials were not. Speculatively, the differences between valid and invalid trials for the remaining conditions are driven by interference (i.e. slowing down) of the prime on subsequent responses. One possibility for such a ‘disruptive’ effect is response conflict (Bartholow, Riordan, Saults, & Lust, 2009; Eder et al., 2012; Greenwald et al., 1996), whereby conflicting responses are evoked by a prime and a subsequent target. Importantly, this response conflict demonstrates that affective primes, though task-irrelevant, biased responses in a fast manner.

A likely explanation for better discrimination of positive upright and inverted faces compared to negative faces is the salience of features such as the presence of teeth or an open mouth. Smiling faces display more teeth than fearful faces. Recent studies have suggested that the prominent features of an affective face influence the discrimination and processing of such a stimulus (Beaudry, Roy-Charland, Perron, Cormier, & Tapp, 2014; Calvo & Nummenmaa, 2011; daSilva et al., 2016; Horstmann, Lipp, & Becker, 2012). The current results highlight the important role of the presence of teeth on priming effects.

The interference effects observed above indicates that primes can bias preparation towards a specific response, which subsequently conflicts with the response activated by the affective target, slowing down responses. This biasing effect, however, does not inform us whether affective primes can also facilitate approach-avoidance responses to subsequent affective target stimuli compared to when no affective information is present to prepare actions. If invalid information between a prime and a target slows down responses relative to when there is no affective information (i.e. negative inverted prime that was not discriminated), then it follows that prime-target validity should speed up the initiation of action relative to when there is no affective information available. Demonstrating this is crucial for determining that affective primes can influence and maximise action preparation in order to carry out fast appropriate responses to emotional situations. As such, Experiment 2 addressed whether valid trials lead to response facilitation when compared to a non-affective baseline. Experiment 2 was therefore concerned not with *how* response preparation occurred, but with whether affective cues are able to prepare the motor system for fast and appropriate responses to emotional targets, thereby demonstrating a specific relationship between emotion and motor processes. That is, does the unexpected sound of crackling leaves in a wooded area really prepare someone to avoid potential threat in a faster manner?

3.4. Experiment 2

3.4.1. Method

3.4.1.1. *Participants*

30 healthy volunteers (mean age = 24.5 years [± 5 S.D.]; 15 female) were recruited as in Experiment 1.

3.4.1.2. *Stimuli and apparatus*

For the training session, 130 neutral (65 female/male) faces were selected from the same databases as in Experiment 1. Presentation of faces during the task was randomised for each subject. Due to insufficient neutral faces, 30 neutral faces were repeated throughout the training session to make each block comprise of 150 trials. The same 30 faces were repeated for all participants. The training session comprised of 2 blocks of 150 trials.

For the main task, 390 male and female faces were selected from the same databases: 130 fearful (negative) faces, 130 smiling (positive) faces, and 130 neutral faces. All faces (178 x 241 pixels) were masked as in Experiment 1. Assignment of faces to blocks and trials was randomised in across participants. Each positive and negative face was used as both a prime and a target, but the same face was never shown as the prime and the target within the same trial. Neutral faces were only shown as primes. Some faces were repeated as primes (9 in total) and some faces were repeated as targets (16 in total) in order to have sufficient stimuli for each block. The same faces were repeated for all participants. Each block comprised of 144 trials (72 positive/negative target faces; 48 positive/negative/neutral prime faces). Stimuli were presented using the same equipment as in Experiment 1.

3.4.1.3. *Training task procedure*

Based on an arbitrary mapping of the gender of face stimuli, participants were trained to approach neutral female faces and avoid neutral male faces (counterbalanced) (Woud, Becker, & Rinck, 2008). This removed the affective component of the primes, and formed a new S-R conflict between the neutral primes and the affective targets, which allowed addressing whether these newly established S-R associations for neutral primes can act in a similar manner to those predisposed valence-action associations.

Participants trained to approach or avoid neutral female or male faces. The procedure was the same as Experiment 1, except that no prime was presented during the task. The training task was counterbalanced across participants, with half approaching female faces and avoiding male faces, and the remaining half approaching males and avoiding female faces. A similar number of males and females were included in each set of training instructions.

The inclusion of the training was important for two reasons: firstly, it ensured that both the affective and neutral primes shared similar response properties (i.e. approach-avoidance), and secondly, it allowed to conclusively demonstrate whether emotional S-R associations can be facilitated by primes. If neutral primes are unable to elicit trained S-R associations, then it would provide indication that learned or conditioned S-R associations are weak, contrary to previous suggestions (Damasio, 1994; Hommel et al., 2001). Furthermore, if no effect arises from neutral primes, then it would serve as a baseline condition with which affective primes can be compared against when determining facilitation and interference effects of the affective primes.

Participants completed two training blocks. Depending on the instructions, participants either moved a manikin towards neutral female faces and away from neutral male faces, or vice versa. Trials started with a fixation cross presented in the centre of the screen (500 ms), followed by the appearance of the neutral target face and the manikin (max. 2000 ms or until the respective target was reached).

To ensure that maximum learning was achieved, participants who made >10% errors during the last 280 trials of the training had to repeat an extra block of 150 trials of the training.

3.4.1.4. Speed of action preparation: Priming task procedure

Following training, participants completed a priming task similar to Experiment 1, with both neutral and affective faces as primes but only affective faces as targets. As such, neutral prime faces were always affectively different from the affective target faces (e.g. neutral prime – positive target) but were still related with respect to the responses they elicit (e.g. neutral female prime followed by positive target – both could facilitate approach) thus allowing for a potential S-R conflict, and mimicking the affective priming task.

The priming task was the same as in Experiment 1 with a few exceptions **(Figure 3.2B)**. Like in Experiment 1, for affective primes, validity was determined by whether the affective prime and targets had the same valence or not (e.g. positive prime followed by a positive target). In contrast, in Experiment 2, for neutral primes, validity was determined by whether the prime and the target had the same response or not (e.g. neutral female prime face followed by a positive target; both are linked to an approach response; neutral male face followed by a positive face; one facilitates avoidance whereas the other one facilitates approach). Contrary to Experiment 1, all prime faces were presented in an upright orientation. This was because Experiment 1 determined that awareness was necessary for priming effects to occur, and therefore inverted faces were dropped. Trial sequence was the same as in Experiment 1. Participants completed two short practise blocks, one congruent and one incongruent, of 72 trials each to familiarise participants with the new instructions.

3.4.1.5. Awareness of emotional content: Discrimination task

The discrimination task was identical to that of Experiment 1 with the exception that participants discriminated neutral faces as well. Participants pressed one of three response keys. In addition, all faces were presented upright.

3.4.1.6. Data analyses

Speed of action initiation: Reaction times

Reaction times were measured as in Experiment 1. Exclusion criteria were also the same. For the training session, wrong responses (e.g. approach males when instructed to avoid males; 7.5% of training trials), too slow (3.0%) or too fast responses (0.3%) and outliers (0.5%) were excluded. A total of 11.3% of trials were excluded from the training data. For the affective priming task, wrong responses (e.g., avoiding when instructed to approach negative faces; 4.1% of trials), too fast (0.9%) or too slow responses (1.8%), and outlier trials (0.3%) were excluded from the analyses. In total, 7.1% of trials were excluded from the main task.

A 2x2x2x2 within-subjects repeated measures ANOVA (RM-ANOVA) with factors *Prime-type* (affective vs. neutral), *Congruency* (congruent vs. incongruent), *Target-Valence* (positive vs. negative) and *Prime-Validity* (valid vs. invalid). Statistical analyses were the same as in Experiment 1.

Training

As participants learn the appropriate responses associated with the male and female neutral faces, reaction times should decrease as participants complete more trials. A curve-fitting toolbox in MATLAB (The Mathworks) was used to fit an exponential function to the mean reaction times across all participants to test for such decrease. RT data was analysed for the first 250 of 300 training trials because, after eliminating training errors, all subjects had up to 250 trials left for analysis. Response errors were compared between the first and second training blocks to assess any further indication of learning throughout the second block.

A 1-way RM-ANOVA was also conducted with factors *Movement Type* (approach vs. avoid) for each counterbalancing independently (i.e. approach female, avoid male and vice versa). Follow-up paired samples t-tests were conducted. Furthermore, an independent samples t-test was calculated between each counterbalancing group for each movement type, to compare any differences in RTs between approaching female and male faces, and avoiding female and male faces.

Awareness of emotional content: Discrimination

Discrimination analyses were the same as in Experiment 1, with the exception that subjective and objective discrimination was calculated for neutral faces as well as positive and negative faces. Discrimination was employed to ensure that participants could perceive the faces at a supraliminal level.

3.4.2. Results

3.4.2.1. *Training task*

The exponential fit revealed a sharp initial decrease in RTs after approximately 25 trials, followed by relatively stable RTs throughout the remaining training (**Figure 3.5**; SSE = 1.69, R^2 = 0.39, adjusted R^2 = 0.38, RMSE: 25.93).

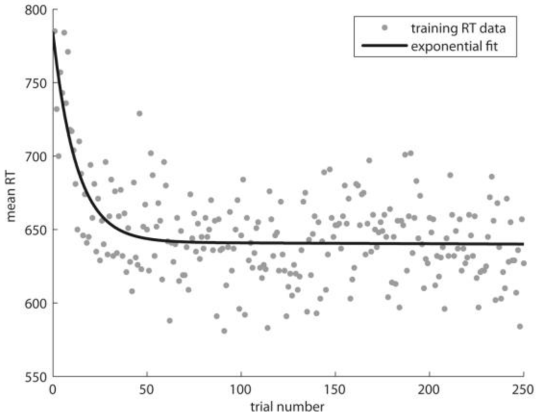


Figure 3.5. Exponential curve showing a sharp decrease in RTs over the course of training. Mean RTs are shown in ms. Participants learned the respective stimulus-response associations (e.g. female neutral – approach, male neutral – avoidance) in the first 25 trials of the task. These RTs subsequently stabilised until the end of the task.

Furthermore, the average number of response errors made during the first block was significantly higher than the number of errors made during the second block (first: 13 ± 0.9: second: 9 ± 0.6; $t_{(29)}$ = 3.81, p = 0.001, Cohen's d = 0.70). Thus, as expected, both RTs and the number of errors successfully decreased during training, indicating that participants learned the respective S-R associations quickly.

The 1-way RM-ANOVA's revealed an effect of gender on approaching and avoiding for counterbalancing group one (*Movement type*; $F_{(1,14)} = 10.10$, $p = 0.005$, $\eta_p^2 = 0.44$), and group two (*Movement type,* $F_{(1,24)} = 16.85$, $p = 0.001$, $\eta_p^2 = 0.55$). For group one, approaching female faces was significantly faster than avoiding male faces (app-fem: 623 ± 22 ms; avoid-male: 648 ± 20 ms; $t_{(14)} = -3.32$, $p = 0.005$, Cohen's d = -0.89), and for group two, approaching male faces was significantly slower than avoiding female faces (app-male: 686 ± 23 ms; avoid-fem: 640 ± 21 ms; $t_{(14)} = 4.10$, $p = 0.001$, Cohen's d = 1.08).

Between-subjects t-tests comparing approach and avoidance between the two groups showed that approaching female faces was not significantly different from approaching male faces ($t_{(29)} = -1.98$, $p = 0.07$, Cohen's d = -0.11), and avoiding female faces was not significantly different from avoiding male faces ($t_{(29)} = 0.31$, $p = 0.76$, Cohen's d = 0.02). This is important as it shows that there was no difference between the two groups for approach and avoidance.

3.4.2.2. *Priming task*

Reaction times

The three factors *Prime-type*, *Congruency*, and *Target-Valence* interacted significantly ($F_{(1,29)} = 6.39$, $p = 0.017$, $\eta_p^2 = 0.18$), and a breakdown of this interaction was conducted separately for each *Target-Valence* (2 x 2 ANOVAs with factors *Prime-type* and *Congruency* collapsed across *Prime-Validity*).

For negative target faces **(Figure 3.6A)**, *Prime-Type* did not affect approach-avoidance responses (*Prime-type*Congruency,* n.s). By contrast, for positive target faces (**Figure 3.6B**; *Prime-type*Congruency*, $F_{(1,29)} = 7.45$, $p < 0.011$, $\eta_p^2 = 0.204$), approaching positive faces was faster when primed by affective faces than when primed by a neutral faces (affective prime: 620 ± 16 ms; neutral prime: 626 ± 16 ms; $t_{(29)} = -2.99$, $p = 0.006$, Cohen's d = -0.55), whereas there were no differences in RTs when avoiding positive target faces. Positive target faces also elicited an expected congruency effect, with approach being faster than avoidance when primed by both positive and neutral faces (positive approach: 620 ± 16 ms, positive avoid: 707 ± 20 ms; $t_{(29)} = -11.94$, $p < 0.001$, Cohen's d = -2.79; neutral approach: 626 ± 16 ms, neutral avoid: 706 ± 20 ms; $t_{(29)} = -11.60$, $p < 0.001$, Cohen's d = -2.58). There was no difference between approaching and avoiding negative target faces.

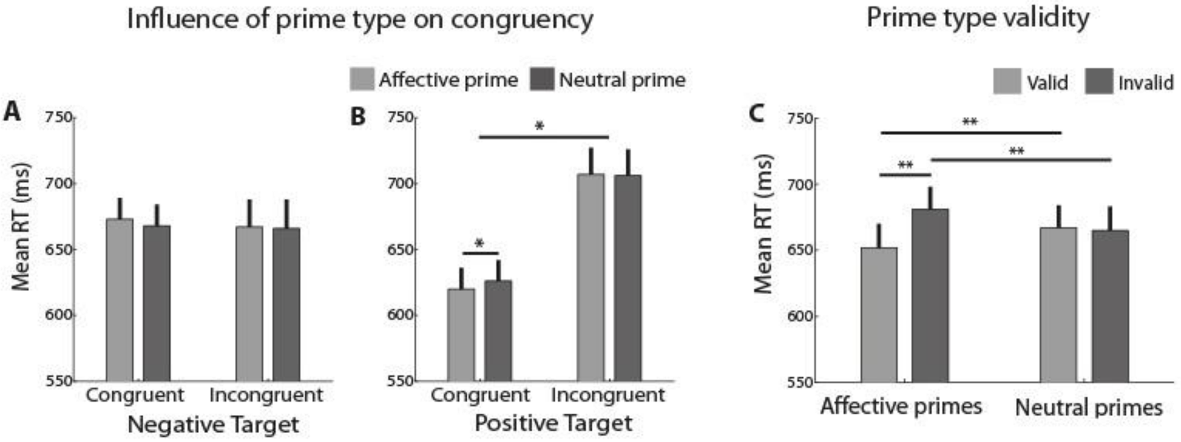


Figure 3.6. Influence of primes and congruency on response initiation. **Left panels**: Mean RTs for the interaction *Prime-type*Congruency*Target-Valence* **(A)** RTs for negative and positive target responses. Negative target faces: RTs did not differ between affective and neutral faces for approaching or avoiding. **(B)** Positive target faces: RTs were significantly faster for approaching when primed by an affective prime than a neutral prime. **Right panel:** Mean reaction times (RTs) for the interaction *Prime type*Prime Validity* **(C)** RTs for affective targets when primed by affective and neutral primes; light bars = valid; dark bars = invalid. light bars = affective primes; dark bars = neutral primes. Error bars (+1 S.E.M.); * significant at $p < 0.05$ level.

Furthermore, the analysis revealed that the *Prime-Type* differentially influenced the S-R validity effect (**Figure 3.6C**; *Prime-type*Prime-Validity,* $F_{(1,29)} = 32.54$, $p < 0.001$, $\eta_p^2 = 0.529$). This was followed up with a 2-way ANOVA with factors *Prime-type* and *Prime-Validity,* collapsed across *Congruency* and *Target-Valence*; *Prime-type*Prime-Validity,* $F_{(1,29)} = 44.83$, $p < 0.001$, $\eta_p^2 = 0.61$). Follow-up paired t-tests showed that valid trials were faster than invalid trials when affective primes were presented (valid: 652 ± 18 ms; invalid: 681 ± 17 ms; $t_{(29)} = -7.30$, $p < 0.001$, Cohen's d = -1.84), but no such difference was found for neutral primes (valid: 667 ± 17; invalid: 665 ± 18; n.s). Overall, responses on valid trials were faster for affective vs. neutral primes (affective valid: 652 ± 18 ms; neutral valid: 667 ± 18 ms; $t_{(29)} = -5.27$, $p < 0.001$, Cohen's d = -1.03). Equally, on invalid trials, responses were slower for affective vs. neutral (affective invalid = 681 ± 18 ms; neutral invalid = 665 ± 18 ms; $t_{(29)} = 6.03$, $p < 0.001$, Cohen's d = 1.08).

3.4.2.3. *Discrimination task*

Subjective d’

Combined across all valences, subjective d’ was above chance level (d’subjective: 1.06 ± 0.14; $t_{(29)}$ =-7.51, $p < 0.001$). When subjective discrimination was split into individual valences, discrimination for all valences was above chance level (d’positive: 0.55 ± 0.27, $t_{(29)}$ = -2.03, $p = 0.05$; d’negative: 1.13 ± 0.31, $t_{(29)}$ = -3.62, $p = 0.001$; d’neutral: 0.61 ± 0.2, $t_{(29)}$ = -3.12, $p = 0.004$), showing participants could confidently discriminate positive, negative and neutral faces.

Objective d’

Combined across all valences, objective discrimination was above chance level (d’objective: $t_{(29)}$ = -22.80, $p < 0.001$). All valences were correctly discriminated by all participants (d’ positive: 1.73 ± 0.06, $t_{(29)}$ = 59.45, $p < 0.001$; d’ negative: 1.60 ± 0.1, $t_{(29)}$ = 29.97, $p < 0.001$; d’ neutral: 1.00 ± 0.11, $t_{(29)}$ = 10.76, $p < 0.001$).

3.4.3. Discussion

The goal of Experiment 2 was to determine whether affective cues can help prepare the motor system for fast responses in anticipation of emotional targets. The results revealed that affective primes facilitate responses to affective target stimuli when the prime and target match in their actions, but slowed down responses when they did not match, when compared to a non-affective baseline. This demonstrates that affective primes can bias preparation such that appropriate behaviour occurs in a fast and timely manner, crucial for avoiding costs and optimising success. The current results support previous work showing that emotional stimuli speed up responses to targets (Eder et al., 2012; Klauer, 1997; Spruyt, Hermans, Houwer, Vandromme, & Eelen, 2007). Emotional stimuli and their associated approach-avoidance tendencies therefore influence action preparation.

The interference effects observed here show that neutral primes did not facilitate the corresponding response tendencies that were invalid with the affective target response (e.g. neutral female prime face that facilitated approach followed by a negative target face that triggered avoidance), and therefore did not slow down target responses. In contrast, invalid affective primes interfered with responses, thus replicating the findings from Experiment 1. With regards to facilitation effects, valid affective primes sped up responses to subsequent targets relative to valid neutral primes. This facilitation of target responses suggests that affective primes can influence the speed of response initiation to affective stimuli of the same valence. Invalid affective primes therefore interfere with, whereas valid affective primes facilitate responses to affective target stimuli.

In Experiment 2, neutral primes were associated to approach or avoidance actions through extensive learning. However, these newly established associations did not lead to valence specific validity effects. One obvious explanation for this is that the valence-specific top-down instructions prevailed over the trained S-R associations for neutral primes, as has been previously shown (Liefooghe, Wenke, & De Houwer, 2012; Waszak et al., 2013). This is unlikely to be the result of insufficient training, as both reaction times and error rates decreased and plateaued during training, suggesting that the newly formed response associations to specific neutral faces were fully established. Importantly, the reaction times when making the same movement towards different genders did not differ, suggesting that the associations were learned to the same extent during training and were not affected by gender. As such, like Experiment 1, Experiment 2 also demonstrated that context-related instructions override learned response associations.

In sum, Experiment 2 confirms the interference effect observed in Experiment 1 and shows that there was also a response benefit when both the prime and the target responses matched, suggesting that action preparation to affective stimuli benefits from relevant affective cues in the environment. By comparing to a baseline, novel evidence is provided that affective primes can both facilitate and interfere with upcoming responses. Approach-avoidance tendencies therefore influence the speed of action preparation, demonstrating a link between emotion and preparatory processes that may benefit survival.

Both Experiment 1 and 2 demonstrated that supraliminal affective primes influence action preparation. Although Experiment 1 demonstrated that awareness was necessary for priming effects to occur, the supraliminal presentation of an inverted prime face may not have the same influence as an upright prime presented subliminally. Previous work has suggested that affective primes have the capacity to influence responses to targets in an unconscious manner (Whalen et al., 1998), and that approach-avoidance tendencies may be triggered unconsciously (Duckworth et al., 2002). To investigate the extent to which unconscious processing of the emotional stimulus will result in priming effects, Experiment 3 presented affective prime faces in a subliminal and supraliminal manner. If emotional primes are capable of influencing responses unconsciously, the effects between subliminal and supraliminal presentations should be similar. Prior to the main task (Experiment 3B), the parameters for subliminal presentation were determined in a pilot (Experiment 3A).

3.5. Experiment 3

3.5.1. Method

3.5.1.1. *Participants*

In Experiment 3A (pilot), 5 healthy participants were recruited (mean age = 25.5 years [± 7 S.D.]; 1 female) as in Experiment 1 and 2.

In Experiment 3B, 14 healthy volunteers (mean age = 25.4 years [± 4 S.D.]; 7 female) were recruited.

3.5.1.2. *Stimuli and apparatus*

For both experiments, 132 male and female faces were selected from the same databases as above: 66 fearful (negative) faces and 66 smiling (positive) faces. All faces (178 x 241 pixels) were masked as in Experiment 1 and 2. It has been shown that a pattern mask is successful at making affective faces subliminal (Kim et al., 2010). Assignment of faces to blocks and trials was randomised across participants. For Experiment 3B, each positive and negative face was used as both a prime and a target, but the same face was never shown as the prime and the target within the same trial. The same faces were repeated for all participants. Stimuli were presented using the same equipment as in Experiment 1 and 2.

Contrary to Experiment 1 and 2, all stimuli were presented on a 20-inch screen (SONY Trinitron, refresh rate: 120 Hz). The improved refresh rate was crucial for subliminal presentations as this allowed better precision for presentation times. For the detection and discrimination tasks, multiples of 10 ms were used as masking durations. For the affective priming task, subliminal stimuli were presented for two refresh rates of 10 ms each giving a total of 20 ms, whereas supraliminal stimuli were presented for 8 refresh rates of 10 ms each giving a total of 80 ms.

3.5.1.3. *Discrimination and detection tasks*

For Experiments 3A and B, a discrimination task was conducted based on Hsu et al. 2008. For both experiments, the discrimination task was identical to that of Experiment 1, with some timing exceptions **(Figure 3.7A)**.

In Experiment 3A (pilot), primes were presented for 20 ms and there were eight different masking durations (10, 20, 30, 40, 50, 60, 70, 80 ms), resulting in a variety of stimulus onset asynchrony (SOA) timings. The duration of the SOA is usually the total time of the prime and mask presentations. There were four blocks in total, two for short SOAs (30 – 60 ms) and two for long SOAs (70 – 100 ms). Each block comprised of 132 trials. Each face was presented in an upright manner and a total of 4 times.

In Experiment 3B, participants completed two discrimination blocks of 132 trials, one for subliminal and another for supraliminal presentations. For subliminal presentations, primes were presented for 20 ms and masked for 80, giving an SOA of 100 ms. Supraliminal primes were presented for 80 ms and masked for 20 ms to give an SOA of 100 ms. As in Experiments 1 and 2, participants had to press two keys in order to give their response.

In Experiment 3A only, a detection task (Kiesel et al., 2007; Kunde, 2004) was also conducted, in which subjects simply indicated whether they detected the presence of a stimulus or not. Thus, the detection task helped identify if subjects could actually see if a stimulus was presented, whereas the discrimination task revealed if subjects were able to discriminate the content of the stimulus. In the detection task, the procedure was the same as in the discrimination task, except that participants were asked if they could detect the presence of a face or not. Catch trials were included in which no face was presented at all.

3.5.1.4. Priming task procedure in Experiment 3B

In Experiment 3B, the priming task was the same as in Experiment 1 with a few exceptions **(Figure 3.7B)**. Like in Experiment 1, for affective primes, validity was determined by whether the affective prime and targets had the same valence or not (e.g. positive prime followed by a positive target). Trial sequence was the same as in Experiment 1. There were six blocks in total, three subliminal and three supraliminal. Subliminal faces were presented using an SOA of 100 ms, which was determined by Experiment 3A as being the ideal presentation time that rendered the stimulus subliminal. Supraliminal faces were presented for 80 ms and masked for 20 ms, so that the SOA was identical to the subliminal SOA. All prime faces were presented upright. Participants completed two short practise blocks, one congruent and one incongruent, of 72 trials each to familiarise participants with the instructions.

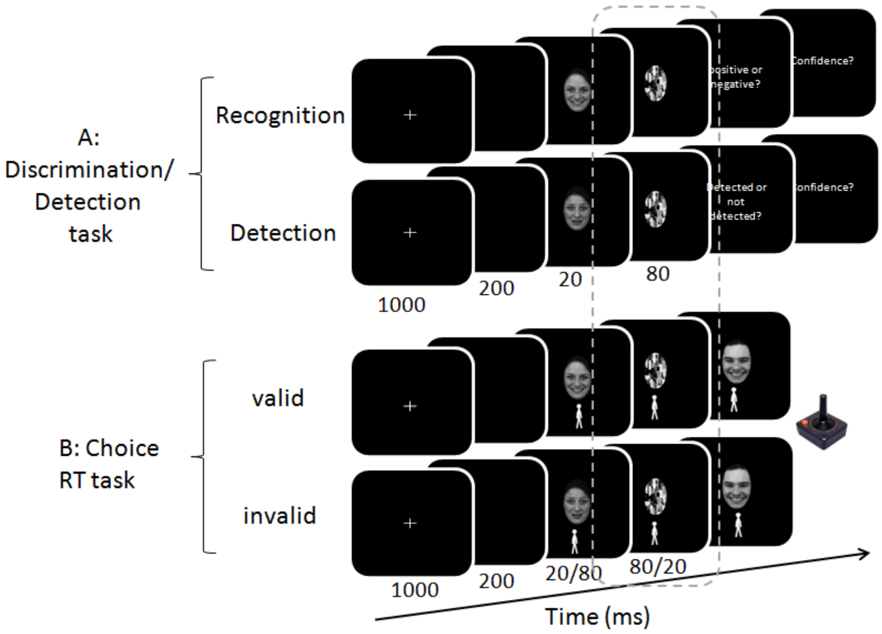


Figure 3.7. Task schematic for Experiment 3. A) Upper panels: trial sequence when participants had to discriminate the valence of the emotional face as positive or negative (objective discrimination) and subsequently say how confident they were (subjective discrimination). Bottom panel: trial sequence when participants had to detect the presence of an emotional face and subsequently say how confident they were. **B)** Trial sequence for valid and invalid trials in the priming task. In the subliminal task, a prime face was shown for 20 ms and a mask was subsequently shown for 80 ms giving an SOA of 100 ms. In the supraliminal task, a prime face was shown for 80 ms and a mask was shown for 20 ms giving an SOA of 100 ms. Participants were subsequently required to approach or avoid the emotional target face depending on the instructions given at the beginning of each block. In valid trials, the valence of the prime and the target face matched, whereas in invalid trials the valence of the prime and target faces mismatched. Participants were never informed of the emotional prime.

3.5.1.5. Data analyses

For Experiments 3A and 3B, discrimination and detection was calculated as in Experiments 1 and 2.

For Experiment 3B, reaction times were measured as in Experiment 1. Exclusion criteria were the same as in Experiment 1. For the affective priming task, wrong responses (e.g., avoiding when instructed to approach negative faces; 5.6% of trials), too fast (1.2%) or too slow responses (2.4%), and outlier trials (0.6%) were excluded from the analyses. In total, 9.8% of trials were excluded from the main task.

A 2x2x2x2 RM-ANOVA with factors *Congruency* (congruent vs. incongruent), *Target Valence* (positive vs. negative), *Prime Validity* (valid vs. invalid) and *Presentation* (subliminal vs. supraliminal) was conducted. For discrimination, a 2-way RM-ANOVA with factors *Presentation* (Subliminal vs. Supraliminal) and *Valence* (Positive vs. Negative) was conducted. Statistical analyses were the same as in Experiment 1. T-tests for the detection and discrimination tasks were adjusted for multiple comparisons using Bonferroni correction using MATLAB code.

3.5.1.6. Power analyses

For both experiments a power analysis was conducted post-hoc using G*Power (version 3.1.9.2) to calculate how many subjects would be necessary for significant effects.

For Experiment 3A, a 2-way RM-ANOVA was initially conducted on the detection and discrimination means across short (30 – 60 ms) and long SOA (70 – 100 ms) latencies from the sample of five subjects, with *Timing* (short vs. long) as a factor. The produced partial correlation was subsequently used for a sample size calculation. For detection, there was a main effect of *Timing* ($F_{(1,4)} = 10.99$, $p = 0.029$, $\eta_p^2 = 0.73$), with better detection in long compared to short SOA's. The partial correlation yielded an effect size of 1.66 and a suggested sample size of 6 subjects to achieve a power of 0.8. In contrast, for discrimination, there was no main effect of *Timing* and the partial correlation used suggested a sample of 84 subjects. Given the results for detection, and the fact that Experiment 3A was a pilot, a sample size of five subjects deemed sufficient.

For Experiment 3B, the partial correlations from the 4-way RM-ANOVA were used. As I was interested on a difference between subliminal and supraliminal presentations, only the partial correlation (η_p^2 - 0.35) of an interaction between *Presentation* and *Validity* was used. This correlation yielded an effect size of 0.73 and a suggested sample size between 16 and 18 to achieve a power of 0.8. Given that this interaction of interest was significant with 14 subjects, and that the suggested sample size was not significantly greater, only 14 subjects were tested.

3.5.2. Results

3.5.2.1. Experiment 3A

3.5.2.1.1. Detection task

Combined across positive and negative faces, detection was significantly above chance level for longer SOAs only compared to short SOAs after correcting for multiple comparisons (**Figure 3.8A**; d'70: p = 0.0054; d'80: p = 0.0014, d'90: p = 0.0015, d'100: p = 0.007). When averaged across long and short SOAs, only priming with long SOAs allowed for significantly above chance detection (short SOAs: $t_{(4)}$ = -1.65, n.s; long SOAs: $t_{(4)}$ = -2.57, p = 0.062).

3.5.2.1.2. Discrimination task

Subjective d'

Combined across positive and negative faces, subjective d' was significantly above chance level after adjusting for multiple comparisons for SOAs 40, 60 and 70 ms **(Figure 3.8B)** (d'30: p = 0.299; d'40: p = 0.010; d'50: p = 0.142; d'60: p = 0.010; d'70: p = 0.038; d'80: p = 0.073; d'90: p = 0.093; d'100: p = 0.467). When averaged across long and short SOAs, both priming with long and short SOAs allowed for above chance discrimination (short SOAs: $t_{(4)}$ = 4.50, p = 0.011; long SOAs: $t_{(4)}$ = -3.98, p = 0.016).

Objective d’

Combined across positive and negative faces, objective d’ was significantly different from chance level after correcting for multiple comparisons for all SOAs except for SOA 50 ms and 100 ms (**Figure 3.8C;** (d’30: $p < 0.001$; d’40: $p = 0.0001$; d’50: $p = 0.011$; d’60: $p = 0.001$; d’70: $p = 0.001$; d’80: $p = 0.016$; d’90: $p = 0.023$; d’100: $p = 0.099$). When averaged across long and short SOAs, both priming with short SOAs allowed for above chance discrimination, but not for long SOAs (short SOAs: $t_{(4)} = 3.22$, $p = 0.032$; long SOAs: n.s.).

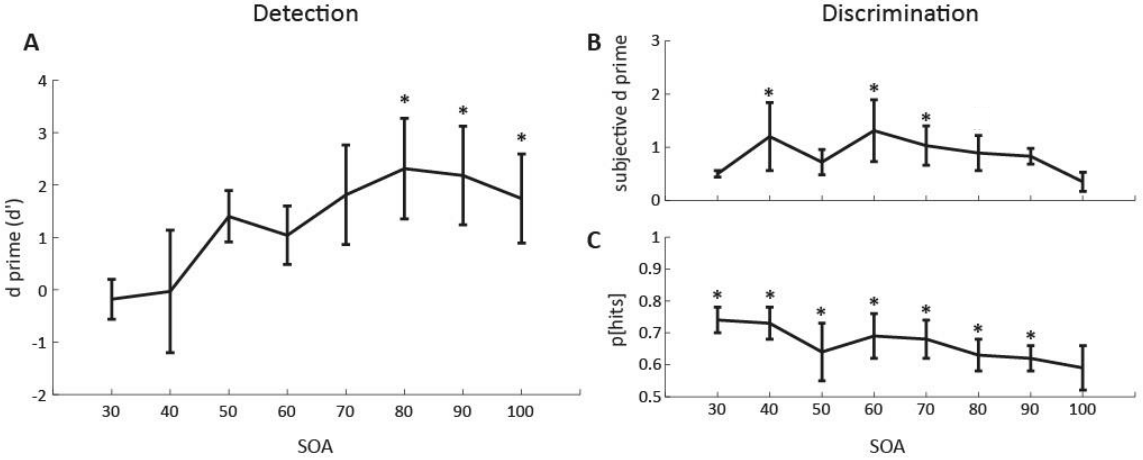


Figure 3.8. Detection and discrimination of affective faces at different SOAs. A) Detection of affective faces at different SOAs shows that participants were marginally better at detecting positive and negative faces with longer SOAs. **B)** Subjective discrimination (i.e. how confident participants were of their decision) of positive and negative faces shows that discrimination was impaired at an SOA of 30, 50 and 100 ms only. **C)** Objective discrimination (i.e. the probability of correct responses) was impaired at an SOA of 100 ms only. For stimuli to be considered subliminal, participants must be able to detect the presence of the stimulus but not be able to discriminate its content. Error bars (+1 S.E.M.); * significant at $p < 0.05$ level.

Combining the data for detection and discrimination tasks, the SOA that led stimuli to being subliminal was 100 ms. Detection was above chance level for 100 ms, yet both objective and subjective discrimination were not significantly different from chance. As such, an SOA of 100 ms was used in the priming task in Experiment 3B.

3.5.2.2. <u>Experiment 3B</u>

3.5.2.2.1. <u>Affective priming task</u>

Overall, there was an effect of target valence on the initiation of approach-avoidance actions (**Figure 3.9A**; *Target valence*Congruency*; $F_{(1,13)} = 136.12$, $p < 0.001$, $\eta_p^2 = 0.91$). RTs were significantly faster when approaching compared to avoiding positive faces (approach: 583 ± 21 ms; avoid: 669 ± 23 ms; $t_{(4)} = -8.23$, $p < 0.001$, Cohen's d = -1.98). There was no difference when approaching negative compared to avoiding (approach: 631 ± 22 ms; avoid: 653 ± 23 ms; $t_{(4)} = 1.79$, n.s.). Participants were faster to approach positive than negative faces ($t_{(4)} = -4.20$, $p = 0.001$, Cohen's d = -1.13). There was no difference in avoidance between positive and negative faces.

The effects of prime-target validity were also different between subliminal and supraliminal presentations (**Figure 3.9B**; *Validity*Presentation*; $F_{(1,13)} = 6.84$, $p = 0.021$, $\eta_p^2 = 0.35$). Results showed that there was no effect of subliminal primes on RTs to affective targets. For subliminal presentations, there was no significant difference between valid and invalid trials (valid: 625 ± 21, invalid: 632 ± 22, n.s.). In contrast, for supraliminal presentations, there was a significant effect of validity (valid: 623 ± 21 ms; invalid: 655 ± 23 ms; $t_{(29)} = -4.03$, $p = 0.001$, Cohen's d = -1.12), replicating Experiment 1.

Additionally, all four factors yielded main effects. There was a main effect of *presentation* ($F_{(1,13)} = 6.19$, $p = 0.027$, $\eta_p^2 = 0.32$) with faster RTs for subliminal compared to supraliminal primes (sub: 629 ± 22 ms; sup: 640 ± 22 ms; $t_{(13)} = -2.52$, $p = 0.026$, Cohen's d = -0.70). There was a main effect of *congruency* ($F_{(1,13)} = 10.04$, $p = 0.007$, $\eta_p^2 = 0.44$), with faster RTs for congruent compared to incongruent movements to affective faces (cong: 618 ± 22 ms; incong: 651 ± 23 ms; $t_{(13)} = -3.16$, $p = 0.008$, Cohen's d = -0.86). There was a main effect of *validity* ($F_{(1,13)} = 21.16$, $p < 0.001$, $\eta_p^2 = 0.62$), with faster action initiation for valid compared to invalid trials (valid: 624 ± 21 ms; invalid: 644 ± 22 ms; $t_{(13)} = -4.62$, $p < 0.001$, Cohen's d = -1.28), and a main effect of *valence* ($F_{(1,13)} = 8.74= 0.011$, $\eta_p^2 = 0.40$), with faster responses to positive compared to negative target faces (pos: 626 ± 21 ms; neg: 642 ± 22 ms; $t_{(13)} = -2.93$, $p = 0.012$, Cohen's d = -0.81)

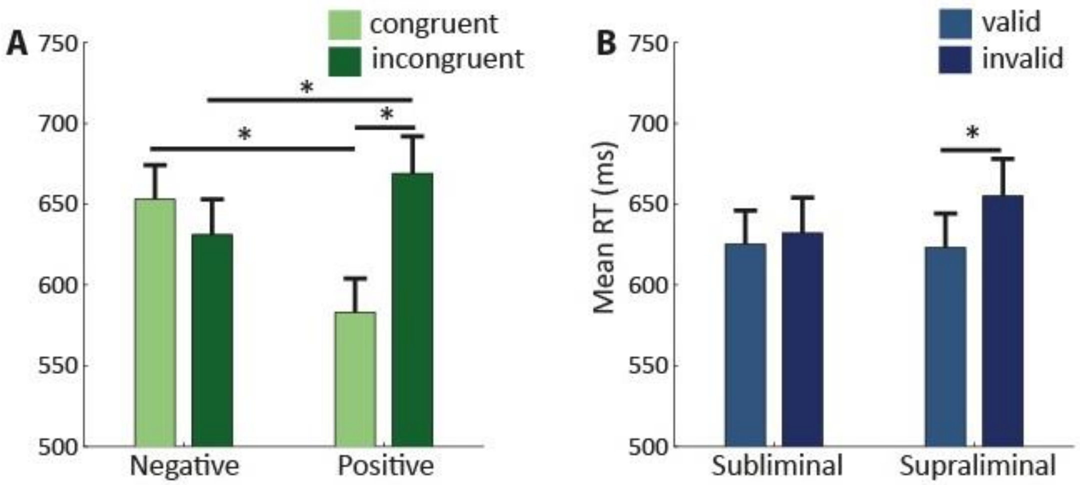


Figure 3.9. Speed of initiation to target faces when subliminal and supraliminal primes are presented. A) Interaction between the valence of the target face and the speed of initiation of approach and avoidance actions for supraliminal presentations. Approaching negative faces was faster than avoiding, whereas approaching positive faces was faster than avoiding. **B)** Interaction between the type of presentation (subliminal vs. supraliminal) and prime-target validity showing that the speed of response initiation was only influenced by supraliminal primes. Responses were faster when supraliminal valid primes were presented compared to when invalid primes were presented. Error bars (+1 S.E.M.); ** significant at $p < 0.001$ level, * significant at $p < 0.05$ level.

3.5.2.2.2. Discrimination task

Subjective d’

There was a main effect of *Presentation* ($F_{(1,13)} = 26.82$, $p < 0.001$, $\eta_p^2 = 0.67$), with discrimination below chance level for subliminal primes (sub: -0.48 ± 0.37), and above chance level for supraliminal primes (sup: 1.06 ± 0.18). Discrimination between both was significantly different from each other (supraliminal: $t_{(13)} = 5.17$, $p < 0.001$, Cohen’s d = 1.35). Subjective d’ for subliminal presentations was not significantly different from chance ($t_{(13)} = 1.27$, n.s), indicating that subjects were not able to discriminate the content of the subliminal primes. In contrast, subjective discrimination was above chance level for supraliminal primes ($t_{(13)} = -5.88$, $p < 0.001$).

When split into positive and negative valences, subjective discrimination for subliminal affective faces was not significantly different from chance. When primes were presented supraliminally, both positive and negative primes were significantly discriminated above chance (negative: 1.32 ± 0.25; $t_{(13)} = 5.38$, $p < 0.001$; positive: 0.81 ± 0.27; $t_{(13)} = 2.97$, $p = 0.011$).

Objective d’

There was a main effect of *Presentation* ($F_{(1,13)}$ = 138.78, $p < 0.001$, $\eta_p^2 = 0.91$), with discrimination below chance level for subliminal primes (sub: 0.12 ± 0.01), and above chance for supraliminal primes (sup: 0.57 ± 0.04). Discrimination between both was significantly different from each other ($t_{(13)}$ = 11.79, $p < 0.001$, Cohen’s d = 15.44). Objective d’ for subliminal presentations was significantly below chance level ($t_{(13)}$ = 26.87, $p < 0.001$), indicating that subjects were not able to discriminate the content of the subliminal primes. In contrast, discrimination was above chance for supraliminal primes ($t_{(13)}$ = -1.92, p = 0.049).

When split into positive and negative valences, objective discrimination for subliminal affective faces was significantly below chance level (positive: 0.13 ± 0.01, $t_{(13)}$ = -24.80, $p < 0.001$; negative: 0.11 ± 0.02, $t_{(13)}$ = -16.86, $p < 0.001$). When primes were presented supraliminally, only negative primes were significantly discriminated above chance (negative: 0.59 ± 0.04; $t_{(13)}$ = 2.27, $p = 0.041$).

3.5.3. Discussion

Experiment 3 aimed to determine the extent to which action preparation by emotional primes can be unconscious. To this end, subliminal and supraliminal prime faces were presented in an approach-avoidance task. Despite using an SOA that made affective primes subliminal, there was no difference in responses between valid and invalid trials, indicating that subliminal primes were unable to influence preparation. In contrast, when primes were presented supraliminally, there was an effect of prime validity, with faster responses for the same prime-target pairings compared to different prime-target pairings. This corroborates the results of Experiment 1 and 2, and confirms that when affective primes are consciously processed and correctly identified they can facilitate or interfere with the initiation of responses to affective targets. The current results contradict previous work suggesting that subliminal primes can affect the initiation of responses (Duckworth et al., 2002; Li, Zinbarg, Boehm, & Paller, 2008; Sweeny et al., 2009).

One could argue that the primes presented were not subliminal because discrimination of subliminal primes during the affective priming task was below chance level. However, Experiment 3A confirmed that using a combined SOA of 100 ms (20 ms prime, 80 ms mask) rendered stimuli subliminal because such stimuli were detected yet not discriminated, suggesting that the visual system was able to process the presence of a stimulus but not correctly identify its content. Indeed, other work has suggested that a combined SOA around 100 ms makes stimuli subliminal (Henson, Mouchlianitis, Matthews, & Kouider, 2008). Thus, during the priming task, subliminal affective primes should have been detected but not identified. Indeed, the discrimination results of the priming task confirm that subjects were unable to correctly discriminate subliminal prime faces. In contrast, supraliminal faces were identified above chance and were therefore consciously processed.

Importantly, there was an overall effect of valence on approach-avoidance responses, with faster approach than avoidance to positive target faces, corroborating previous work demonstrating an effect of congruency (Chen & Bargh, 1999; Lavender & Hommel, 2007; Roelofs et al., 2009). In contrast, there was no difference in approaching or avoiding negative targets, as seen in Experiment 1 and 2, and in support of evidence shown in Chapter Two. However, when combined across positive and negative valences, response initiation was faster for congruent trials, demonstrating approach-avoidance tendencies in goal-directed contexts.

In sum, primes are only capable of influencing the preparation of approach-avoidance responses if they can be correctly discriminated and consciously detected. Action preparation is dependent on the conscious evaluation of affective information.

3.6. General Discussion

Having established an effect of approach-avoidance tendencies and context on the selection and initiation of actions in Chapter Two, the current chapter examined whether task-irrelevant emotional information would anticipate upcoming approach-avoidance responses, thereby leading to enhanced preparation. Experiment 1 demonstrated that affective primes influence action preparation according to their task-related associations and that such primes are capable of interfering with target responses. Experiment 2 replicated these results and confirmed that, when compared to a neutral control baseline, affective primes also speed up responses when primes matched targets. Experiment 3 further showed that subliminal affective primes do not unconsciously influence the preparation of approach-avoidance responses to affective targets. The current chapter provides novel evidence on how affective primes influence the preparation of responses to upcoming emotional stimuli.

Affective and neutral primes do not activate their predisposed stimulus-response (S-R) mappings

Both Experiment 1 and 2 confirmed that top-down influences established through task instructions determine how affective primes bias approach-avoidance responses, supporting the *action-trigger account* (Kiesel et al., 2007; Kunde et al., 2003). Thus, despite previous proposals that predisposed tendencies are immediately triggered upon stimulus evaluation (Chen & Bargh, 1999), this work shows that top-down instructions can override response tendencies, in support of previous work (Bunzeck, Guitart-Masip, Dolan, & Düzel, 2011; Liefooghe et al., 2013; Waszak et al., 2013). This is also supportive of the common-coding account (Lavender & Hommel, 2007; Eder & Rothermund, 2008), which proposes that movement instructions may drive the preparation of approach-avoidance responses. Thus, contrary to the results of Eder & Klauer (2009), positive and negative primes do not automatically predispose for approach and avoidance, respectively. This result corroborates previous work showing that affective primes do not automatically influence flexion (approach) and extension (avoidance) movements to affective targets (Rotteveel & Phaf, 2004; Experiment 3). Experiment 2 replicated Experiment 1, and further showed that neutral face primes did not affect responses to affective targets. It is likely that, despite extensive training, the newly established S-R associations for neutral primes were overridden by task-relevant instructions (Vandenbosch & De Houwer, 2011). Indeed, it is suggested that preparation only occurs in cases when the irrelevant prime information is task-relevant (Hommel, 2000). As the task instructions were valence-related, the neutral prime information was task-irrelevant. In line with Chapter Two, the current results further show that action preparation is guided by context-related influences.

Affective primes can slow down and speed up the initiation of responses to affective targets

The results further revealed that preparation had beneficial or interfering effects depending on the validity of the prime-target pairing. Compared to neutral primes, affective primes interfered with responses to subsequent affective target when the prime-target pairing was invalid, presumably due to response conflict between the prime and target. In contrast, affective primes facilitated target responses when prime-target pairings were valid, supporting other work (Klauer, 1997). The results suggest that relative to neutral primes, affective primes influenced action preparation, even though primes were task-irrelevant. This is further supported by the observation that the lateralised readiness potential (LRP), a neural measure of response preparation, increases rapidly following prime onset but before target onset, suggesting rapid preparation for impending action by affective information (Bartholow et al., 2009; Eder et al., 2012; Eimer & Schlaghecken, 1998; Hsu et al., 2008; Leuthold, 2003; Schmidt, Haberkamp, & Schmidt, 2011).

The influence of emotional primes on action preparation most likely occurred because despite being task-irrelevant, their emotional content was prioritised by attentional mechanisms (Ohman et al., 2001; Vuilleumier, 2005; Vuilleumier et al., 2001) thereby enhancing perceptual processing of the target (Pessoa et al., 2002; Pessoa & Adolphs, 2010; Scharlau, 2002). This suggests that affective primes do hold some automatic influence on action preparation, congruent with proposals that task instructions are unconsciously applied to primes (Dehaene et al., 1998), and that this influence interacts with top-down instructions. This hypothesis is further supported by the fact that in Experiment 2, despite being correctly discriminated, neutral prime information did not seem to have been prioritised relative to emotional primes, evident in the lack of priming effect in the neutral condition.

Overall, the results show that in a given environment, emotional cues may be used to determine preparation for an impending emotional stimulus, like when scary music in a movie prepares us for a potentially scary impending scene. To my knowledge, this is the first demonstration that affective primes can influence the preparation of approach-avoidance actions.

Correct discrimination of the prime is essential for interference effects

All experiments assessed participants' objective and subjective discrimination ability, based on previous reports that even in the absence of awareness, affective primes can still influence responses (Sweeny et al., 2009). In Experiment 1, there was no interference effect when positive target faces were primed by negative inverted faces. This may have resulted from negative inverted faces not being discriminated subjectively above chance (albeit objective discrimination was above chance) and therefore were not perceived as negative. It has been previously suggested that subjective awareness provides a better estimation of priming effects and that objective awareness alone may be insufficient to elicit priming effects (Hsu et al., 2008). Failure to perceive an affective prime correctly as negative meant that the associated response was not activated by the prime and no conflict occurred with the target.

In contrast, when a negative target was primed by a positive inverted face there was a response interference effect because positive inverted faces were discriminated both subjectively and objectively above chance. This supports previous work (Lipp, Price, & Tellegen, 2009), and demonstrates that the correct subjective discrimination of the affective prime is a pre-requisite for driving interference/facilitatory effects between the prime and the target. This was further demonstrated in Experiment 3, which showed no influence of subliminal affective primes on action preparation. These results emphasize the need for correct discrimination of affective content to influence action preparation. Indeed, recent work demonstrated that correct affective categorisation requires awareness (Lähteenmäki, Hyönä, Koivisto, & Nummenmaa, 2015). However, the fact that subliminal faces did not lead to priming effects does not negate the fact that supraliminal emotional primes are still prioritised by the visual system. Rather, it suggests that the conscious evaluation of an emotional stimulus is a necessity for the prioritisation of emotional stimulus. This is supportive of studies suggesting that awareness of the emotional stimulus automatically engages attentional mechanisms (Pessoa et al. 2002; Pessoa, 2005). In sum, there are no unconscious effects of affective information on action preparation.

Two types of response conflict slow down reaction times to positive and negative target faces

In the current experiments, two types of response conflict driving interference effects were observed. Firstly, the expected conflict between prime and target responses when both their responses and affective component did not match (*validity conflict*) (Bartholow et al., 2009). Secondly, in incongruent blocks there was the additional conflict of approaching negative and avoiding positive faces (*congruency conflict*). Previous studies have suggested that incongruent movements are slower to execute because they conflict with predisposed tendencies (Roelofs et al., 2009; van Peer et al., 2007).

In all experiments, approaching positive target faces was faster than avoiding, demonstrating a degree of predisposition that influences the speed of initiating instructed responses. Therefore, in incongruent trials, avoiding positive faces conflicted with the natural tendency to approach positive faces, slowing down responses. Furthermore, in Experiment 1, responses were slower for invalid trials. As such, responses were slowest on trials in which movements were incongruent with the natural tendency to approach and in which the targets were invalidly cued, suggesting that a “double interference” occurred. It is possible that two different types of response conflicts were activated simultaneously, one by the prime-target pairing and the other by the approach-avoidance valence mapping.

For negative target faces, in all experiments there was a trend toward faster approach than avoidance but was not significant. Responses were slowest in trials in which participants had to avoid fearful faces and in which the targets were invalidly cued, resembling the “double interference” seen for positive faces. This approach-avoidance trend is difficult to interpret because previous studies have shown either a clear avoidance (Ozono, Watabe, & Yoshikawa, 2012; Seidel, Habel, Kirschner, Gur, & Derntl, 2010) or approach (Hammer & Marsh, 2015; Marsh, Ambady, & Kleck, 2005) tendency for fearful faces. Our current results suggest that avoidance may not always be the natural tendency when encountering negative (fearful) faces. For example, although fearful faces are classified as negative faces, they can either be interpreted as alerting someone of impending danger and thus eliciting avoidance, or as a face showing a “cry for help” which elicits approach (Marsh et al., 2005). One can only speculate that given the ambiguous nature of the fearful faces, either approach or avoidance is elicited depending on the interpretation of the subject. Each participant could subjectively perceive the fearful face either as an "alert for danger" or as a "cry for help", which leads to either avoidance or approach. Indeed, Chapter Two has shown that negative stimuli can result in both approach and avoidance depending on the context. Furthermore, priming effects between fear and disgust, two emotions classified as negative, have been demonstrated to be context-dependent (Lee, Kang, Lee, Namkoong, & An, 2011). Given the existing conflictive results in the literature regarding responses to fearful faces, it is likely that fearful faces are subjectively classified differently. Therefore, subjective ratings of how participants perceive the face to be would be a good measure to employ in situations where reaction times do not differ between approach and avoidance of fearful faces.

In brief, there was not only a response conflict between the prime and the target, but also interference related to a conflict between an instructed response (e.g. avoid positive) and the emotional tendency (e.g. approach positive). Both of these conflicts resulted in an overall greater slowing down of responses. Future studies could look at the neural basis of when and where these two types of conflicts arise, for example by looking at the LRP. It is likely that response conflict between the prime and the target would arise first in an automatic manner and that congruency interference between the movement and the valence would arise second, via a slower and more cognitive mechanism.

Conclusion

To conclude, the current chapter provides novel evidence on the ability of affective information to anticipate and prepare for impending actions. Importantly, this preparation is determined by top-down influences that override response tendencies, supporting the *action-trigger account* but contradicting the *valence-trigger account*. Furthermore, the correct discrimination and conscious awareness of the affective content of the primes is essential for influencing preparation. Finally, this chapter shows that two types of interference contribute to slowing down of responses during preparation: *validity* and *congruency* conflict. Taken together, Chapter Two and Three demonstrate that emotional stimuli and the context in which actions take place are key influences on action selection and preparation processes.

Chapter Four. Action execution is influenced by emotional valence: evidence from response vigour

4.1. Abstract

Approach-avoidance response tendencies influence action selection. The ability of such tendencies to bias behaviour may not just stop at the action selection stage. For instance, selecting to run away from a dangerous animal may need to be complemented by running away faster in order to achieve a successful outcome. Thus, the appropriate implementation of action parameters established through motor planning is what will ultimately determine how successful behaviour is. Biases on motor planning have recently been demonstrated in the vigour of an action, that is, the effort necessary to achieve a beneficial outcome. For instance, rewards and punishments have been shown to influence how vigorous actions are. In emotional situations, positive stimuli could be seen as rewarding, whereas negative stimuli can be considered punishments. It is therefore possible that emotional stimuli that lead to positive or negative outcomes also influence motor planning (and consequently vigour). However, emotional stimuli have associated approach-avoidance tendencies that may also bias motor planning. Whether emotional stimuli and their associated approach-avoidance tendencies bias the planning of action parameters remains unresolved. To address this, a novel task was designed in which participants moved a manikin on a screen either towards or away from an emotional picture by pressing on force buttons. Results showed there was an influence of valence and arousal on vigour, with high-arousing negative pictures leading to increased vigour relative to positive pictures. In contrast, approach-avoidance tendencies did not influence vigour, but did influence the speed of action selection. The results therefore demonstrate that approach-avoidance tendencies do not influence different motor processes. Instead, motor planning and action execution are influenced by negative stimuli that may activate a defensive circuitry that optimises behaviour in threatening contexts.

4.2. Introduction

Approach and avoidance tendencies influence the speed at which actions are selected and initiated when encountering emotional stimuli, as demonstrated in Chapters Two and Three. However, the ability of approach-avoidance tendencies to bias behaviour may not just stop at the action selection stage. Selecting to run away from a dangerous animal may not be sufficient to avoid a costly outcome. Running away faster, for example, is what will lead to a successful outcome. Appropriate behaviour therefore encompasses the selection of the best available action and the implementation of high-quality movement. Indeed, after an action is selected, the action is subsequently planned (Cos, Duque, & Cisek, 2014; Wong et al., 2015), determining the parameters (e.g. speed, strength) that will define how an action is executed (Desmurget et al., 1999; Marteniuk et al., 1987; Paulignan et al., 1997). The appropriate implementation of these action parameters is what will ultimately determine how successful behaviour is. The specification of action parameters, just like action selection, relies on sensory information from the environment, for example, the relation of the body to an object in space (Cisek, 2007). This is important because it suggests that information that biases one process may also bias the other. As such, it is possible that emotional biases on action selection will also bias the planning of movement parameters for successful behaviour, and this is evident through execution (Shadmehr & Krakauer, 2008).

Biases on motor planning have recently been demonstrated in the vigour of an action (Guitart-Masip et al., 2011, 2014; Niv et al., 2005; Niv, Daw, Joel, & Dayan, 2007; Wong, Lindquist, Haith, & Krakauer, 2015). Here, vigour reflects the opportunity cost of an action: how much effort should I make given the available benefits? This can be quantified by changes in, for example, the speed (Guitart-Masip et al., 2012) or the strength (Coombes et al., 2007, 2008) of a response throughout execution. Evidence has shown that vigour is influenced by appetitive and aversive environments (Niv et al., 2005), and that performance is biased by the value of a predicted outcome, i.e. reward vs. punishment (Guitart-Masip et al., 2011; Guitart-Masip et al., 2014). For example, a rewarding stimulus will lead to more vigorous action, whereas punishment will lead to less vigorous action. Furthermore, the effort one must produce during execution informs individuals about the value of a reward, with increasing amounts of perceivable effort seeming less rewarding and leading to less vigorous actions (Klein-Flügge et al., 2015). The nature of a reward or punishment therefore appears to influence the planning and vigour of the action made to achieve the outcome (Shadmehr & Krakauer, 2008).

Emotional situations can be assigned positive or negative value, depending on the nature of the emotional stimulus (Rolls, 2000). Indeed, brain areas that encode reward value, such as the ventromedial prefrontal cortex, have also been associated to the encoding of emotional stimuli (Schoenbaum, Roesch, Stalnaker, & Takahashi, 2009; Vrtička, Sander, & Vuilleumier, 2011; Winecoff et al., 2013), suggesting that similar value encoding mechanisms work for rewards and punishments and emotional stimuli. For example, positive stimuli could be seen as rewarding, whereas negative stimuli can be considered punishments (Lang & Bradley, 2008; Rolls, 2000). If rewards and punishments, which are classified as positive and negative in value, bias the vigour of actions, then it is possible that this bias translates to positive and negative emotional stimuli. However, unlike common rewards and punishments, such as monetary gains and losses, emotional stimuli have associated approach-avoidance tendencies that may also bias opportunity costs. For example, approaching a positive stimulus may be rewarding, but approaching a negative stimulus may be potentially costly. The same action is assigned a different value given the emotional stimulus and this may impact performance. Indeed, work has shown that performance is better when participants need to respond to obtain a reward (which could be seen as an approach) but worse when they need to respond to avoid a punishment (Guitart-Masip et al., 2012). This gives an indication that both actions and valence bias opportunity costs. In emotional situations, response tendencies may bias vigour in order to achieve the desired outcome (e.g. avoid a threatening stimulus). To the best of my knowledge, this question currently remains unresolved.

Emotional stimuli and associated response tendencies may impact vigour

Work has demonstrated an effect of emotional valence on vigour (Ambron & Foroni, 2015; Coombes, Cauraugh, & Janelle, 2006; Coombes et al., 2008; Ferri et al., 2010). Emotional valence increases the strength of responses relative to neutral stimuli (Coombes et al., 2008; Naugle, Coombes, Cauraugh, & Janelle, 2012), and decreases the speed of movement when compared to neutral stimuli (Ambron & Foroni, 2015; Ferri et al., 2010). Thus, emotional stimuli appear to bias the planning of execution parameters relative to neutral stimuli. Vigour may also be modulated by approach-avoidance tendencies. Studies using whole body movements showed that the presentation of emotional stimuli influences the velocity and size of stepping made towards or away from such stimuli (Koch, Holland, Hengstler, & van Knippenberg, 2009; Naugle, Hass, Joyner, Coombes, & Janelle, 2011; Stins et al., 2011). For example, stepping tends to be smaller and slower when presented with negative compared to positive pictures (Stins et al., 2015). Furthermore, approach is faster when presented with positive stimuli relative to negative stimuli (Esteves et al., 2016). Thus, approaching is enhanced in positive contexts, whereas responding is diminished in negative contexts. This supports an interaction between action and valence that influences performance in emotional contexts (Guitart-Masip et al., 2012).

In contrast, other evidence suggests that emotional stimuli and approach-avoidance tendencies do not influence vigour (Coombes et al., 2007, 2007; Stins & Beek, 2011; Stins et al., 2011). For instance, the magnitude and speed of stepping towards or away from an emotional stimulus are unaffected by approach-avoidance tendencies (Stins & Beek, 2011; Stins et al., 2011). Similarly, the speed and magnitude of avoidance is not influenced by positive or negative stimuli (Coombes et al., 2007, 2007). The evidence for an effect of approach-avoidance tendencies and emotional valence on vigour is mixed and inconclusive.

The parameters of vigour established during motor planning should reflect opportunity cost biases arising from approach-avoidance tendencies (Paulignan et al., 1997; Desmurget et al., 1999). Do tendencies associated to positive and negative stimuli bias the planning of action parameters that will be implemented during action execution? If this is the case, then it would add to evidence in favour of such tendencies influencing action selection. Thus, an effect on selection and planning would demonstrate a capacity for such approach-avoidance tendencies to influence different motor processes that occur prior to execution. At present, this issue remains unresolved. To this end, the aim of this study was to determine if approach-avoidance tendencies bias motor planning and the vigour of actions.

Investigating the influence of approach-avoidance tendencies on action execution

This chapter is concerned with how approach-avoidance tendencies influence the vigour of our actions. To investigate this, a novel task was designed in which participants were required to move a manikin on a screen either towards or away from an emotional picture by pressing on force buttons with their index fingers. Here, force and speed of movement quantified vigour. Based on previous studies (Chen & Bargh, 1999; Rotteveel, Spinhoven, Tollenaar, Roelofs, & Van Peer, 2010), it was expected that participants would be faster at initiating approach than avoidance for positive stimuli, and faster at initiating avoidance than approach for negative stimuli. Further, in line with previous evidence (Esteves et al., 2016; Stins et al., 2015), I expected predisposed actions to be more vigorous. For example, subjects were expected to press harder and move faster to approach than to avoid positive pictures, and to press harder and move faster to avoid than approach negative pictures. If only action selection but not planning is influenced by approach-avoidance tendencies, an effect on response initiation (i.e. the reaction time) but not on vigour is expected. Such an effect would dissociate between the effects of emotional tendencies on selection and planning. In contrast, if both action selection and planning are biased by approach-avoidance tendencies, then an effect of approach-avoidance on both initiation and vigour should be seen, demonstrating an ability of such tendencies to influence different motor stages.

4.3. Methods

4.3.1. Participants

24 healthy volunteers (mean age = 22.7 years [± 3.7 S.D.]; 20 female) were recruited from the University College London Psychology database, with local ethics approval (UCL). All participants had normal or corrected-to-normal vision. Participants gave written informed consent to participate in the study, and received monetary compensation for their time and travel (7.5£/h).

4.3.2. *Stimuli and apparatus*

160 pictures were selected from the IAPS (Lang, Bradley & Cuthbert, 2008): 80 negative pictures with valences 1.8-3.8 (1.6 = most negative), and 80 positive pictures with valences 6.2-8.2 (8.2 = most positive). All pictures (maximum 240 x 180 pixels) were matched for luminance and matched as closely as possible in their arousal (with an equal proportion of high and low). Only pictures depicting humans or animals were included. The assignment of pictures in each of the 8 blocks and order of presentation was randomised for each subject. Block order was counterbalanced across participants. Each block comprised of 80 trials (40 positive/negative).

All stimuli were presented on a 19-inch LCD monitor of a Dell Optiplex-780 computer (refresh rate: 60 Hz), using the Cogent 2000 toolbox (v1.32; University College London, http://www.vislab.ucl.ac.uk/Cogent2000/index.html) and MATLAB (v.7.9.1.705; The MathWorks Inc.). A white manikin (2.8 x 1.9 cm) represented the self. A black square with yellow border (240 x 180 pixels), the same size as the pictures, represented the “away” target and was presented on the bottom half of the screen. The manikin was moved smoothly on the screen by increasing or decreasing the pixels of the y-coordinates. Subjects had to move the manikin 180 y-coordinates upwards or downwards, depending on the target.

A custom-made USB force button box translated force into movement on the screen. The button boxes consist of four minibeam load cells (Omega Engineering Inc.) and one four-channel in-house developed instrument amplifier. The analogue output for each channel, proportional to the exerted force, was acquired using a Phidget21 InterfaceKit (v2.1.8, Phidgets Inc.) and fed into a Phidget A/D board. The force applied translated into online movement of the manikin on the screen via MATLAB code at a sampling rate of 60 Hz. Depending on the strength, the manikin moved faster or slower (by moving more or less pixels on the screen during a specific time). The buttons were sensitive to force but because the buttons themselves did not move (i.e. isometric force), participants did not receive explicit (bodily) feedback on the strength of their responses.

4.3.3. Calibration

To account for individual differences in strength, participants completed a calibration session in which they pressed with each index finger independently as hard as possible. An arrow pointing either to the left or the right indicated which index finger to press with. Participants began pressing when they saw the word start until they saw the word stop. They were required to press with their maximum strength for three seconds. This was repeated three times for each finger. An average of the three traces for each finger was calculated to obtain a mean maximum voluntary contraction (MVC) level for each finger independently. This MVC was used to set the starting threshold for when the manikin should start moving (20% of MVC) and was also used to calculate the speed at which the manikin should move on the screen (30% of 20% MVC).

4.3.4. Experimental task

Participants were seated in front of a computer at a distance of approximately 50 cm. The force button box was placed in front of them. Participants were instructed to move the manikin either towards or away from the pictures, according to the instructions at the beginning of each block. They were specifically told that the goal of the task was to move to the correct target as accurately as possible. Neither force nor speed were ever emphasized. Vigour was therefore implicit. Participants were instructed to imagine that the manikin represented them on the screen, as in previous chapters.

In line with previous chapters, blocks were congruent or incongruent with response tendencies. In one block type, participants were instructed to move towards positive and away from negative pictures. In another block type, they had to move towards negative and away from positive pictures. Each block type was repeated 4 times, meaning each picture was repeated four times, twice in each condition. In total there were 160 repetitions for each experimental condition. Participants were always instructed of the mapping at the beginning of each block. To avoid potential confounds with one finger being stronger than the other, half the subjects were instructed to press to move towards with their left index finger and to press to move away with their right index finger. The remaining half had the opposite mapping.

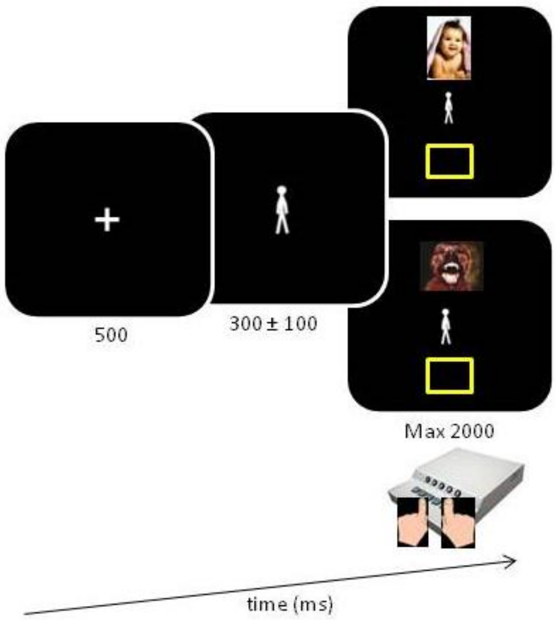


Figure 4.1. Task schematic depicting two trials. Participants were presented with a fixation cross (500 ms), followed by the presentation of the manikin on the centre of the screen (300 ± 100). Subsequently, an emotional picture and a yellow “away” target were simultaneously displayed for a total duration of 2000 ms. According to the instructions given at the beginning of the block (e.g. move the manikin towards positive, move away from negative pictures), participants were required to press the respective force key to approach or avoid. The emotional picture remained on the screen irrespective of how fast the manikin moved to the target area.

Figure 4.1 shows the task schematic for two trial sequences. Trials started with a central fixation cross (500 ms), followed by the appearance of the manikin at the centre of the screen (randomly jittered – mean 300 ± 100 ms), and then the appearance of the picture on the upper half of the screen and the away target area on the bottom half of the screen (2000 ms). The manikin was moved to the respective target as a function of force (the harder subjects pressed the faster the manikin moved). However, to discourage subjects from removing the pictures from the screen faster by pressing harder, all pictures remained on the screen for 2000 ms irrespective of when the subjects reached the correct target area. Thus, there was no time benefit of reaching the target area as fast as possible.

Before the experiment, participants completed two short training blocks, one with each valence-movement mapping, of 30 trials each to familiarise participants with the task. After completion of the experimental session, participants rated the valence and arousal of all 180 pictures on a scale of 1 (i.e. very negative/very low arousal) to 9 (i.e. very positive/very high arousal).

4.3.5. *Variables of interest and data analyses*

Response initiation was quantified by reaction times (RTs), whereas vigour was quantified by the speed of movement and strength of responses during execution. These two measures for vigour were taken because it is conceivable that in two trials the strength of the response is similar, but that the peak strength is reached at different times.

Speed of action initiation: Reaction times

To determine the speed of action selection and initiation, RTs were measured as in Chapters Two and Three. RTs were determined from the time of target onset to when the force exceeded the MVC threshold (20% MVC).

Speed of vigour: movement times and acceleration

Two measures revealed influences on the temporal profile of vigour: movement times (MTs) and peak acceleration.

MTs reveal the total duration of movement from time of movement onset (RT) until the target area was reached. MTs reflect the overall speed of movement. Approach-avoidance tendencies may influence how fast an action is performed (e.g. moving towards a negative stimulus may be slower than moving away because it is not a predisposed tendency). MTs are therefore on way to quantify the vigour of a response throughout a trial.

However, just knowing whether an action was faster than another may not be sufficient to reveal the influence of approach-avoidance tendencies on vigour. Two movements may have similar movement times but there may be changes in the speed of a movement during a given trial (i.e. acceleration) that are unaccounted for by MTs. Acceleration was calculated by dividing the change in force (end force minus RT force) by the change in time (end time minus the RT) throughout the trial. While two trials may have similar MTs, they may have different values at the RT force and end force **(Figure 4.2)**, and this will result in different acceleration.

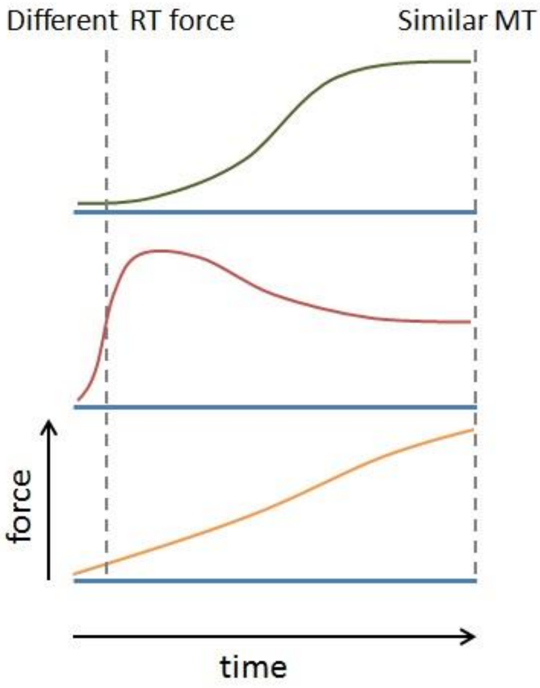


Figure 4.2. Potential differences between MT and acceleration (not based on real data). While three trials may have the same MT, the RT force used to calculate acceleration may differ, resulting in differences in acceleration. For instance, the second trial had a greater RT force than the first trial.

Strength of vigour: changes in force production

The spatial profile of vigour was investigated by measuring peak force (max RT force), the timing of when peak force occurred (time of max RT force) and the amount of effort made throughout a trial (force integral).

Avoiding a threatening dog may increase the force output relative to approaching a threatening stimulus. Max RT force was calculated as the maximum force value during a period from the RT until the participants had reached the respective target. This will give a value reflecting the maximum vigour achieved. The timing of when this maximum force is reached distinguishes between early or late influences on vigour. Some profiles may have the same peak force but there may be differences in how early this was reached. Avoiding a negative stimulus, for instance, may not only be stronger but reaching the desired strength may also happen faster. The early spatiotemporal properties of movement are dissociated from later properties (Messier & Kalaska, 1999) and reveal biases on movement planning that occurs prior to action initiation. Maximum force was expected to be highly correlated with acceleration and MTs.

The peak force simply reveals an overall effect on vigour and does not reflect changes on force that occur over a period of time. To assess this, the force integral was calculated. A consistently higher force throughout a trial may be more vigorous than a briefly high and subsequently low force. Here, the force integral reflects effort. The force integral takes into account the magnitude and timing of movement and was calculated by taking the difference in force from RT until participants reached the target area and multiplying it by the MT.

Variability of action execution: coefficient of variation

Variability reflects the consistency of performing an action. For instance, approaching a positive stimulus may be more consistent than approaching a negative stimulus due to approach-avoidance tendencies. Assessing variability therefore indicates the level of bias of tendencies on movement planning. To assess this, the Coefficient of Variation (CV) was measured by taking the standard deviation of max RT force and dividing it by the max RT force. The CV measures variability relative to the mean of the population and thus controls for mean changes.

4.3.6. *Statistical analyses*

For RTs, all trials in which the movement did not match the instructions (e.g., avoiding when instructed to approach negative pictures; 2.4% of trials), with RTs below 100 ms (0.8%) or exceeding 2000 ms (3.4%) were excluded from the analyses. Outlier RTs (1.3%) were calculated per block for each subject using Grubb's test, $\alpha = 0.05$. All force traces were normalised to zero before calculating maximum force measures. As above, outlier force values (0.5%) were calculated per block for each subject using Grubb's test. In total, 8.4% of trials were excluded.

A 2x2 within-subjects repeated measures ANOVA (RM-ANOVA) was conducted with factors *Movement type* (approach vs. avoid) and *Valence* (positive vs. negative) for each dependent variable. Bivariate Pearson's correlations (two-tailed) were also conducted to assess correlations between maximum force production and the force integral, and MTs and acceleration.

To analyse the effects of valence and arousal on both RTs and force, a multiple regression was first calculated by splitting RTs and force into approach and avoidance and having *valence* and *arousal* as independent variables. This assessed the strength and direction of the relationship between *valence* and RTs/force and *arousal* and RTs/force. The regression yielded beta coefficients (i.e. values indicating the strength and direction of the relationship between RTs and factors of interest) that were subsequently used in a two-way RM-ANOVA with factors *Movement type* (approach vs. avoidance) and *Variable type* (valence vs. arousal). The beta coefficients were taken as an indication of which of the independent variables (valence or arousal) had a greater impact on the RTs and maximum force.

Paired samples t-tests were conducted between the IAPS and individual picture ratings for positive and negative pictures separately, and for high and low arousal separately. For all analyses, partial-η^2 is reported as a measure of effect size. Statistical threshold was fixed at 0.05. Significant interactions were followed up using two-tailed paired-sample t-tests, in addition to calculating Cohen's *d*. RT means and standard error of the mean (SEM) are reported in brackets.

4.4. Results

4.4.1. Individual picture ratings

Subjective picture ratings for valence and arousal differed significantly from the IAPS picture ratings. Participants rated negative pictures as more negative than the IAPS ratings (IAPS: 2.53 ± 0.00, ratings: 2.19 ± 0.11; $t_{(23)} = -3.15$, $p = 0.004$) and rated positive pictures the same as the IAPS ratings (IAPS: 7.30 ± 0.00, ratings: 7.59 ± 0.15; $t_{(23)} = 0.63$, $p = 0.535$). Importantly, participants rated negative and positive pictures as different from each other (neg ratings: 2.19 ± 0.11, pos ratings: 7.59 ± 0.15; $t_{(23)} = -23.92$, $p < 0.001$), indicating that all subjects perceived the pictures as being their correct valence.

Participants rated low arousal pictures as being less arousing than the IAPS ratings (IAPS: 5.13 ± 0.00, ratings: 4.16 ± 0.27; $t_{(23)}$ = -4.30, $p < 0.001$), and also rated high arousal pictures as being less arousing than the IAPS (IAPS: 6.54 ± 0.00, ratings: 5.02 ± 0.32; $t_{(23)}$ = -4.82, $p < 0.001$). Importantly, participants rated low and high arousal pictures as being different from each other (low: 4.16 ± 0.10, high: 5.19 ± 0.12; $t_{(76)}$ = -4.93, $p < 0.001$), indicating that participants correctly perceived low and high arousal pictures as being different from each other.

4.4.2. *Calibration force*

To ensure that MVC did not differ significantly between the left and right index fingers, the individual MVC values for the right and left hand for each counterbalancing group were compared separately. Paired sample t-tests showed that the left and right MVC's did not differ significantly for either counterbalancing group (Group 1: left: 81 ± 6, right: 83 ± 7, $t_{(13)}$ = -9.35, n.s; Group 2: left: 69 ± 5, right: 67 ± 6, $t_{(11)}$ = 9.28, n.s.).

4.4.3. *Speed of action initiation: Reaction times*

To assess the influence of approach-avoidance tendencies on action selection and initiation, an interaction between the type of movement made and the valence of the emotional picture was expected. Indeed, the 2-way RM-ANOVA yielded this interaction (**Figure 4.3**; *Movement type*Valence*, $F_{(1,23)}$ = 34.12, $p < 0.001$, η_p^2 = 0.60), indicating that the valence of the emotional pictures influenced how fast approach and avoidance actions were initiated. There was also a main effect of *Movement type,* $F_{(1,23)}$ = 8.59, $p = 0.008$, η_p^2 = 0.27, with faster initiation of movements to approach than to avoid pictures (app: 745 ± 20 ms; avoid: 769 ± 19 ms; $t_{(23)}$ = -2.93, $p < 0.008$, Cohen's d = -0.60).

Follow-up paired t-tests of the 2-way interaction revealed that subjects were faster to approach than to avoid positive pictures (app: 721 ± 19 ms; avoid: 803 ± 22 ms; $t_{(23)}$ = -6.56, $p < 0.001$, Cohen's d = -1.38), and were faster to avoid than to approach negative pictures (app: 769 ± 23; avoid: 735 ± 19 ms; $t_{(23)}$ = 2.54, $p = 0.018$, Cohen's d = 0.55). Furthermore, subjects were faster to approach positive than negative pictures ($t_{(23)}$ = -3.71, p = 0.001, Cohen's d = -0.81), and to avoid negative than positive pictures ($t_{(23)}$ = -4.93, p < 0.001, Cohen's d = -1.04).

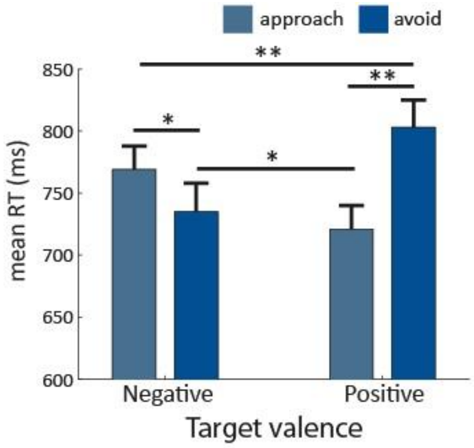


Figure 4.3. The speed of action initiation when approaching and avoiding. Emotional pictures triggered their automatic response tendencies: when negative pictures were presented, participants were faster to initiate avoidance than approach, and when positive pictures were presented, approach was faster than avoidance. Initiating approach was faster when presented with positive relative to negative pictures, and initiating avoidance was faster when presented with negative relative to positive pictures. Error bars (+1 S.E.M.); light blue bars = approach; dark blue bars = avoidance. ** significant at p < 0.001 level, * significant at p < 0.05 level.

Regression analyses conducted to assess the influence of factors *valence* and *arousal* on RTs confirmed the above results. A 2-way ANOVA conducted on the regression betas revealed an influence of *valence* only on the speed of initiation of approach and avoidance (**Figure 4.4A**; *Movement type*Variable type*, $F_{(1,23)}$ = 41.28, p < 0.001, η_p^2 = 0.64). Follow-up t-tests indicated that when approaching, as valence increases (i.e. becomes more positive) RTs decrease (i.e. become faster), as indicated by a mean negative beta (app: -0.13 ± 0.03). In contrast, when avoiding as valence increases RTs increase, as shown by a mean positive beta (avoid: 0.17 ± 0.03). These beta values differed significantly from each other ($t_{(23)}$ = -5.97, p < 0.001, Cohen's d = -1.91). Importantly, for *valence*, the betas for approaching and avoiding were significantly different from zero (app valence: $t_{(23)}$ = -3.82, p = 0.001; avoid valence: $t_{(23)}$ = 5.31, p < 0.001), indicating a significant impact of valence on RTs. However, for the variable *arousal*, there was no difference between the betas for approach and avoidance, and these were also not significantly difference from zero.

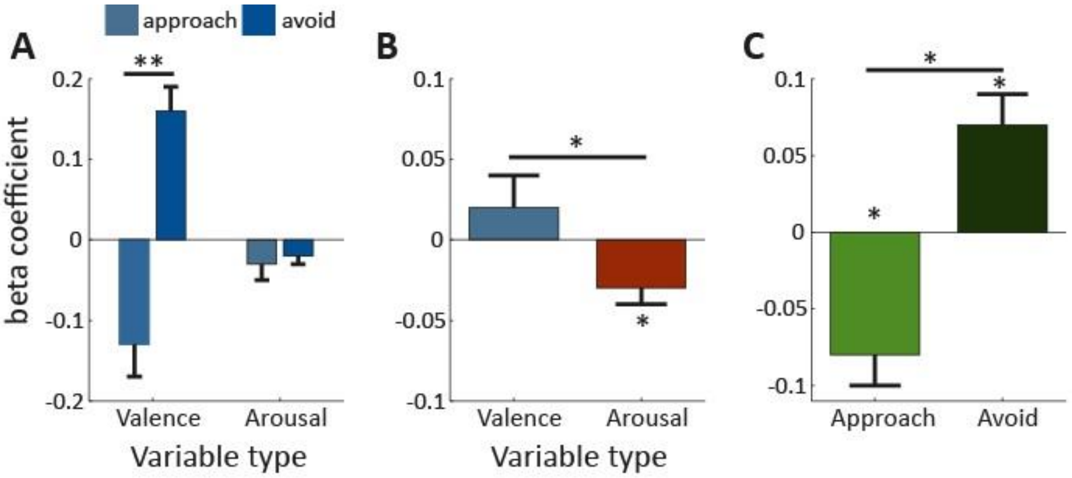


Figure 4.4. The influence of valence and arousal on the speed of action initiation of approach-avoidance responses. A) Interaction between approach-avoidance and variable type showing that only valence influenced the speed of action initiation. As valence increased (i.e. became more positive), approaching was faster and as valence decreased (i.e. became more negative), avoidance was faster. **B)** Main effect of variable type showing that as arousal increased, participants were faster to initiate actions. Only arousal was significantly different from zero. **C)** Main effect of movement type showing that RTs were faster when approaching compared to avoiding, irrespective of valence. Both are significantly different from zero. Error bars (+1 S.E.M.); ** significant at p < 0.001 level, * significant at p < 0.05 level.

There was also a significant main effect of *Variable type* (**Figure 4.4B**; $F_{(1,23)} = 5.35$, p = 0.03, $\eta_p^2 = 0.19$). As valence increased and became more positive, participants were slower to initiate actions (valence: 0.02 ± 0.02). As arousal increased, participants were slower to initiate their actions (arousal: -0.03 ± 0.01). However, the betas for valence did not differ from zero, most likely as a result of the approach and avoidance betas cancelling each other out, whereas there was a difference for the arousal betas ($t_{(23)} = -3.73$, p = 0.001). There was also a main effect of *Movement type*, (**Figure 4.4C**; $F_{(1,23)} = 23.50$, $p < 0.001$, $\eta_p^2 = 0.51$) with faster approaching compared to avoiding (app: -0.08 ± 0.02, avoid: 0.07 ± 0.02; $t_{(23)} = -4.55$, $p < 0.001$, Cohen's d = -0.96). These betas were significantly different from zero (app: $t_{(23)} = -3.76$, p = 0.001; avoid: $t_{(23)} = 3.81$, p = 0.001).

4.4.4. *Vigour of responses: maximum force from RT*

A 2-way RM-ANOVA conducted to evaluate the influence of emotional valence on the force produced to approach and avoid yielded a main effect of *Valence* only, (**Figure 4.5A**; $F_{(1,23)} = 10.24$, p = 0.004, $\eta_p^2 = 0.31$) with participants pressing harder for negative compared to positive pictures (neg: 76.3 ± 4.4; pos: 74.7 ± 4.4; $t_{(23)} = 3.20$, p = 0.004, Cohen's d = 0.66).

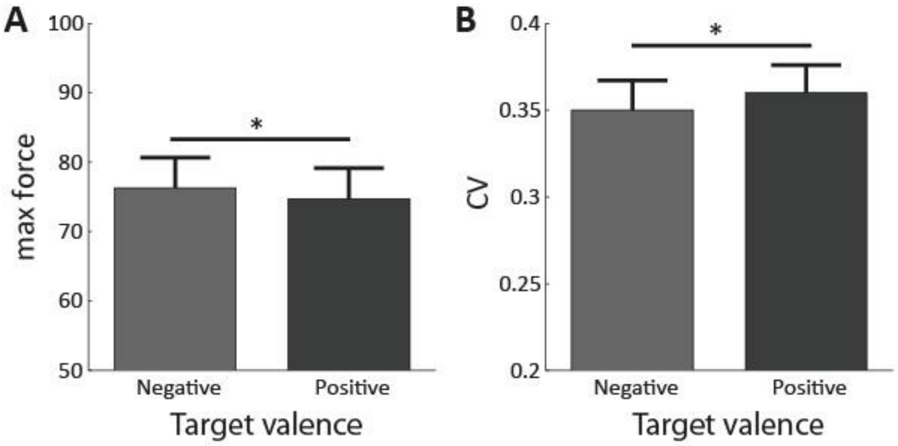


Figure 4.5. Influence of valence on the strength and consistency of action execution. A) Participants were more vigorous in pressing when negative pictures were presented relative to positive pictures. **B)** Force was less variable when presented with negative relative to positive pictures. Error bars (+1 S.E.M.); * significant at p < 0.05 level.

Regression analyses confirmed the above results. If valence had an impact on force production while approaching and avoiding, an interaction between *Variable type (*valence vs. arousal) and approach-avoidance movements was expected. However, the 2-way ANOVA only revealed a significant main effect of *Variable type*, (**Figure 4.6**; $F_{(1,23)} = 19.26$, $p < 0.001$, $\eta_p^2 = 0.46$) suggesting that approach-avoidance tendencies had no effect on force. *Valence* had a mean negative beta (-0.06 ± 0.02), suggesting that as valence increased (i.e. became more positive), force decreased, and *arousal* had a mean positive beta (0.015 ± 0.01), suggesting that as arousal increased, force increased. Paired samples t-tests revealed that only the betas for *valence* were significantly different from zero ($t_{(23)} = 2.69$, $p = 0.013$). Thus, only valence had an impact on force. Furthermore, the betas for *valence* were significantly different from those for *arousal* ($t_{(23)} = -4.15$, $p < 0.001$, Cohen's $d = -1.03$).

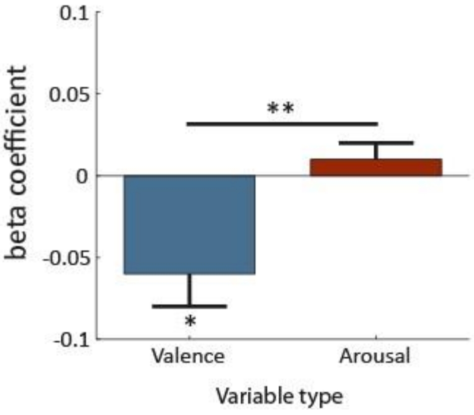


Figure 4.6. Influence of picture valence and arousal on the strength of responses. As valence decreased (i.e. became more negative), force increased, whereas as arousal increased, force increased. However, only the effect of valence on force was significantly different from zero. Error bars (+1 S.E.M.); ** significant at p < 0.001 level; * significant at p < 0.05 level.

4.4.5. Time to peak force

The time taken to reach peak force while approaching or avoiding was influenced by the valence of the picture (*Valence*Movement type,* $F_{(1,23)} = 45.56$, $p < 0.001$, $\eta_p^2 = 0.64$). For negative pictures, participants were numerically faster to reach the maximum peak when avoiding compared to approaching but this was not significant (app: 937 ± 28 ms; avoid: 926 ± 25 ms; $t_{(23)} = 1.25$, n.s.). For positive pictures, participants were faster to reach the maximum peak when approaching compared to avoiding (app: 902 ± 27 ms; avoid: 986 ± 28 ms; $t_{(23)} = -6.56$, $p < 0.001$, Cohen's d = -1.43). Participants were also faster to reach peak force when approaching positive pictures compared to negative pictures ($t_{(23)} = -3.48$, $p = 0.002$, Cohen's d = -0.75), and were faster to reach peak force when avoiding negative compared to positive pictures ($t_{(23)} = -2.94$, $p = 0.001$, Cohen's d = -0.88). Approach-avoidance tendencies therefore influenced how fast maximum vigour was reached.

A main effect of *movement type* ($F_{(1,23)} = 21.68$, $p < 0.001$, $\eta_p^2 = 0.52$) with participants being faster to reach the peak force when approaching compared to avoiding (app: 920 ± 27 ms; avoid: 956 ± 25 ms; $t_{(23)} = -4.66$, $p < 0.001$, Cohen's d = -1.02) was also found.

4.4.6. Consistency of force: coefficient of variation of force from RT

Approach-avoidance tendencies may influence the consistency of movement. When calculating the CV from the time of action initiation, there was a significant main effect of *valence* on the variability of vigour (**Figure 4.5B**; $F_{(1,23)} = 5.79$, $p = 0.025$, $\eta_p^2 = 0.20$), indicating that emotional valence influenced the consistency of force during action execution. Vigour was less variable when shown negative pictures compared to positive pictures (neg: 0.35 ± 0.017; pos: 0.36 ± 0.016; $t_{(23)} = -2.34$, $p = 0.028$, Cohen's d = -0.41).

4.4.7. Effort: Force integral

The effort made to approach or avoid after movement initiation was not affected by the valence of the picture (**Figure 4.7**; $F_{(1,23)} = 3.36$, $p =$ n.s.), although there was a trend for less effort required to avoid negative compare to positive pictures.

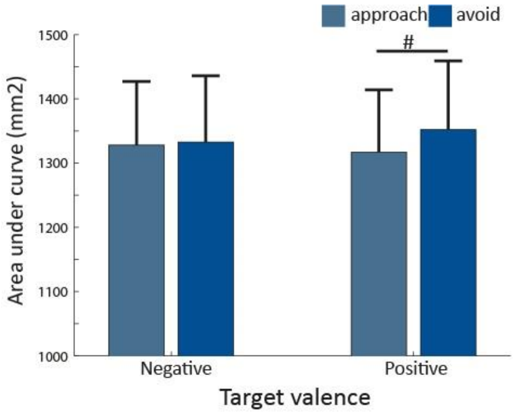


Figure 4.7. The effect of valence on effort. Participants worked harder to avoid than to approach positive pictures. It was easier for participants to approach positive than negative pictures. There was no difference between the work expended to avoid negative and positive pictures. Light blue bars = approach; Dark blue bars = avoid; Error bars (+1 S.E.M.); # depicts a trend.

4.4.8. Speed of action execution: Movement times

The 2-way RM-ANOVA yielded a main effect of *Valence* (**Figure 4.8A**; $F_{(1,23)} = 5.45$, p = 0.029, $\eta_p^2 = 0.19$), with faster movements for negative than positive pictures (neg: 290 ± 15 ms; pos: 295 ± 15 ms; $t_{(23)} = -2.33$, p = 0.029, Cohen's d = -0.47). Because the speed at which the manikin moved was directly related to how hard participants pressed, a correlation between MTs and maximum force was calculated. MTs and maximum force collapsed across movement type correlated significantly across all subjects (neg: r = -0.47, n = 24, p = 0.022; pos: r = -0.44, n = 24, p = 0.032). Therefore, MTs can be explained as a function of force production. Movement execution was influenced by valence only.

4.4.9. Rate of change in the speed of action execution: Acceleration

Subjects were numerically faster when moving in response to negative pictures compared to positive pictures (**Figure 4.8B**; neg: 0.26 ± 0.03 m/sec; pos: 0.25 ± 0.03 m/sec; $t_{(23)} = 1.99$, p = 0.060, Cohen's d = 0.47). Correlation analyses revealed that acceleration was highly correlated with maximum force produced. As expected, the harder subjects pressed when executing an action to negative pictures correlated with increased acceleration (neg: r = 0.79, n = 24, p < 0.001; pos: r = 0.78, n = 24, p < 0.001).

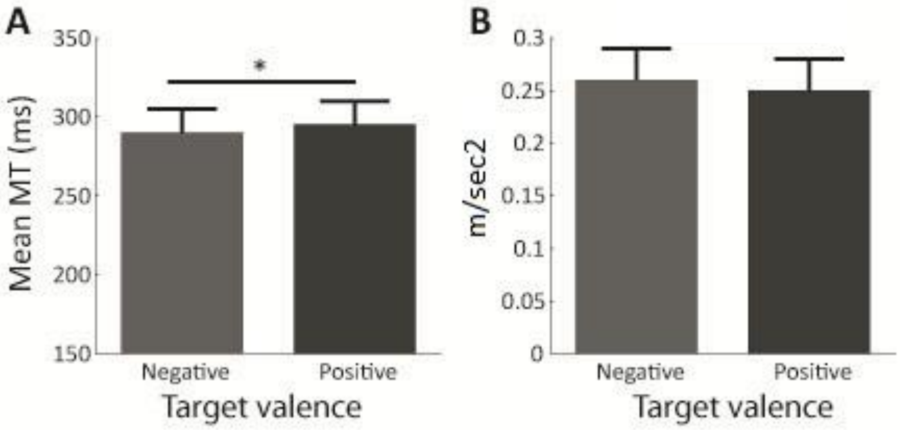


Figure 4.8. Speed of action execution. A) Executing actions in negative contexts was faster than in positive contexts. **B)** Increased acceleration when moving in negative relative to positive contexts. Error bars (+1 S.E.M.); * significant at $p < 0.05$ level.

4.5. Discussion

The current experiment investigated whether valence-related approach-avoidance tendencies influence vigour. More specifically, do approach-avoidance tendencies associated to positive and negative stimuli bias the planning of action parameters that will be implemented during action execution? To achieve this, participants were required to move a manikin on a screen either towards or away from an emotional picture by pressing on force buttons. Thus, vigour was quantified by the speed and strength of responses, parameters that will have been determined during the planning phase of movement generation.

The results are clear-cut: approach-avoidance tendencies influence the selection and initiation of movement but do not influence vigour, supporting previous work (Coombes et al., 2007, 2007; Stins & Beek, 2011; Stins et al., 2011). Instead, motor planning and action execution appear to be influenced by the valence of emotional stimuli, with vigour being greater when presented with negative relative to positive pictures in accordance with some evidence (Coombes et al. 2006; Coombes et al., 2008; Naugle et al., 2012). The data therefore demonstrate that approach-avoidance tendencies bias decision processes related to the selection of actions, but this bias is not translated into motor planning and action execution, suggesting a distinction in the influence of such tendencies on various motor processes.

Action selection is influenced by approach-avoidance tendencies

The current results replicate previous studies (Chen & Bargh, 1999; Eder & Klauer, 2009; Roelofs et al., 2009; Rotteveel & Phaf, 2004), showing that we are faster to initiate approach to positive and avoidance to negative stimuli, even when subjects are not instructed to respond as fast as possible. Importantly, regression analyses confirmed that only valence, and not arousal, triggered approach-avoidance tendencies. Thus, action selection and initiation are affected by valence-related tendencies, confirming the results from Chapters Two and Three.

Action selection of approach-avoidance has been suggested to occur via top-down mechanisms engaged by context and task-instructions (Lavender & Hommel, 2007; Eder & Rothermund, 2008). This is supported by evidence showing that areas of the prefrontal cortex (PFC) are involved in the selection of approach-avoidance tendencies (Etkin, Egner, Peraza, Kandel, & Hirsch, 2006; Roelofs et al., 2009; Volman et al., 2011). The left orbitofrontal cortex (OFC) appears to be activated when individuals need to overcome predisposed tendencies and select opposite actions (Roelofs et al., 2009), for example, in cases where one needs to approach a threatening spider in order to kill or remove it. Indeed, selecting opposite actions is slower than selecting established tendencies. This complements studies which have shown that the OFC is involved in overriding previous reward associations (Elliott, Dolan, & Frith, 2000; Rushworth, Behrens, Rudebeck, & Walton, 2007). Similarly, disruption to the anterior PFC leads to deficits in the selection of predisposed tendencies (Volman et al., 2016, 2011). Moreover, the ventromedial PFC has been shown to encode the value of emotional stimuli as positive or negative (Winecoff et al., 2013). This value information may complement contextual information that will eventually inform the selection of approach or avoidance.

In accordance with the *affordance competition hypothesis* (Cisek & Kalaska, 2010), it is unlikely that prefrontal areas are solely responsible for guiding the selection of approach-avoidance actions. For instance, recent evidence shows that amygdala activation is modulated by whether an approach or avoidance is required in threatening contexts (Radke et al., 2015). Reciprocity between cortical and subcortical areas has also been shown while participants execute actions in emotional situations (Pereira et al., 2010). Similarly, other work has shown extensive reciprocal connections between top-down and bottom-up areas which are likely to guide action selection in emotional contexts (Rolls, 1999). Action selection of approach-avoidance actions is therefore guided by top-down and bottom-up processes: bottom-up processes drive automatic responses, whereas top-down processes override these tendencies.

Approach-avoidance tendencies do not influence action execution

In contrast to the influence on action selection, the results showed that approach-avoidance tendencies had a mixed influence on vigour. The time taken to reach the peak force was significantly influenced by valence and associated response tendencies, with participants reaching peak force faster when presented with positive pictures during approach, and faster when presented with negative pictures during avoidance. This supports recent work showing that reaching maximum velocity while approaching is faster in positive relative to neutral contexts (Esteves et al., 2016). This evidence points to a possible influence of approach-avoidance tendencies on execution, although it is more likely that the influence on force peak times was influenced by the faster initiation times of approach-avoidance tendencies. The lack of an effect of emotional tendencies on other spatiotemporal properties of vigour supports this conclusion. For instance, there was no influence of such tendencies on the strength, speed or the variability of movements. Because the spatial and temporal profiles of vigour were highly correlated, it was not expected that these properties would be influenced independently from each other.

Overall, there appears to be no evidence indicating that approach-avoidance tendencies bias the planning of parameters that will be implemented during action execution. This is supportive of previous work showing no influence of approach-avoidance tendencies on action execution (Coombes et al., 2007; Stins & Beek, 2011; Stins et al., 2011). The current work therefore demonstrates a distinction in the influence of these tendencies on different motor stages: approach-avoidance tendencies influence the selection but not the planning of actions.

This work contrasts with studies which have demonstrated an influence of positive and negative value and action (respond/don’t respond) on vigour (Niv et al. 2005; Niv et al. 2007; Guitart-Masip et al., 2014). There are three possible reasons why there was no influence of approach-avoidance tendencies on vigour. Firstly, despite work showing that rewards and punishments and emotional stimuli are highly related (Bradley & Lang, 2008; Rolls, 2000), other work has suggested that while they may be similar, there are differences between them (Roseman, 2008). Rewards and punishments lead to highly goal-directed and intentional actions typically associated to hedonic experience (e.g. *I want to obtain a reward to feel good*). In contrast, emotional stimuli lead to predisposed actions, which can be triggered without a particular intention and that are not biased by hedonic experience (*e.g. immediately running away from a bear to stay alive*). Furthermore, rewards and punishments can increase or decrease in value, whereas emotional stimuli do not. The positive and negative values associated to rewards and punishments and emotional stimuli may not be related.

Secondly, participants may not have viewed approach and avoidance as rewards and punishments, respectively. Situations of rewards and punishment typically lead to real positive or negative outcomes. For instance, in reward/punishment experiments, participants can receive real monetary rewards or losses. In the current experiment this was not the case. While participants approached and avoided positive and negative stimuli, there was no real positive or negative outcome. For example, approaching a picture of a spider did not lead to a punishment because there was no negative consequence of approaching the negative stimulus. Indeed, work has shown that planning of a particular outcome is tightly linked to the anticipated consequences of the action (Eder & Rothermund, 2013; Eder & Hommel, 2013; Kühn, Keizer, Rombouts, & Hommel, 2011). This logic does not apply to action selection because selecting approach and avoidance does not lead to an outcome. Performing an action is what ultimately leads to the outcome. Thus, participants did not associate approach and avoidance to rewards and punishments, and this may have led to no biases in vigour.

Lastly, it may be possible that approach-avoidance tendencies influence the early formation of goals that serve to help choose the most appropriate response. Any process that occurs after selection may not be biased by these motor goals because presumably the bias will have already occurred. Indeed, there is sufficient evidence showing how such tendencies guide action selection (Lavender & Hommel, 2007; Roelofs et al., 2009; Volman et al., 2011), but very little evidence for an influence on processes after action selection

(Esteves et al., 2016). Speculatively, subsequent processes may instead be influenced by a more global and less goal-directed emotional mechanism, whereby valence biases the planning and implementation of action parameters (see below).

Action execution is influenced by the valence and arousal of an emotional stimulus

While there was no influence of approach-avoidance tendencies, emotional valence and arousal on their own did affect vigour: as valence decreased (i.e. became more negative), maximum force increased, and as arousal increased, maximum force increased. These results corroborate previous studies which have shown that relative to neutral pictures, positive and negative pictures increase vigour (Esteves et al., 2016; Naugle et al., 2012; Schmidt et al., 2009), demonstrating that both the valence (Coombes et al., 2006) and the arousal (Bouman, Stins, & Beek, 2015; Coombes, Corcos, Pavuluri, & Vaillancourt, 2011; Coombes et al., 2008; Schmidt et al., 2009) of emotional stimuli influences the execution of actions.

Furthermore, results suggest that negative stimuli have more impact in vigour relative to positive stimuli. This was demonstrated by the fact that both speed and strength were greater and less variable when shown negative pictures compared to positive pictures, in support of previous work that found greater vigour during extension movements without compromising movement variability when exposed to unpleasant images (Coombes et al., 2006). Overall these results suggest that the planning of movement parameters and their implementation is influenced by negative valence. Being stronger, faster and more consistent at pushing an aggressive person away is more beneficial for survival than being stronger, faster and more consistent at approaching to pet a puppy.

Increased vigour and decreased variability found in negative contexts may arise as a result of the activation of a fast defensive circuitry (LeDoux, 2012; LeDoux, 2000; Ohman & Soares, 1998) that has an immediate impact on action execution in order to optimise the outcome and minimise costs. The activation of a defensive circuit would suggest that in negative contexts it is important to both initiate and execute actions appropriately, and suggests a global rather than selective effect of negative valence on motor processing. Alternatively, the effect of highly-arousing negative stimuli on vigour may be related to the fact that these stimuli tend to be prioritised relative to less threatening stimuli (Ohman et al., 2001; Vuilleumier et al., 2005). Faster attentional prioritisation leads to increased perceptual processing that results in improved performance (Pessoa et al., 2002).

In sum, vigour is affected by the valence and arousal of emotional pictures, but not by related approach-avoidance tendencies. Moreover, vigour is greater and more consistent in negative contexts, leading to the speculation that this might be related to increased attentional resources and the activation of a defensive circuitry that biases opportunity costs and promotes survival in threatening situations.

Conclusion

In sum, the results lend support to previous evidence showing that emotional stimuli have a differential impact on motor processing: valence-related approach-avoidance tendencies influence the action selection stages of movement but do not influence motor planning. Instead, motor planning is influenced by emotional valence: vigour was greater and less variable in negative relative to positive contexts. Motor planning of execution parameters and their implementation is therefore biased by negative stimuli, possibly guided by a primitive defensive mechanism that biases opportunity costs. Making more effort in negative or threatening situations is more beneficial and will lead to a more successful outcome.

Chapter Five. Differential influence of approach-avoidance tendencies and valence on response inhibition

5.1. Abstract

Suppressing actions that are no longer appropriate or advantageous is an important characteristic of successful behaviour. Valence-related approach-avoidance tendencies influence action selection. Such tendencies may also influence our ability to inhibit actions. Two competing processes dictate the speed of response inhibition: the preparation of “go” processes and the preparation of “stop” processes. Emotional approach-avoidance tendencies may influence these preparatory processes, influencing the speed of response inhibition. Two experiments were conducted. Experiment 1 investigated the influence of approach-avoidance tendencies on the preparation of “go” processes. Experiment 2 investigated the influence of approach-avoidance tendencies on the preparation of “stop” processes. In Experiment 1, participants approached or avoided emotional stimuli presented as “go” cues, but on a proportion of trials were required to inhibit their prepared movement in response to an abstract acoustic cue. In Experiment 2, participants approached or avoided abstract cues and in some trials were required to inhibit their prepared movement in response to an emotional stimulus. This difference allowed tapping into the preparation of “go” and “stop” processes separately. Experiment 1 showed an influence of approach-avoidance tendencies on the speed and variability of inhibition, suggesting an influence of approach-avoidance tendencies on the “go” preparatory processes. In Experiment 2, inhibition was influenced by valence only, with faster inhibition in negative relative to positive and neutral contexts. This suggests an influence of valence on the preparation of “stop” processes. Overall, the results show that approach-avoidance tendencies influence preparation processes prior to when an action needs to be executed, while stopping processes are influenced by negative information, possibly modulated by a defensive circuit.

5.2. Introduction

Our social and emotional interactions require us to select appropriate actions and inhibit inappropriate or unsafe response alternatives (Aron, 2007; Aron et al., 2007; Aron & Verbruggen, 2008; Verbruggen & Logan, 2008). Much as valence-related approach-avoidance tendencies influence action selection and initiation, as seen in Chapters Two, Three and Four, such tendencies may also influence our ability to inhibit actions that may be potentially costly. This chapter addresses if action tendencies influence how fast we stop or inhibit a prepared motor response from being executed in light of ever-changing environments.

Response inhibition involves the suppression of an already planned movement and the initiation of a stopping response (Verbruggen & Logan, 2008, 2009). This has primarily been studied using the stop-signal paradigm (Logan & Cowan, 1984; Verbruggen & Logan, 2008), whereby participants plan and execute a response when a particular go stimulus is presented (“go” process), but are required to occasionally withhold this response if a stop signal is presented (“stop” process) after a particular delay (stop-signal delay; SSD). The speed of inhibition is quantified by estimating the stop-signal reaction time (SSRT) as a function of the reaction time distribution of the “go” process and the SSD **(Figure 5.1).**

The “horse-race model” has been proposed as a general model for response inhibition (**Figure 5.1;** Logan & Cowan, 1984). In this model, how quickly inhibition occurs is thought to depend on a race between the competing “go” and “stop” processes. The resolution of this competition (i.e. which process ultimately wins the race) is determined by the extent of preparation of each competing response. For instance, if the “stop” process is completed before the “go” process, inhibition will be successful (i.e. if the stop-signal is presented early enough that preparation is biased towards inhibition), and if the “go” process is completed before the “stop” process, no inhibition will occur (i.e. the stop-signal was presented too late to bias preparation towards inhibition). The speed of response inhibition may therefore inform about the underlying preparation processes of behaviour (De Jong et al., 1990; Verbruggen & Logan, 2009): faster response inhibition means that the preparation of “go” responses was slower, whereas slower response inhibition indicates that preparation processes for the "go" responses were faster than the preparation of "stop".

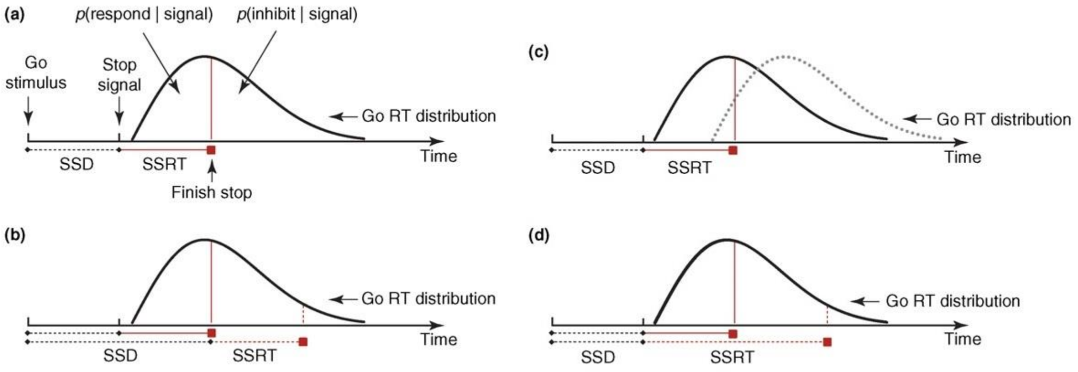


Figure 5.1. Horse-race model of response inhibition (Logan & Cowan, 1984). **A)** The success of response inhibition is determined by the relative finishing times of the go and the stop process. The probability of responding and inhibiting is influenced by the **b)** SSD, **c)** the distribution of the "go" RTs and the **d)** SSRT. If "go" RTs are longer than SSD + SSRT they are successfully inhibited; if "go" RTs are shorter than SSD + SSRT they are not inhibited. Taken from Verbruggen & Logan (2008).

In emotional situations, response inhibition may be beneficial as it would avoid the execution of potentially costly actions. For example, we may be tempted to extend our arm to approach and pet a cute dog, but may need to quickly inhibit the prepared movement if the dog became suddenly aggressive. Inhibition in this situation is crucial to avoid getting bitten. Because emotional stimuli predispose for specific action tendencies which are prepared faster than other actions (Eder & Klauer, 2009; Eder & Rothermund, 2008; de Oliveira et al., 2012), this may influence the resolution of competition between "go" and "stop" processes. It is possible that actions that are prepared faster may be more difficult to inhibit than those that are prepared more slowly. For example, inhibiting avoidance to positive stimuli may be faster than inhibiting an approach because avoidance is prepared more slowly than approach in positive contexts.

Previous work has shown that inhibiting a prepared action within positive contexts is more difficult relative to negative contexts, and that initiating an action is faster when presented with positive pictures (Albert et al., 2010). Similarly, positive information biases the motor system to act, as shown by increased preparatory excitability prior to movement, whereas negative information decreases the tendency to act (Chiu et al., 2014; de Oliveira et al., 2012). The tendency for slower movement initiation in negative contexts is supported by evidence showing that threatening stimuli can often result in immobility (i.e. freezing) of responses in both rats (Lang et al., 2000) and humans (Facchinetti et al., 2006; Roelofs et al. 2010; Stins et al., 2013). Freezing, or slower response initiation, may have evolved to avoid potentially costly actions in threatening situations (LeDoux, 1996). Thus, it appears that inhibition is more difficult when subjects need to initiate responses in positive contexts and easier when initiating responses in negative contexts. Initiation in this case might be considered an “approach” action. Thus, in positive contexts “approach” was prepared faster whereas in negative contexts “approach” was prepared slower, leading to differences in inhibition.

Surprisingly, little is known about how approach-avoidance tendencies influence our ability to stop our actions. Response inhibition is a process that interacts with and influences motor processes, and is guided by neural mechanisms that interact with emotion (Albert et al., 2010; Goldstein et al., 2007; Shafritz et al., 2006). Investigating if approach-avoidance tendencies influence response inhibition would show that emotion can selectively influence different processes and underlying mechanisms, furthering our understanding of how emotions are linked to action. To my knowledge, this remains unknown.

Emotional stop-signals speed up response inhibition

The stop-signal task (Logan & Cowan, 1984) allows for revealing underlying preparatory mechanisms of “go” and “stop” processes. Presenting emotional stimuli as stop-signals can facilitate (i.e. speed up) inhibition (Chiu, Holmes, & Pizzagalli, 2008; Pawliczek et al., 2013; Pessoa et al., 2012; Senderecka, 2016). For instance, when an emotional stimulus is presented as a stop-signal *after* the go-signal, inhibition of positive and negative stimuli is faster relative to neutral pictures (Pessoa et al., 2012; Senderecka, 2016), and inhibition of negative stimuli is faster relative to positive stimuli. In terms of preparation, it appears as though emotional stimuli speed up the preparation of competing “stop” processes, biasing competition resolution towards inhibition.

Two mechanisms may underlie the speeding up of inhibition. Firstly, faster inhibition relative to neutral stimuli may occur as a result of increased perceptual processing and attentional allocation (Pessoa, 2007; Pessoa, 2009), whereby emotional stop-signals generate enhanced sensory representations in the visual system (Pessoa et al., 2002; Vuilleumier et al., 2005). Secondly, faster inhibition of negative relative to positive stimuli is likely to reflect "freezing" mechanisms triggered by the presence of threatening information, supporting previous work (Chiu et al., 2014; Facchinetti et al., 2006).

Emotional stop-signals therefore influence the preparation of the "stop" process by biasing competition between "go" and "stop" processes towards inhibition. However, if the success of inhibition relies on the state of preparation of "go" processes, then presenting emotional information prior to a stop-signal is as informative about inhibition as presenting an emotional stop-signal. Presenting emotional information as go-signals may influence the preparation of "go" processes, influencing the resolution of competition between "go" and "stop" processes. Indeed, Verbruggen & Logan (2008) showed that the success of inhibition is influenced by both the distribution of the "go" RTs ("go" process; **Figure 5.1c**) and the SSRTs ("stop" process; **Figure 5.1d**). It is currently unknown whether presenting emotional information prior to a stop-signal also speeds up inhibition.

Moreover, the state of preparation of "go" and "stop" processes may be influenced by approach-avoidance tendencies **(Figure 5.2)**. The preparation of "go" processes may be faster for predisposed tendencies compared to actions that are not predisposed, biasing the competition between "go" and "stop" towards responding. In contrast, the preparation of "stop" processes may be slower for approach-avoidance tendencies. In either case, presenting emotional information as the "go" or "stop" signal should inform of the influence of approach-avoidance tendencies on inhibition. To the best of my knowledge no study has compared inhibition guided by the preparation of "go" processes and of "stop" processes under situations of approach-avoidance. Thus, the main goal of this chapter was to investigate the process of response inhibition in emotional situations and determine if approach-avoidance tendencies influence the resolution of competing responses by biasing the preparation of "go" or the preparation of "stop" processes, or both. To my knowledge this remains unknown. If approach-avoidance tendencies influence inhibition, it would demonstrate their capacity to influence a variety of motor processes, giving further evidence of their privileged relationship with the motor system. If there is no such influence of tendencies on inhibition, it would demonstrate that these tendencies do not have a widespread bias throughout the motor system, and their influence may be potentially confined to selection processes, as seen in Chapters Two, Three and Four.

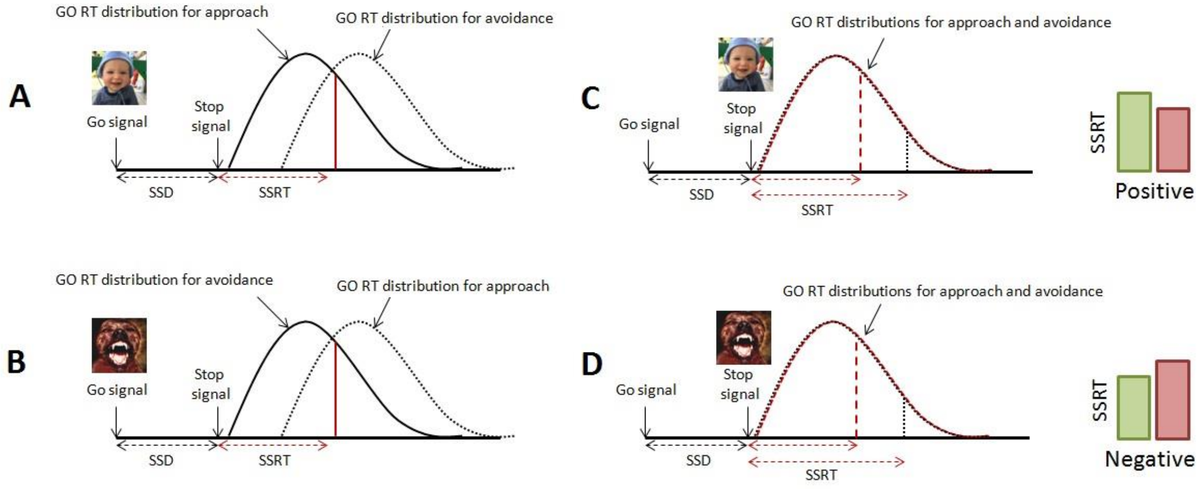


Figure 5.2. Inhibition predictions based on the preparation of "go" and "stop" processes. A) When a positive stimulus is presented, approach (solid black curve) should be prepared faster than avoidance (dotted black curve), reflected on different GO RT distributions. The faster preparation of approach should "win" the competition between "go" and "stop" processes, making inhibition harder, whereas the slower preparation of avoidance should make inhibition easier. **B)** A similar principle applies to negative stimuli. Preparation of avoidance (solid black curve) should be faster than approach (dotted black curve), leading to differences in inhibition. **C)** The preparation of approach and avoidance to abstract stimuli should not differ, meaning the "go" process is the same. The presentation of a positive stop-signal during approach should slow down the preparation of the "stop" process, leading to delayed inhibition (dotted black line), whereas the preparation of a "stop" process should be faster during avoidance (dotted red line). SSRTs should differ. **D)** The presentation of a negative stop-signal during avoidance should slow down the preparation of the "stop" process, leading to delayed inhibition (dotted black line), whereas the preparation of a "stop" process should be faster during approach (dotted red line). Approach-avoidance biases on the "go" or "stop" processes are predicted to have the same effect on the SSRTs. **A** and **C** should lead to faster SSRTs when avoiding (red bars) than approaching (green bars). **B** and **D** should lead to faster SSRTs when approaching (green bars) than avoiding (red bars).

Valence-related approach-avoidance tendencies and inhibition

Two experiments were conducted to investigate the influence of the preparation of "go" and "stop" processes on inhibition of approach-avoidance tendencies. Experiment 1 tested the hypothesis that positive and negative "go" signals bias the preparation of approach-avoidance "go" processes and this would in turn influence the speed of inhibition.

Participants were instructed to approach or avoid depending on the valence of the go-signal. In 30% of trials, a non-emotional auditory tone was presented as the stop-signal. Participants were required to inhibit their movement when this stop-signal was presented. Given valence-related approach-avoidance tendencies, an interaction between valence and the type of movement made was expected. It should be more difficult to inhibit approach-avoidance tendencies because they are prepared faster (Chen & Bargh, 1999). Accordingly, inhibition should be slower when prepared to approach positive and avoid negative stimuli, than when prepared to avoid positive and approach negative stimuli, given that the latter is a response considered to be counterintuitive to the natural response (Roelofs et al., 2009).

Experiment 2 tested the hypothesis that emotional stop-signals and their related tendencies influence the speed of preparation of the "stop" process. Abstract go-signals (e.g. shapes) linked to approach-avoidance responses were presented. These go-signals therefore still triggered the preparation of approach and avoidance "go" processes. Positive, negative and neutral stimuli served as the stop-signals. Here, neutral was included as a control condition. In line with previous work, emotional stop-signals were expected to speed up stopping in comparison to neutral stimuli (Pessoa et al., 2012; Senderecka, 2016). As a result of approach-avoidance tendencies, faster inhibition of avoidance was expected when presented with a positive stop-signal and faster inhibition of approach when presented with a negative stop-signal. No differences in inhibition of approach and avoidance were expected when presented with neutral stop-signals. Furthermore, there should be faster overall inhibition when presented with negative stop-signals relative to positive and neutral stop-signals, due to such stimuli being low in their level of threat (Pessoa et al., 2012).

5.2.1. Experiment 1

5.2.1.1. Method

5.2.1.1.1. Participants

19 healthy volunteers (mean age = 22.4 ± 3.9 S.D. years; 14 female) from the University College London Psychology database, with local ethics approval (UCL) were tested. Subjects gave written informed consent to participate in the study, and received monetary compensation for their time and travel (£7.5/hr).

5.2.1.1.2. Stimuli and apparatus

80 pictures were selected from the International Affective Picture System (IAPS; (P.J. Lang et al., 2008): 40 negative pictures with valences 1.8-3.8 (1.6 = most negative) and 40 positive pictures with valences 6.2-8.2 (8.2 = most positive). All pictures (maximum 240 x 180 pixels) were matched for luminance. Pictures were matched in their arousal (with an equal proportion of high and low). However, despite my best efforts to match as closely as possible, positive pictures were on average slightly less arousing than negative pictures. The assignment of pictures in each of the 8 blocks and order of picture presentation was randomised for each subject. Block order was counterbalanced across participants. Each block comprised of 80 trials (40 positive/negative). Each picture was repeated eight times during the entire experiment. In total there were 160 trials for each experimental condition.

All visual stimuli were presented on an 19 inch LCD monitor of a Dell Optiplex-780 computer (refresh rate: 60 Hz), using the Cogent 2000 toolbox (v1.29; University College London, http://www.vislab.ucl.ac.uk/Cogent2000/index.html) and MATLAB (v.7.9.1.705; The MathWorks Inc.). A white manikin (2.8 x 1.9 cm) represented the self. A small yellow circle (38 x 33 pixels) represented the “away” target that participants had to move to when avoiding. The manikin was presented in either the upper or lower half of the screen in a pseudo-randomised order. A sound stimulus (50 Hz noise) was generated using MATLAB and presented binaurally via headphones and was used as the stop-signal.

As in Chapters Two and Three, the manikin was moved across the screen using an analogue joystick connected to a CED1401 (Cambridge Electronic Design) machine. Joystick data were recorded using a CED1401-MATLAB interface (matced32; Cambridge Electronic Design) between MATLAB and the data acquisition device.

5.2.1.1.3. Experimental task

The approach-avoidance task used in Chapter Two was adapted for the present experiments. Participants were seated in front of a computer at a distance of approximately 40 cm. The joystick was fixed to the table on their right-hand side. Participants were instructed to move the manikin towards or away from the emotional stimulus as fast as possible, according to the instructions at the beginning of each block. In *congruent* blocks (approach-positive, avoid-negative), participants moved the manikin towards positive pictures and away from negative pictures. In *incongruent* blocks (approach-negative, avoid-positive), participants moved the manikin towards negative and away from positive pictures. As in previous chapters, participants were instructed to imagine that the manikin represented them on the screen.

The stop-signal paradigm was used to indirectly measure the speed of response inhibition (**see figure 5.1**; Logan & Cowan, 1984). A stop-signal occurred at specific delays after the presentation of the emotional go-signal (stop-signal delay; SSD). The shorter the SSD (i.e. the earlier the stop-signal is presented), the easier it should be for participants to withhold their response because the stop process will have started earlier than the go process. As the SSD increases, the stop process should start later and thus finish after the go process, making inhibition harder.

Figure 5.3 depicts two typical trial sequences. Trials started with the presentation of a fixation cross (500 ms), followed by the simultaneous appearance of the manikin and fixation cross (jittered with a mean of 500 ± 200 ms). The jitter prevented participants from anticipating the exact timing of the go-signal. After the jittered delay, an emotional picture appeared on the screen (max 2000 ms or until participants reached the target area). On 30% of all trials, a beep occurred (duration 50 ms) at a specific SSD to signal that participants should withhold their prepared response (stop-trials). The remaining 70% were go-trials. Participants were instructed to always respond as fast as possible and not to worry if they were unable to inhibit their responses. Previous literature (Verbruggen, Chambers, & Logan, 2013) has argued that participants sometimes strategically slow down their responses in order to maximise response inhibition. To avoid this from happening, reaction time (RT) feedback was provided after every block and encouraged subjects who exceeded a certain RT threshold (i.e. 700 ms) to increase the speed of their responses.

The SSD was fixed at 300 ms at the beginning of every block. The SSD was changed throughout the block using a staircase procedure. In stop-trials, if participants successfully inhibited their response the SSD increased by 50 ms. If inhibition was unsuccessful, the SSD decreased by 50 ms (Pessoa et al., 2012). This tracking method (± 50) essentially determines the SSD at which subjects inhibit their responses 50% of the time and typically results in a probability of responding given the presence of the stop signal [p(respond/signal)] of approximately 0.5. The SSD varied independently for each of the four conditions: approach-positive, avoid-negative, approach-negative and avoid-positive. Thus, there were four independent SSDs that varied as a function of which group of trials they belonged to. For example, in trials in which participants approached positive pictures the SSD decreased or increased as a function of successful inhibition in that specific group of trials, and this SSD was different from the SSD used in the other types of trials. Participants only got feedback in successful trials.

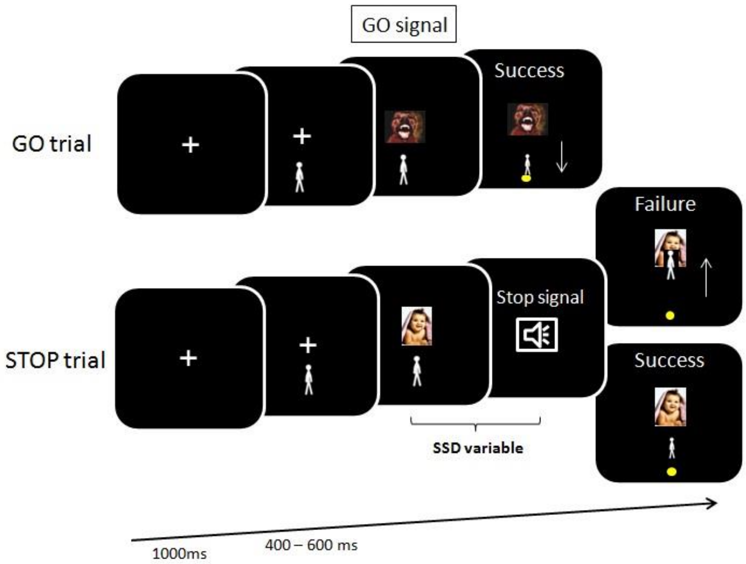


Figure 5.3. Task schematic of two trial sequences. A manikin appears on the screen above or below a fixation cross. A positive or negative picture was subsequently presented. In go-trials, participants moved the manikin towards or away from the picture, depending on the block instructions. In stop-trials, a beep was played for 50 ms at a variable time after the presentation of the picture (stop-signal). Participants had to withhold their response when they heard this beep. Participants received feedback when they made a wrong response (e.g. approach instead of avoid) and when inhibition was successful.

The main goal of Experiment 1 was to assess the influence of approach-avoidance tendencies on the preparation of “go” processes and how this influences response inhibition. Crucially, this design allowed participants to prepare approach-avoidance responses to positive and negative stimuli prior to the presentation of a stop-signal. These early preparatory processes were expected to bias the competition between “go” and “stop” processes towards “go”.

5.2.1.1.4. Data analyses and variables of interest

To assess the influence of valence-related approach-avoidance tendencies on the ability to suppress actions the following variables were measured: Reaction Times (RTs), SSRTs and the parameters of the RT and SSRT distributions, mean (μ), spread (σ), and skew (τ).

To assess inhibition, the RT was here considered the most important variable. Without the RT distribution it is impossible to estimate the SSRT. As such, RTs were measured in order to give an estimate of the ability to inhibit approach-avoidance movements. RTs were determined from the time of shape onset to the initiation of joystick movement. Joystick data were recorded in XY-coordinates and joystick onset was calculated based on vertical y-axis coordinate deviations (±10 y-coordinates) from trial baseline. The baseline was recorded while the manikin was stationary prior to the appearance of the target.

SSRTs provide an inferred measure about the latency of the stop process. The SSRT corresponds to the time interval between when the stop process begins and when it finishes. The point at which the stop process finishes is estimated from the observed RT distribution.

A problem often encountered by considering only the mean RT and SSRT is that distributions may have the same mean but have different variance (i.e. one distribution may be more consistent than the other; **Figure 5.2**). I used a method that not only gave me the mean RT and SSRT, but also gave me the parameters of the distributions that may reveal underlying influences on inhibition that may not otherwise be revealed by mean values. Three distribution parameters were of interest: mu (μ) and sigma (σ), which represent the mean and the standard deviation of the distribution respectively, and tau (τ), which gives an indication of the skew of the distribution. The mean of the distribution is meant to reflect the mean RT and is not expected to greatly differ from the RT calculated without taking into account other distribution measures. The standard deviation, however, is expected to determine the consistency (or variability) of response initiation and suppression. Smaller σ values, for example, give an indication of greater consistency, that is, inhibition occurred at similar speeds in each trial for a given condition (i.e. stopping approach to positive stimuli).

Consistency may be important for indicating how uncertainty biases inhibition. Stopping some actions is more uncertain than stopping others. For instance, stopping an approach to a positive stimulus may not be only harder, but also more uncertain regarding the outcome. In contrast, stopping an action to a negative stimulus is more certain. Indirectly, this might also give an idea of automaticity, with the initiation or inhibition of predisposed actions being less variable. The skew of the distributions may also influence the estimation of the SSRT (Verbruggen et al. 2013), and therefore τ will be important in determining whether the tail-end of the distributions was a determining factor in the estimations. Greater τ values indicate a more positively skewed distribution.

Mean RTs and SSRTs, and distribution parameters were calculated using BEESTS (Bayesian Ex-Gaussian Estimation of Stop-Signal RT distributions; Matzke et al., 2013). This Bayesian parametric approach (BPA; **Figure 5.4**) assumes that SSRTs are ex-Gaussian distributed and uses a Markov Chain Monte Carlo sampling (MCMC) to obtain posterior distributions for RT and SSRT parameters and hence estimate the mean and variance of the speed of go and stopping processes. MCMC algorithms are used for sampling from the probability distributions of a particular sample and construct a Markov Chain with the desired distribution. Markov chains typically use a random walk algorithm, which explores the entire sample distribution in a random fashion, walking forward one step and walking back two steps, which can increase the chance of covering the majority of the sample. The quality of the chain will improve the more steps there are. Similarly, the more chains, the more likely it will lead to converging distributions. To demonstrate that the chains have properly converged BEESTS also computes the Gelman-Rubin R statistic. If the chains have converged properly, R needs to be lower than 1.1.

RTs and SSRTs were calculated at the hierarchical (group) level using 3 chains, 36000 samples, 12000 burn-in and 12 thinning in accordance to Matzke et al. (2013). Hierarchical analysis was used as there was a relatively small number of observations per participant and as this takes into account between-subject variability of the participant-level parameters (Matzke, Dolan, Logan, Brown, & Wagenmakers, 2013). In the current case, this analysis provides accurate parameter estimates with fewer observations per participant than the individual analysis and yields less variable estimates than single-level parameter estimation. Individual analyses were still conducted for comparison, but are not presented.

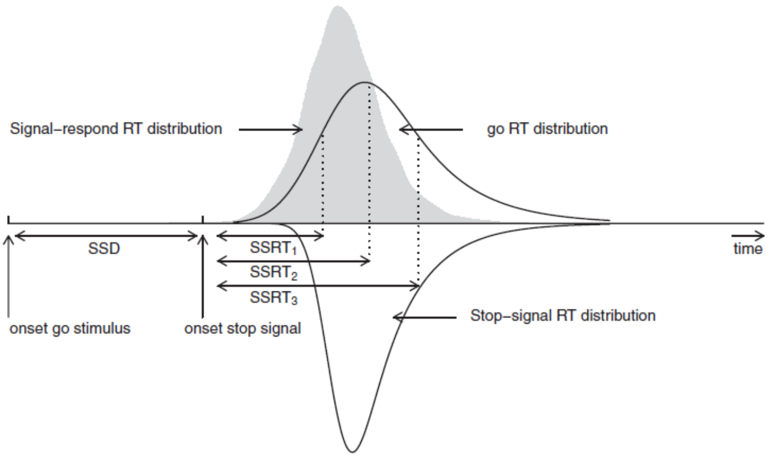


Figure 5.4. Assumptions of the Bayesian parametric approach (BPA). Two distributions are considered: the signal-respond RT (i.e. the RTs of those trials in which a stop-signal is presented but participants still responded; grey shaded area) and the SSRT. The signal-respond RT is considered the "go" RT in this case, which is censored by the SSRT distribution. The censoring point can take on a different value on each stop-signal trial (e.g. SSD + SSRT$_1$, SSD + SSRT$_2$, and SSD + SSRT$_3$). If the "go" RT is longer than the SSD + SSRT value, responses are successfully inhibited. If the "go" RT is shorter than the SSD + SSRT value, the response is not inhibited and it results on a signal-respond RT (from Matzke et al. 2013).

Using BEESTS, I obtained the following parameters: summary statistics (including the RT, SSRT, μ, σ, and τ), posterior distributions, MCMC chains, deviance, and goodness-of-fit. The prior distribution is the distribution of the parameter(s) before any data is observed, whereas the posterior distribution takes into account the observed data. The prior distributions are updated by the incoming data and ultimately yield the posterior distribution. The spread of the posterior distributions quantifies the uncertainty about the parameter estimates: the larger the spread, the greater the uncertainty of parameter estimation. Prior and posterior distributions are therefore necessary to determine if the μ, σ, and τ parameters are adequate and trustworthy. Parameters are obtained for "go" and "stop" data, but "go" parameters are more reliable calculated because they are estimated from both the GO RTs and signal-respond (unsuccessful stop trials) RTs. Before interpreting the parameters, we need to check that the data is adequate. This is done by verifying that the posterior distributions of the model parameters are unimodal and by running multiple MCMC chains. If the MCMC chains converge they should look like "hairy caterpillars".

As a control, BEESTS results were validated using the mean method (Logan, 1994). The mean method requires subtracting the mean SSD for a particular condition from the mean RT for that condition (e.g. condition 1 mean RT-condition 1 mean SSD). Contrary to

BEESTS, it does not take into account underlying distributions and variance into the calculation of SSRTs. The mean method is the most widely used for estimating the SSRTs in the response inhibition literature. By comparison, BEESTS is a recent method that has only been used in a small fraction of the inhibition literature. As such, the comparison between the BEESTS and the mean method output served to confirm the reliability of BEESTS. Nonetheless, evidence suggests that the mean method should be abandoned due to its susceptibility to miscalculating the SSRT as a result of skewed RT distributions and strategic slowing of RTs by participants (Verbruggen et al., 2013).

5.2.1.1.5. Statistical analysis and trial exclusion

All trials in which the movement did not match the instructions (e.g., avoiding when instructed to approach; 5.1% of trials), and with RTs below 100 ms or exceeding 2000 ms (1.5%) were excluded from the analyses. Outlier RTs (0.9%) were calculated per block for each subject using a Grubb's test, $\alpha = 0.05$. In total, 7.6% of trials were excluded.

A 2x2 within-subjects repeated measures ANOVA (RM-ANOVA) with factors *Valence* (positive vs. negative) and *Movement type* (approach vs. avoid) was conducted separately for RTs, SSRTs and the posterior distribution μ, σ and τ parameters. All statistical analyses were calculated using the statistical package SPSS (v. 22).

Because each picture has a valence and arousal, and both may influence the speed of action initiation differently, a multiple linear regression was conducted on the RTs to assess the influence of different variables. The RTs for each condition (e.g. approach positive) were taken separately and were used as the dependent variable (i.e. the measure that will be affected by other factors). The independent variables *valence* and *arousal* (i.e. the measures that might influence RT) were then regressed against the RTs obtained for each condition. The multiple regression yielded beta coefficients that indicated the direction (e.g. negative or positive) and strength of the relationship of each variable to the RTs. If an independent variable has a significant impact on the RT then the beta value should be significantly different from 0. The regression yielded betas for four conditions: the influence of *valence* and *arousal* when participants approached positive, avoided negative, approached negative and avoided positive pictures. These betas were then used to compute a 3-way RM-ANOVA with factors *Picture Valence* (negative vs. positive), *Movement type* (approach vs. avoidance) and *Variable type* (valence vs. arousal).

For all analyses, partial-η^2 is reported as a measure of effect size. Statistical threshold was fixed at 0.05. Significant interactions were followed up using two-tailed paired-sample t-tests. For paired-samples t-tests Cohen's *d* is reported. RT and SSRT means and standard error of the mean (SEM) are shown and reported in milliseconds.

5.2.2. Results

5.2.2.1. *Individual picture ratings*

Subjects rated the valence and arousal of all negative and positive pictures. For negative pictures, participants rated negative pictures as being more negative than the IAPS ratings (individual: 2.42 ± 0.19, IAPS: 3.00 ± 0.00; $t_{(18)} = 3.01$, $p = 0.007$). However, individual positive ratings did not differ from the IAPS ratings (individual: 6.79 ± 0.20, IAPS: 7.00 ± 0.00, n.s.).

With respect to arousal, participants did not rate the arousal of negative pictures as being different from the IAPS ratings (individual: 5.26 ± 0.40, IAPS: 6.00 ± 0.00; *n.s.*). In contrast, participants rated the arousal of positive pictures as being less arousing than the IAPS ratings (individual: 3.37 ± 0.32, IAPS: 5.00 ± 0.00; $t_{(18)} = 5.00$, $p < 0.001$).

Overall, the results suggest that participants perceived pictures as being their correct valence, and identified the correct level of arousal for each picture. For this reason, analysis was carried out using the IAPS ratings only.

5.2.2.2. *Hierarchical analysis using BEESTS*

The results for the group-level analysis using all subjects are displayed below. All results were obtained using BEESTS.

5.2.2.2.1. Speed of action initiation: Reaction Times

To determine whether positive and negative pictures influenced the speed of initiation of approach-avoidance actions, an interaction between *valence* and *movement type* was expected. Indeed, results showed that valence impacted on the initiation of approach and avoidance (**Figure 5.5A**; *Valence*Movement type*, $F_{(1,18)} = 17.04$, $p = 0.001$, $\eta^2_p = 0.49$). Subjects were faster to approach than avoid positive pictures (app: 578 ± 16 ms, avoid: 630 ± 16 ms; $t_{(18)} = -6.81$, $p < 0.001$, Cohen's d = -1.57). There was no difference in approaching or avoiding negative pictures (app: 601 ± 19 ms, avoid: 609 ± 19 ms; n.s). Approach was also faster for positive compared to negative pictures ($t_{(18)} = 2.46$, $p = 0.024$), and avoidance was faster for negative compared to positive pictures ($t_{(18)} = -2.75$, $p = 0.013$). There was also a main effect of *Movement type* ($F_{(1, 18)} = 30.82$, $p < 0.001$, $\eta^2_p = 0.63$), with participants being faster at initiating approach (590 ± 17 ms) compared to avoidance (619 ± 17 ms) movements ($t_{(18)} = -5.55$, $p < 0.001$, Cohen's d = -1.23). This result however, could not be attributed to one arm movement being easier than another due to the fact that the manikin appeared above and below, meaning that both approach and avoidance required pull and push movements. Overall, the results demonstrate an effect of approach-avoidance tendencies action selection and initiation.

5.2.2.2.2. Speed of action suppression: Stop-Signal Reaction Times

If valence affects the speed of inhibition of approach-avoidance actions, an interaction between *valence* and *movement type* should be observed. However, this was not the case, as there was no difference in inhibiting avoidance or approach movements when presented with emotional pictures (**Figure 5.5B**; *Valence*Movement type*, *n.s*). Participants were numerically faster at inhibiting avoidance (206 ± 15 ms) compared to approach (220 ± 15 ms) irrespective of the valence. However, follow-up paired samples t-tests did not reveal a significant difference between inhibition of approach and avoidance ($t_{(18)} = 1.29$, n.s). At first glance, the speed of response inhibition was not influenced by valence-related approach-avoidance tendencies.

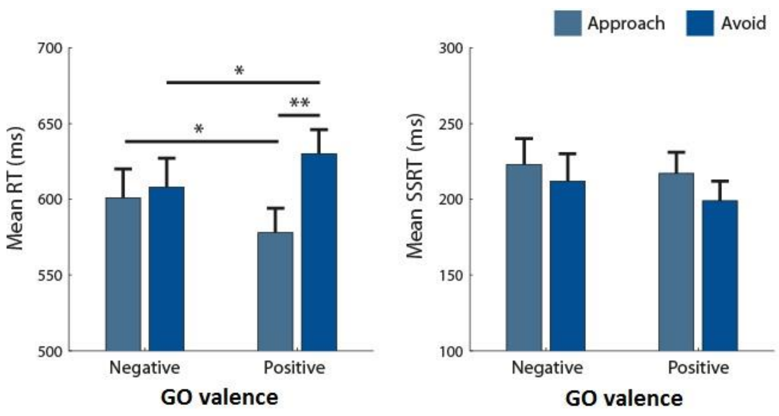


Figure 5.5. Speed of action initiation and inhibition. A) Mean RTs showing that approach was faster for positive compared to negative pictures, and avoidance was faster for negative compared to positive pictures. **B)** SSRTs showing the speed of inhibition when approaching and avoiding positive and negative pictures. There was no effect of valence on inhibition. Error bars (+1 S.E.M.); ** significant at $p < 0.001$ level, * significant at $p < 0.05$ level.

5.2.2.2.3. The certainty of parameter estimation: prior and posterior distributions, R statistic and goodness-of-fit

The advantage of BEESTS is that it uses the RT and SSRT distributions to better quantify the effects on the initiation and suppression of actions. BEESTS yielded parameters for μ (the mean of the RT and SSRT distributions), σ (the spread) and τ (the skew). The certainty that these parameters are accurate is given by the prior and posterior distributions. **Figure 5.6A** shows the posterior and prior distributions (top panel) for the group analysis for the condition where participants had to approach positive pictures. As mentioned above, the posterior distribution is a measure of how uncertain the parameters yielded are. In **Figure 5.6A**, the prior distributions (black dotted lines) are adequately updated and the posteriors (black solid lines) are narrower than the priors, indicating less degree of uncertainty in the parameters. **Figure 5.6B** shows the MCMC chains for this particular condition converged adequately, and this was verified by the fact that the Gelman-Rubin R convergence diagnostic values were all lower than 1. All subjects had an R value lower than 1.1 for all conditions. Overall, in this particular example, one can be confident in the parameters μ, σ, and τ obtained by the analysis.

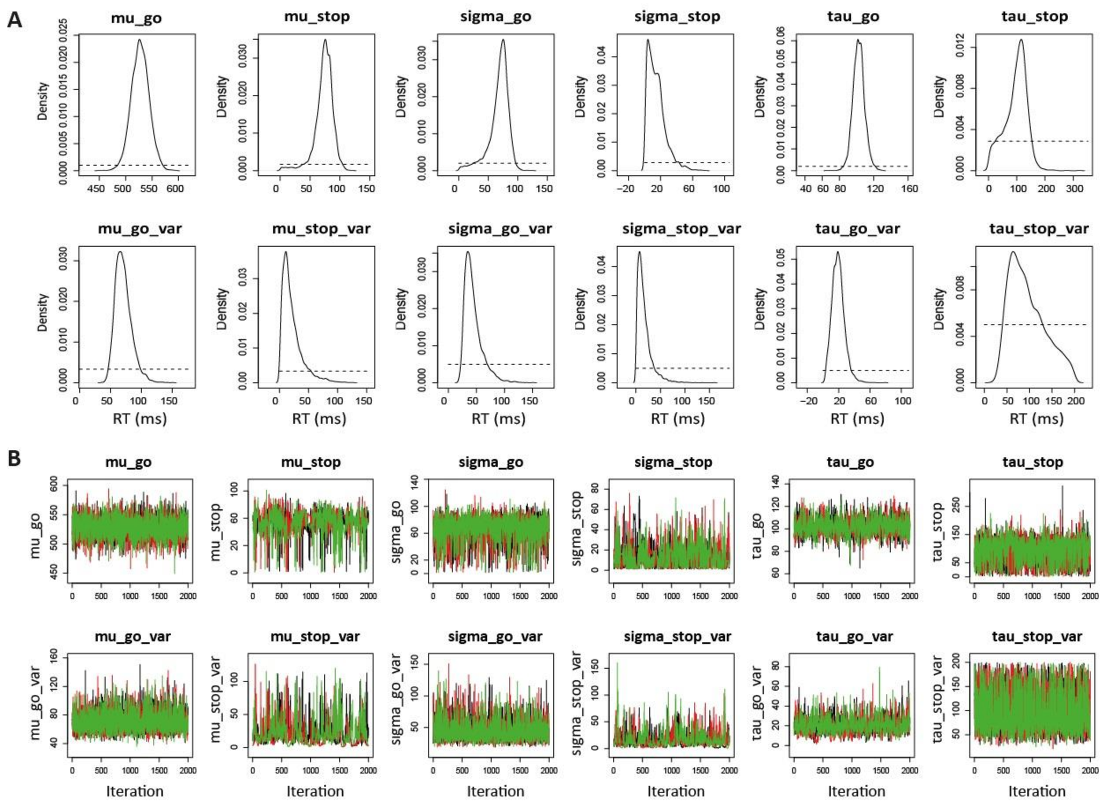


Figure 5.6. A) Posterior and prior distributions for the hierarchical group analysis when approaching positive pictures. The prior distributions (black dotted lines) are adequately updated and the posteriors (black solid lines) are unimodal for both the group-level mean (upper panel) and group-level variability (lower panel). **B) MCMC chains when approaching positive pictures.** All three chains converged adequately for parameters mu, sigma and tau in the GO and STOP conditions both the group-level mean (upper panel) and group-level variability (lower panel). Black, green and red reflect the results for each individual chain.

Figure 5.7 is a comparison of the posterior predictive model checks for individual **(Figure 5.7A)** and hierarchical BPA **(Figure 5.7B)** for Participant 1. I present both model checks for the sake of demonstrating how similar the individual and hierarchical analyses were and to show that group-level analyses did not significantly distort the results for each individual. This comparison also gives an idea of the goodness-of-fit. For the selected stop-signal delays (SSDs), the observed median signal-respond RTs (i.e. black triangles) are within the 2.5th and 97.5th percentile of the predicted median signal-respond RTs, and are approximated by the median of the predicted median signal-respond RTs (i.e. white circles). This indicates that both the individual and hierarchical BEESTS appropriately accounted for the observed data, adding to the certainty of the observed parameters.

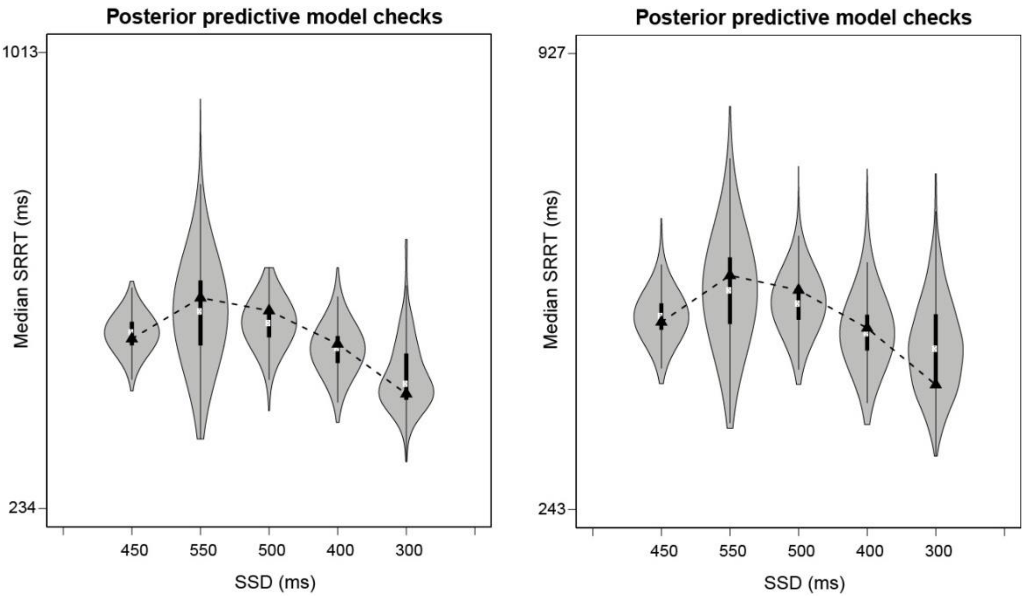


Figure 5.7. Posterior predictive model checks for A) individual and B) hierarchical BPA for participant 1. These checks give an idea of goodness-of-fit. For each SSD, the figures show the observed median signal-respond RTs (black triangles), the predicted median signal-respond RTs (white circles in the grey violin plot), and a boxplot from the 25th to 75th percentile of the predicted median signal-respond RT. Both the individual and hierarchical BEESTS approximately accounted for the observed data.

5.2.2.2.4. Parameters of the RT and SSRT distributions: μ, σ, and τ

Speed of action initiation: μ-Go (mean of the RT distribution)

μ represents the mean of the distribution. Similar to the mean RT results above, there was an effect of valence on approach-avoidance actions (**Figure 8A**; *Valence***Movement type*, $F_{(1,\ 18)} = 5.60$, $p = 0.029$, $\eta^2_p = 0.24$). Subjects were faster to approach than avoid positive pictures (app: 484 ± 14 ms, avoid: 528 ± 15 ms; $t_{(18)} = -5.60$, $p < 0.001$, Cohen's d = -1.31). However, participants were also faster to approach than avoid negative pictures (app: 496 ± 17 ms, avoid: 515 ± 18 ms; $t_{(18)} = -2.57$, $p = 0.019$, Cohen's d = -0.59). There was no difference in the initiation of approach for positive and negative stimuli, and the initiation of avoidance for negative and positive stimuli. There was also a main effect of *Movement type* ($F_{(1,\ 18)} = 28.54$, $p < 0.001$, $\eta^2_p = 0.61$), with participants being faster at initiating approach (490 ± 15 ms) compared to avoidance (522 ± 16 ms) movements ($t_{(18)} = -5.37$, $p < 0.001$, Cohen's d = -1.09).

Variability of action initiation: σ-Go (spread of the RT distributions)

The valence of the picture and the type of movement made (approach vs. avoid) did not significantly affect the variance of the RT distributions.

Direction of action initiation: τ-Go (skew of the RT distribution)

When looking at the skew of the distribution for RTs, there was a 2-way interaction between *Valence* and *Movement type* ($F_{(1,\ 18)} = 8.22$, $p = 0.01$, $\eta^2_p = 0.31$), indicating that valence affected the tail-end of the distribution depending on the type of movement made. For negative pictures, the tail-end distribution was significantly smaller (or shorter) for avoidance than approach (app: 106 ± 4 ms, avoid: 93 ± 4 ms; $t_{(18)} = 3.38$, $p = 0.003$, Cohen's d = 0.79), indicating that avoidance had less of a positive skew in comparison to approach, and suggesting a more compact distribution when making avoidance movements. For positive pictures the opposite trend was observed but this was not significant (app: 94 ± 5 ms, avoid: 103 ± 3 ms; $t_{(18)} = -1.65$, *n.s*).

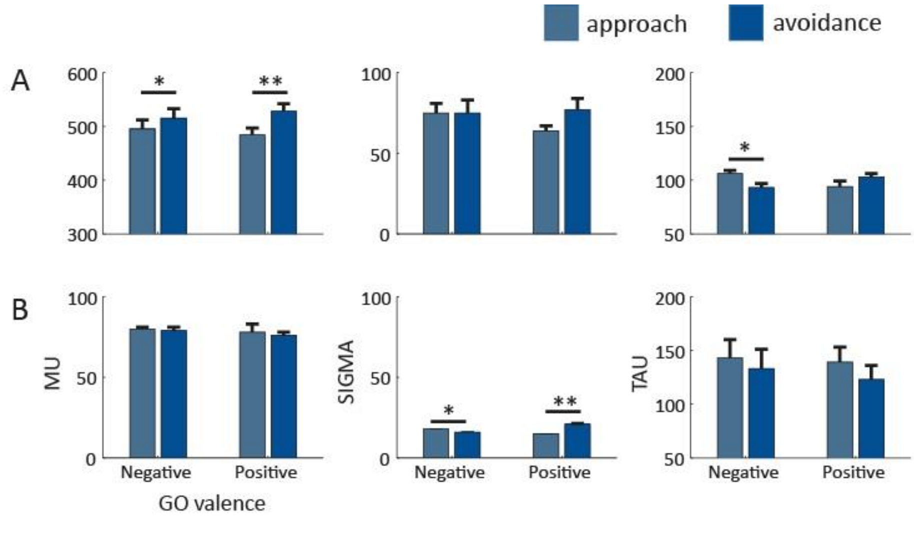


Figure 5.8. Mu, sigma and tau parameters for A) GO and B) STOP conditions. **A)** Results for GO-MU display a similar RT pattern to the RT results shown above, with subjects being faster at approaching than avoiding positive and negative pictures. There were no differences for SIGMA-GO. **B)** Results for STOP-MU confirm that there were no differences in inhibition of approach and avoidance movements when presented with positive or negative pictures. STOP-SIGMA shows that the variability of SSRTs was affected by *valence* and *movement type.* Error bars (+1 S.E.M.); ** significant at p < 0.001 level, * significant at p < 0.05 level.

In sum, the RT distributions reveal an effect of approach-avoidance tendencies on the shape of the distribution but not on the speed and consistency of initiation.

Speed of action suppression: μ-Stop (mean of the SSRT distribution)

There was no difference in the speed of inhibiting avoidance or approach movements when presented with negative or positive pictures (**Figure 5.8B**; *Valence***Movement type*, *n.s*). No main effects were significant, corroborating the SSRT results above.

Variability of action suppression: σ-Stop (spread of the SSRT distribution)

There was an effect of *Valence* and *Movement type* on the variance of the SSRT distributions (*Valence*Movement type,* $F_{(1, 18)} = 315.02$, $p < 0.001$, $\eta^2_p = 0.95$). Thus, although the SSRT distributions had similar means across all conditions, the spread of such distributions was different, demonstrating that the consistency of stopping was affected by emotional stimuli and their associated response tendencies. For negative pictures, there was less variability when inhibiting avoidance compared to approach (app: 18 ± 0.15 ms, avoid: 17 ± 0.31 ms; $t_{(18)} = 3.64$, $p = 0.002$, Cohen's d = 0.78), whereas for positive pictures there was less variability when inhibiting approach compared to avoidance (app: 15 ± 0.13 ms, avoid: 21 ± 0.38 ms; $t_{(18)} = -16.02$, $p < 0.001$, Cohen's d = -4.13). There was a main effect of *Valence* ($F_{(1, 18)} = 52.17$, $p < 0.001$, $\eta^2_p = 0.74$), with less variability in inhibiting movements to negative compared to positive pictures (neg: 17 ± 0.19 ms, pos: 18 ± 0.21 ms; $t_{(18)} = -7.22$, $p < 0.001$, Cohen's d = -1.55). There was also a main effect of *Movement type* ($F_{(1, 18)} = 76.34$, $p < 0.001$, $\eta^2_p = 0.81$), showing less variability when inhibiting approach versus avoidance movements (app: 16 ± 0.11 ms, avoid: 19 ± 0.31 ms; $t_{(18)} = -8.74$, $p < 0.001$, Cohen's d = -2.93). Thus, both the valence and the type of movement made influenced the variability of inhibition.

Direction of action suppression: τ-Stop (skewness of the SSRT distribution)

Valence and movement type did not significantly affect the tail-end of the SSRT distributions.

To sum up, the consistency, but not the speed, of stopping was affected by approach-avoidance tendencies. Stopping was more consistent when approaching positive and avoiding negative pictures, demonstrating some sort of automaticity that leaked into movement initiation. Furthermore, it demonstrates a dissociation between the effects of approach-avoidance on response suppression: movement planning was influenced by approach-avoidance tendencies but action selection was not.

5.2.2.2.5. Validating BEESTS: SSRTs calculated using the mean method analysis

SSRT results were validated using the mean method. Results did not show an influence of valence on inhibition of approach-avoidance actions, nor did they suggest any main effects of valence or the type of movement made. These results therefore confirm the SSRT results obtained via the BEEST method.

5.2.2.2.6. Regression analyses

Regression analyses assessed whether valence and arousal impacted the RTs. Multiple regression yielded beta coefficients representative of the strength and direction of the influence of each variable on RTs. A 3-way RM-ANOVA with factors *Picture Valence* (positive vs. negative)*, Movement type* (approach vs. avoidance) and *Variable type* (valence vs. arousal) was subsequently conducted using these beta coefficients to observe the impact of valence and arousal on RTs for approaching and avoiding positive and negative pictures. The results revealed an interaction between *Valence* and *Variable type* (**Figure 5.9**; $F_{(1,18)} = 20.15$, $p < 0.001$, $\eta^2_p = 0.52$). As negative pictures become less negative, RTs increase, and as the arousal of the negative pictures increase the RTs decrease, although these trends were not significantly different from zero (valence betas: 0.75 ± 3.37, arousal betas: -4.27 ± 2.23). As positive pictures become more positive, RTs decrease and as the arousal of positive pictures increases, RTs increase, and these trends were significantly different from zero (valence betas: -7.65 ± 1.93, $t_{(18)} = 3.95$, $p = 0.001$, Cohen's d = -1.52; arousal betas: 6.65 ± 1.42, $t_{(18)} = -4.68$, $p < 0.001$, Cohen's d = 1.88). Despite there being only a trend for negative pictures, the positivity or negativity of the emotional pictures and their associated arousal appeared to impact on the speed of action initiation, suggesting that the automaticity of emotional tendencies may be dependent on how positive and negative the stimuli are.

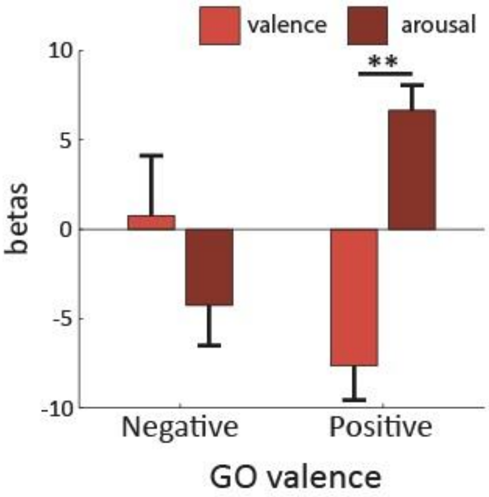


Figure 5.9. Regression showing the effect of valence and arousal on the speed of approaching and avoiding positive and negative pictures. As negative pictures become less negative, RTs increase, and as the arousal of negative pictures increase, RTs decrease. As positive pictures become more positive, RTs decrease, and as the arousal for positive pictures increases, RTs increase. Error bars (+1 S.E.M.); ** significant at $p < 0.001$ level.

5.2.3. Discussion

Experiment 1 investigated whether positive and negative go-signals bias the preparation of approach and avoidance “go” processes and if this influences the speed of inhibition. I expected that inhibiting approach-avoidance tendencies would be more difficult because they are prepared faster. The results demonstrate that the speed of initiation was influenced by approach-avoidance tendencies, confirming the influence of such tendencies on action selection. In contrast, the speed of response inhibition was not affected by approach-avoidance tendencies and the preparation of “go” processes. However, the consistency of stopping was, indicating a possible influence of such tendencies on preparation processes involved in response inhibition.

Selection and initiation of approach-avoidance actions is affected by the valence of emotional pictures

The results replicate previous findings: participants were faster to initiate approach than avoidance when presented with positive pictures (Chen & Bargh, 1999; Chapter Two, Three and Four), but there was no difference in approaching or avoiding negative pictures

(Chapter Two and Three). However, participants were faster to approach when presented with a positive compared to negative picture, and faster to avoid negative compared to positive pictures, demonstrating an approach-avoidance effect. Regression analyses confirmed that the speed of initiation of approach-avoidance actions is only influenced by the valence and not the arousal of the emotional pictures. This finding confirms that approach-avoidance tendencies influence the selection and initiation of actions, as has been demonstrated in Chapters Two, Three and Four of this thesis.

Approach-avoidance tendencies influence the consistency but not the latency of stopping

The effect on the speed of initiation of approach-avoidance actions demonstrates that valence influenced the speed of preparation of “go” processes. Based on my predictions, this effect should have biased the resolution of competing “go” and “stop” processes influencing the speed of inhibition. However, this was not the case. Albeit non-significant, results showed the expected trend for faster inhibition of avoidance responses when preceded by positive pictures. This follows the clear RT result for positive pictures which showed faster initiation (and therefore preparation) of approach compared to avoidance. Previous work has proposed that it is more difficult to inhibit “go” responses within positive contexts (Albert et al., 2010, Chiu et al., 2014). Here ”go” responses could be seen as an “approach” response. The current results support previous work by showing that inhibiting a prepared approach response to positive pictures is more difficult than inhibiting avoidance, presumably due to differences in the speed of preparation of each. Speculatively, approach tendencies to positive stimuli may have a possible influence on the selection and inhibition of actions.

In contrast, the effect of negative pictures on the speed of inhibition was less clear and this may be because there was no difference in the initiating avoidance or approach when negative pictures were presented. This result corroborates that of Chapter Two, which showed no difference in the selection of approach-avoidance actions, possibly as a result of conflicting “fight-or-flight” responses. If inhibition reflects the state of action preparation, and RTs demonstrate that there is apparently no difference in the preparation of these two actions, then there should be no impact on inhibition. Indeed, this was the case, demonstrating no effect of negative stimuli on the speed of action selection or inhibition. If “go” preparatory processes had been engaged, however, it may have influenced inhibition. Furthermore, the analysis revealed that the distributions of RTs when negative pictures were presented were skewed such that they may have compromised the calculation of the SSRTs (Verbruggen et al., 2013), suggesting that these results should be taken with caution.

Despite the lack of a clear effect on the latency of inhibition, there was an effect on the consistency of the speed of inhibition. The distribution of SSRT responses revealed an influence of the “go” valence on the variability of inhibitory responses, with less variability at inhibiting avoidance when presented with negative pictures and less variability inhibiting approach for positive pictures. Thus, although the mean value of the SSRTs may not have been affected by approach-avoidance tendencies, the consistency of the speed of stopping was. This effect suggests that response inhibition is indeed affected by approach-avoidance tendencies but this is manifested in the consistency and not the latency of stopping. The consistency of behaviour is a measure of motor planning and uncertainty (Coombes et al., 2007; Shadmehr & Krakauer, 2008). In this case, motor planning occurred relative to the “go” process, which was biased by the certainty of the outcome of predisposed actions. Speculatively, less variability at inhibiting approach-avoidance tendencies suggests a bias of the consistency of the “go” preparatory process on inhibitory processes. Valence-related approach-avoidance tendencies therefore influence the variability but not the latency of inhibitory responses, suggesting an influence of “go” preparatory processes on the resolution of competing “go” and “stop” processes.

Subjects were also more consistent at inhibiting their responses to negative pictures compared to positive pictures, suggesting a possible predisposition for immobility in negative contexts (LeDoux, 1995). This may be guided by two possible mechanisms. Firstly, negative stimuli may have triggered “freezing-like” responses, in accordance with previous work (Facchinetti et al., 2006; Roelofs et al. 2010; Stins et al., 2013). Freezing, or slower response initiation, may have evolved to avoid potentially costly actions in threatening situations (LeDoux, 1996). Immobility in negative contexts therefore leads to less costly outcomes. Accordingly, environmental uncertainty is less in negative contexts and inhibition is easier. Secondly, threatening information may have increased perceptual processing and increased attentional resources, devoting them to improving the consistency of inhibition in negative contexts (Pessoa et al., 2002). However, the effect on variability is not supported by effects on latency, and therefore these suggestions are purely speculative.

It may be possible that the null result on inhibition was due to the experiment lacking the adequate power. To account for this, a post-hoc power analysis was conducted (GPower 3.1). Using the partial effect sizes derived from SPSS on the 19 subjects tested, a sample size needed for a power of 0.8 was calculated. This power analysis suggested a sample size of 70 subjects would be necessary to yield statistically meaningful results for SSRTs. The same calculation suggested that only a sample of 6 subjects was necessary to obtain meaningful approach-avoidance RTs. Thus, it is clear that insufficient subjects were test but due to time constraints further testing was not possible.

Despite this, the results indicate that the state of preparation of “go” processes may determine the speed and consistency of inhibition of approach-avoidance responses. Speculatively, approach tendencies appear to bias the competition between “go” and “stop” processes towards “go”, possibly as a result of “go” preparation of predisposed tendencies being faster. To my knowledge, this is the first demonstration that “go” preparatory processes may be under the influence of predisposed biases. Improved power may help solidify the above speculation.

Can approach-avoidance tendencies bias response inhibition by influencing the preparation of “stop” processes?

In contrast to Experiment 1, Experiment 2 tested the hypothesis that emotional stop-signals and their related approach-avoidance tendencies would bias the preparation of the “stop” process. Abstract go-signals linked to approach-avoidance responses were presented. These go-signals therefore still triggered the preparation of approach-avoidance “go” processes but preparation was expected to be equal for approaching and avoiding. Positive, negative and neutral stimuli served as the stop-signals. Emotional pictures were therefore expected to influence the preparation of “stop” processes. “Stop” preparatory processes were expected to be slower for approach-avoidance tendencies. Neutral pictures were included as a control condition.

5.3. Experiment 2

5.3.1. Method

5.3.1.1. Participants

26 healthy volunteers (mean age = 26.4 years [± 5.6 S.D.]; 15 female) were recruited as in Experiment 1. Two subjects were excluded from the data analysis for having a total number of errors two S.D. above the mean. Data analysis was therefore conducted on data from 24 subjects only.

5.3.1.2. Stimuli and apparatus

120 pictures were selected from the same database as in Experiment 1: 40 negative pictures, 40 neutral pictures (e.g. plates, chairs) with valences 4.5-5.5, and 40 positive pictures. The assignment of pictures in each of the 6 blocks and order of picture presentation was randomised for each subject. Block order was counterbalanced across participants to avoid all subjects starting with the same stop-signal valence. This was important because participants do improve their stopping abilities throughout the experiment. Each block comprised of 120 trials (40 positive/negative/neutral) and each picture was repeated six times throughout the experiment.

There were six experimental conditions: approach movement, stop negative; approach movement, stop positive; approach movement, stop neutral; avoidance movement, stop negative; avoidance movement, stop positive; avoidance movement, stop neutral. In blocks where the stop-signal was a negative picture, the go-signals were positive and neutral pictures. In blocks where the stop signal was a positive picture, the go-signals were neutral and negative pictures. In blocks where the stop signal was a neutral picture, the go-signals were negative and positive pictures. In total there were 40 repetitions for each experimental condition.

All stimuli were presented using the same apparatus used in Experiment 1. For simplicity, in contrast to Experiment 1, the manikin was only presented on the bottom half of the screen. This was not expected to impact performance. A small black rectangle with yellow border (103x35 pixels) represented the “away” target where participants moved to when avoiding and was presented on the bottom half of the screen. A grey circle and square (134 x 134 pixels) were used as stimuli to approach and avoid. Each shape was created using Microsoft Paint.

5.3.1.3. *Experimental task*

The experimental procedure was similar to that of Experiment 1. Only differences will be described. Participants were instructed to move the manikin towards or away from the circle or square as fast as possible, according to the instructions at the beginning of each block. To avoid confounds of a shape being easier to approach or avoid, half the participants were instructed to move the manikin towards circles and away from squares in all blocks, and vice versa for the remaining half. They were told that in all trials, an emotional picture would appear shortly after the appearance of the shape. According to the instructions at the beginning of each block, participants were instructed to inhibit their response when a picture of a specific valence appeared (e.g. do not move when a negative picture is shown on the screen) but to respond when a picture of another valence appeared. Thus, participants were required to evaluate the valence of the picture presented shortly after the shape in order to know whether they were to move or not. All pictures were presented for 300 ms, after which the shape would be shown on the screen again. Therefore, the initial presentation of the shape prepared subjects for the type of movement they had to make (approach vs. avoid), and the valence of the picture acted as either the go or stop signal.

Figure 5.10 shows a trial sequence. Trials started with a central fixation cross (500 ms), followed by the simultaneous appearance of the fixation cross and manikin on the screen (jittered, mean 500 ± 100 ms). A grey shape replaced the fixation cross, and remained on the screen until the appearance of an emotional picture. In go trials, the appearance of the picture on the screen was jittered (with a mean of 300 ± 200 ms) and was presented for 300 ms. The jitter essentially prevented participants from guessing when the picture would appear but also to match the fact that the stop-signal was displayed at different latencies due to changing SSD. In stop trials, the appearance of the stop-signal picture was determined by the SSD derived from a staircase procedure. SSD was fixed at 300 ms at the beginning of the experiment and was adjusted dynamically throughout the whole experiment. If participants successfully inhibited their response the SSD would increase by 50 ms. If inhibition was unsuccessful, the SSD decreased by 50 ms. The SSD varied independently for each of the six experimental conditions. The picture was then replaced by the grey shape once again until the end of the trial (1500 ms). Like in Experiment 1, reaction time feedback was provided at the end of each block to discourage strategic slowing.

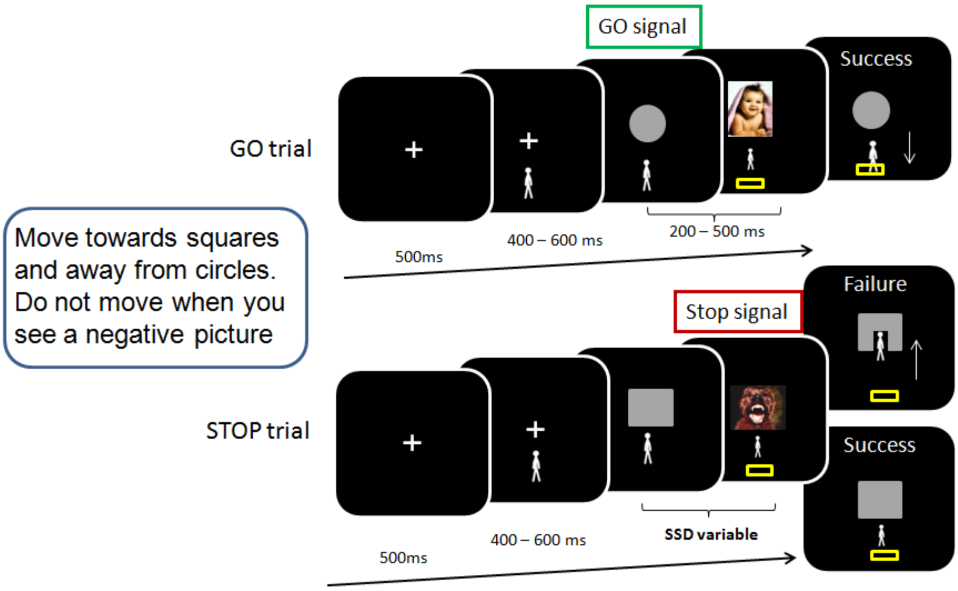


Figure 5.10. Experiment 2 task schematic. Participants were instructed to move the manikin towards squares and away from circles (go-signal). After a certain delay, an emotional picture (positive, negative or neutral) appeared (for a duration of 300 ms). In go trials this delay was jittered around a mean of 500 ms. In stop trials, this delay corresponded to the stop signal delay (SSD), which varied as a function of the previous stop trial. After the emotional picture disappeared, the original shape, either a circle or a square, reappeared on the screen and participants made or inhibited their movement. Thus, each trial was divided into three phases: a preparation phase in which participants were informed of the type of movement they had to make (approach or avoid), a go/stop phase in which participants were informed whether they had to execute or inhibit the movement, and an execution/inhibition phase in which participants either initiated movement or inhibited their movement until the next trial started. Participants received feedback when they made a wrong response (e.g. approach instead of avoid) and when inhibition was successful. Despite having a preparation phase, subjects were still instructed to move as fast as possible once the shape appeared on the screen.

Using this design, “go” preparatory processes to abstract shapes should have been the same. This was important because I did not want differences in “go” preparation to influence inhibition. Instead, inhibition should be influenced by biases of valence on “stop” processes.

Before the experiment, participants completed three short training blocks, one with each valence as the stop-signal, of 30 trials each (20 GO, 10 stop-trials) to familiarise participants with the task. After completion of the experimental session, participants rated the valence and arousal of all the pictures on a scale of 1 (i.e. very negative/very low arousal) to 9 (i.e. very positive/very high arousal).

5.3.1.4. *Data analyses and trial exclusion*

Data analyses were conducted like in Experiment 1. Only differences will be highlighted in this section. All trials in which the movement did not match the instructions (e.g., avoiding when instructed to approach; 4.2% of trials), with RTs below 100 ms (2.2%) or exceeding 2000 ms (5.3%) were excluded from the analyses. Outlier RTs (1.2%) were calculated per block for each subject using a Grubb’s test, α = 0.05. In total, 12.9% of trials were excluded.

RTs were analysed in two different ways. Firstly, the influence of the go-signal valence on approach-avoidance RTs irrespective of block type (e.g. stop-positive) was assessed to test for any influence of the go valence on action initiation (GO-RT). To calculate this, go valences were collapsed across blocks, that is, all RTs when the go-signal was positive, neutral or negative. GO-RT should essentially reflect incidental influences of approach-avoidance tendencies on action initiation. This is because task instructions did not explicitly ask participants to approach or avoid the emotional pictures, but rather the abstract shapes. Secondly, RTs within each block (e.g. stop-negative block, RTs for GO positive and GO neutral collapsed) for approach and avoidance irrespective of the valence of the GO picture were determined (block-RTs). The distribution of the collapsed block-RTs was used to calculate the SSRT distributions.

Like in Experiment 1, hierarchical analyses were conducted on the entire data set. Due to the complexity of the task, some subjects were deliberately slow in their responses in order to maximise their chances of successful inhibition and therefore had very high RTs

(> 1000 ms). Previous work has demonstrated that strategic slowing down by subjects in anticipation of the stop-signal has an effect on the estimation of SSRTs (Verbruggen et al., 2013), and therefore this slowing down of responses by some of the subjects may have compromised the SSRT estimations of the hierarchical (group) analysis. To control for this, an overall RT mean was calculated collapsed for all conditions and across all subjects to serve as a baseline. Subjects that had RTs below that of the baseline mean (+1 SEM) were subsequently included in a further hierarchical analysis. With this approach, only 13 subjects were selected for further analyses.

A 3x2 within-subjects repeated measures ANOVA (RM-ANOVA) with factors *Valence* (positive vs. negative vs. neutral) and *Movement type* (approach vs. avoid) was conducted separately for GO-RTs, SSRTs and parameter estimates. For block-RTs only a 3x2 within-subjects RM-ANOVA was conducted with factors *Block type* (pos-stop vs. neg-stop vs. neu-stop) and *Movement type* (approach vs. avoid). For all analyses, where sphericity was violated, a Greenhouse-Geisser correction was applied. Statistical reporting was the same as in Experiment 1.

Regression analyses were conducted as in Experiment 1. Because each picture has an associated valence and arousal, and both may influence inhibition differently, a multiple regression was conducted on the RTs to assess the influence of different variables. This regression yielded beta coefficient values representing the strength and direction of the influence of each variable on the RTs. A 3-way RM-ANOVA with factors GO *valence* (negative vs. positive vs. neutral), *Movement type* (Approach vs. Avoidance) and *Variable type* (valence vs. arousal) was subsequently computed using these beta values.

As in Experiment 1, BEESTS results were validated using the mean method.

5.3.1.5. *Power analysis of sample size*

Like in Experiment 1, a power analysis was calculated. Using the effects sizes for the main effects in SSRTs and RTs, a sample size of ~30 participants was necessary to obtain significant results for main effects for SSRTs and RTs. However, for SSRTs, for the interaction between factors *Valence* (positive vs. negative. vs. neutral) and *Movement type* (approach vs. avoidance), a sample size of >100 participants was required. Due to time constraints, it was not possible to test 100 participants. Thus, only main effects were expected given the sample size.

5.3.2. Results

5.3.2.1. Individual picture ratings

Subjects rated the valence and arousal of all negative, neutral and positive pictures. For negative pictures, participants rated negative pictures as being more negative than the IAPS ratings (individual: 2.08 ± 0.10, IAPS: 3.00 ± 0.00; $t_{(23)} = 8.92$, $p < 0.001$). Participants also rated positive pictures as being more positive than the IAPS ratings (individual: 7.29 ± 0.17, IAPS: 7.00 ± 0.00; $t_{(23)} = 4.30$, $p < 0.001$). However, individual neutral ratings did not differ from the IAPS ratings (individual: 5.04 ± 0.07, IAPS: 5.00 ± 0.00, n.s.).

With respect to arousal, participants the arousal of negative pictures as being the same as the IAPS ratings (individual: 6.00 ± 0.32, IAPS: 6.00 ± 0.00; *n.s.*). Similarly, the arousal of positive pictures was the same as the IAPS ratings (individual: 4.21 ± 0.40, IAPS: 5.00 ± 0.00; *n.s*). In contrast, participants rated neutral pictures as being less arousing than the IAPS ratings (individual: 1.58 ± 0.19, IAPS: 3.00 ± 0.00; $t_{(18)} = 7.47$, $p < 0.001$).

The results suggest that participants perceived pictures as being their correct valence, and identified the correct level of arousal for each picture.

5.3.2.2. Hierarchical analysis using BEESTS

Group-level analyses on the data from all subjects are presented first and subsequently the results from analyses on a sub-group of 13 subjects. The second hierarchical analysis on the sub-group was conducted due to possible strategic slowing of response initiation.

5.3.2.2.1. Speed of action initiation: Reaction Times

To investigate influences of the valence of the go-signal on the initiation of approach and avoidance actions, RTs were collapsed across all blocks and sorted into each go valence (e.g. approach and avoidance RTs when the go-signal was positive, irrespective of block). An influence of the valence of the go-signal should manifest as an interaction between *valence* and *movement type*. Indeed, results showed an effect of valence on the initiation of approach-avoidance actions (**Figure 5.11**; *Valence*Movement type,* $F_{(2, 46)} = 3.68$, $p = 0.033$, $\eta^2_p = 0.14$). Follow-up paired t-tests revealed that this interaction was influenced by a numerical difference, albeit not significant, between avoidance and approach for negative go-signals, (app: 832 ± 23 ms, avoid: 816 ± 23 ms; $t_{(23)} = 1.78$, p = n.s). For positive and neutral pictures, there were no differences between initiating approach and avoidance. In general, there were no incidental influences of approach-avoidance tendencies on action initiation.

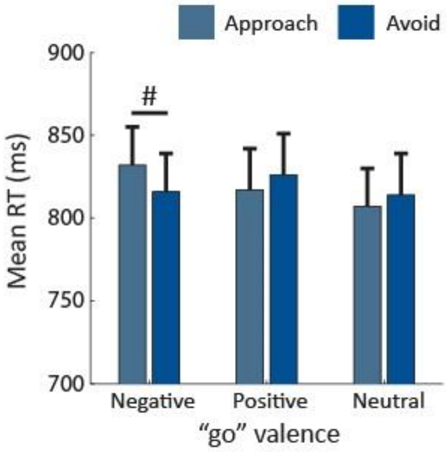


Figure 5.11. RTs as a function of the type of GO picture that was presented. In GO trials, when a negative picture was presented as a GO signal, participants were numerically faster at initiating avoidance compared to approach movements. There were no differences in approach or avoidance when positive or neutral GO signals were presented. Error bars (+1 S.E.M.); # depicts a numerical trend.

To assess whether the valence of the stop-signal (and therefore the type of block) had an influence on the speed of initiation of approach and avoidance, RTs were collapsed across valence but separated into blocks (e.g. approach RTs collapsed across neutral and negative go-signals when the stop-signal was positive). Results showed a main effect of the stop-valence of the block type (Fig 10; $F_{(2, 46)} = 5.01$, $p = 0.011$, $\eta^2_p = 0.18$). Subjects were faster to move in blocks where the stop signal was negative (and therefore the go-signals were positive and neutral), compared to blocks where the stop-signal was positive or neutral (stop-neg: 818 ± 25 ms, stop-pos: 836 ± 24 ms, stop-neu: 867 ± 28 ms; neg-pos difference: $t_{(23)}$ = -2.33, p = 0.029, Cohen's d = -0.48; neg-neutral difference: $t_{(23)}$ = -3.07, p = 0.005 Cohen's d = -0.62). Similarly, subjects were faster to move in blocks where the stop-signal was positive relative to that where the stop-signal was neutral but this was not significant.

In sum, there appeared to be no incidental effects of the valence of the go picture on the initiation of approach-avoidance actions. However, there was an incidental effect of valence, with slower initiation of actions, irrespective of whether an approach or avoidance was required, when positive and negative stimuli were the go-signals in comparison to neutral go-signals. Emotional stimuli therefore delayed action initiation compared to neutral stimuli.

5.3.2.2.2. Speed of action suppression: Stop-Signal Reaction Times

If positive and negative stop-signals influence the ability to stop ourselves from initiating approach-avoidance actions, then an interaction between *valence* and *movement type* should be observed. However, there was no difference in the speed of inhibiting avoidance or approach movements when presented with emotional pictures (*Valence***Movement type*, *n.s*). Despite the lack of a significant interaction, paired-samples t-tests revealed that inhibition of approach was significantly faster than avoidance for negative pictures (**Figure 5.12A**; app: 274 ± 41 ms, avoid: 365 ± 45 ms; $t_{(23)}$ = -2.96, p = 0.007, Cohen's d = -0.66). Inhibition of approach and avoidance for positive and neutral pictures did not differ from each other.

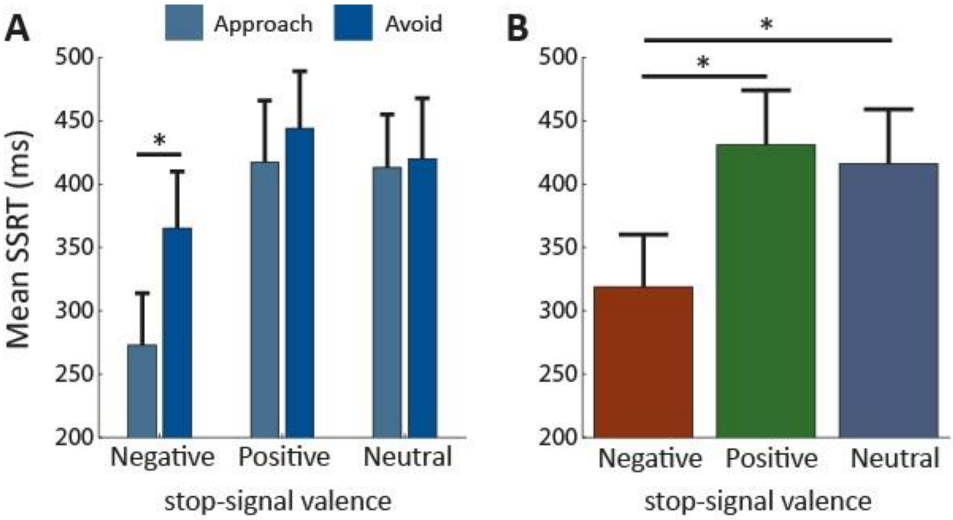


Figure 5.12. Speed of action suppression as shown by the mean SSRTs. A) When negative stop-signals were presented, approach was significantly faster to inhibit compared to avoidance. Differences were not observed for positive or neutral stop-signals. **B)** Movement inhibition was significantly faster when presented with negative stop pictures compared to positive and neutral pictures. There was no difference in movement inhibition between positive and neutral stop pictures. Error bars (+1 S.E.M.); * significant at p < 0.05 level.

There was a significant main effect of *Movement type* ($F_{(1, 23)}$ = 4.76, *p* = 0.04, η^2_p = 0.17) indicating that participants were faster at inhibiting approach compared to avoidance irrespective of the stop valence. Follow-up paired t-tests showed a significant difference between inhibition of approach and avoidance (app: 368 ± 37 ms, avoid: 409 ± 34 ms, $t_{(23)}$ = -2.18, p = 0.04, Cohen's d = -0.51). Results also showed a main effect of stop *Valence* (**Figure 5.12B**; $F_{(1, 23)}$ = 4.32, *p* = 0.019, η^2_p = 0.16), with faster inhibition for negative pictures compared to positive (neg: 319 ± 40 ms, pos: 431 ± 43 ms) and neutral (neu: 416 ± 42 ms). Follow-up paired t-tests confirmed that inhibition of negative pictures was significantly faster than positive ($t_{(23)}$ = -2.59, *p* = 0.016, Cohen's d = -0.46) and neutral ($t_{(23)}$ = -2.11, *p* = 0.046, Cohen's d = -0.33). There was no difference in inhibition of positive and neutral pictures.

5.3.2.2.3. The certainty of parameter estimation: prior and posterior distributions, R statistic and goodness-of-fit

Figure 5.13A shows the posterior and prior distributions for Participant 15 for the condition where they had to approach negative pictures. The prior distributions (black dotted lines) are adequately updated and the posteriors (black solid lines) are narrower than the priors indicating that we can be certain that the parameters obtained are adequate. **Figure 5.13B** shows the MCMC chains for this particular condition converged adequately, and this was verified by the fact that the Gelman-Rubin R convergence diagnostic values were all lower than 1. All subjects had an R value lower than 1.1 for all conditions. Overall, the example demonstrates a high degree of certainty in the accuracy of the parameters obtained.

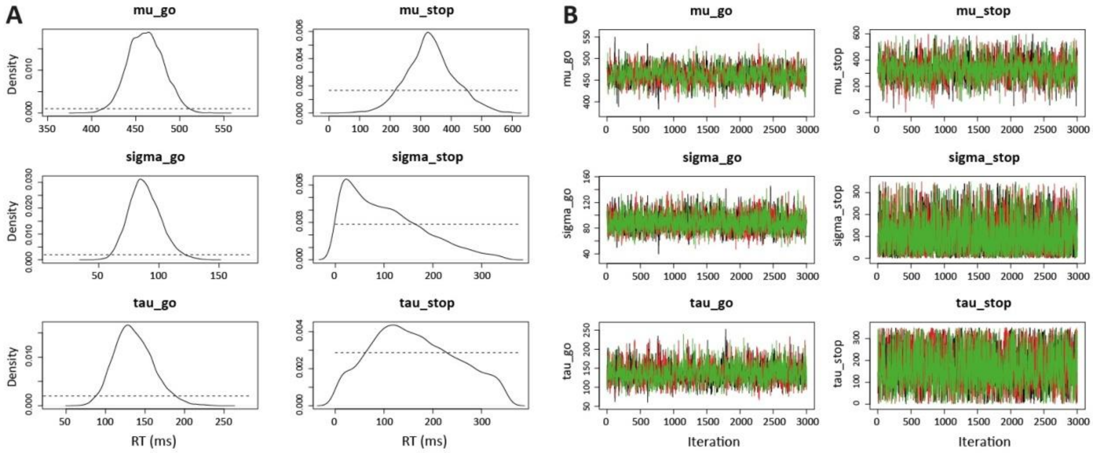


Figure 5.13. A) Posterior and prior distributions for participant 15 when approaching negative pictures. The prior distributions (black dotted lines) are adequately updated and the posteriors (black solid lines) are unimodal. **B)** MCMC chains when approaching negative pictures. All three chains converged adequately for all parameters in the GO and STOP conditions. Black, green and red reflect the results for each individual chain.

5.3.2.2.4. Parameters of the RT and SSRT distributions: μ, σ, and τ

Speed of action initiation: μ-Go (mean of the RT distribution)

Similar to the RT results above for *Block type*, the μ parameters also showed a main effect of the *valence* of the stop-signal in each block ($F_{(2, 46)} = 4.08$, $p = 0.026$, $\eta^2_p = 0.19$). Subjects were faster to move in blocks where the stop signal was negative (and therefore the go-signals were positive and neutral), compared to blocks where the stop-signal was positive or neutral (stop-neg: 639 ± 34 ms, stop-pos: 670 ± 31 ms, stop-neu: 699 ± 34 ms). Paired-samples t-tests revealed that negative stop-signal blocks were significantly faster than neutral stop-signal blocks; $t_{(23)} = -2.91$, $p = 0.008$, Cohen's d = -0.62). There were no other significant results.

Variability of action initiation: σ-Go (spread of the RT distributions)

The *Block type* also significantly affected the variance of the RT distributions ($F_{(2, 46)}$ = 4.01, p = 0.027, η^2_p = 0.19), with less variability in blocks with a negative stop-signal (due to go-positive and go-neutral pictures) compared to positive and neutral stop-signal blocks (stop-neg: 123 ± 12 ms, stop-pos: 137 ± 13 ms, stop-neu: 154 ± 13 ms). Paired-samples t-tests revealed that negative stop-signal blocks were significantly less variable than neutral stop-signal blocks; $t_{(23)}$ = -2.80, p = 0.011, Cohen's d = -0.59). There were no other significant results.

Direction of action initiation: τ-Go (skewness of the RT distribution)

Block type and *movement type* did not significantly affect the tail-end of the RT distributions.

The speed and variability of movement initiation was affected by the valence of the stop-signal, with faster and less variable movement initiation when negative stop-signals were presented (and positive and neutral go-signals were displayed), indicating an effect of threat on action initiation.

Speed of action suppression: μ-Stop (mean of the SSRT distribution)

Contrary to the SSRT data from above, there was a difference in the μ parameters for inhibiting avoidance or approach movements when presented with emotional stop pictures (*Valence***Movement type*, $F_{(2, 46)}$ = 4.46, p = 0.019, η^2_p = 0.21). Paired t-tests revealed that for negative pictures, inhibition of approach was faster than inhibition of avoidance (app: 161 ± 33 ms, avoid: 220 ± 38 ms, $t_{(23)}$ = -2.40, p = 0.027, Cohen's d = -0.57). For positive pictures, inhibition of approach was also faster than avoidance (app: 222 ± 44 ms, avoid: 299 ± 40 ms, $t_{(23)}$ = -2.40, p = 0.028, Cohen's d = -0.57). Neutral stop-signals did not influence the speed of inhibition of approach-avoidance actions (app: 266 ± 34 ms, avoid: 230 ± 38 ms, $t_{(23)}$ = -1.69, n.s). Inhibition of approach was faster for emotional stop-signals, relative to neutral.

There was also a significant main effect of *Movement type* ($F_{(2, 46)}$ = 5.52, *p* = 0.031, η^2_p = 0.26) indicating that participants were faster at inhibiting approach compared to avoidance irrespective of the valence. Follow-up paired t-tests showed a significant difference between inhibition of approach and avoidance (app: 204 ± 28 ms, avoid: 234 ± 32 ms, $t_{(23)}$ = -2.16, p = 0.043, Cohen's d = -0.47). Contrary to the SSRT data from above, there was no main effect of *valence*.

Variability of action suppression: σ-Stop (spread of the SSRT distribution)

Variability of inhibiting approach-avoidance movements was differentially affected by emotional pictures (*Valence***Movement type*, $F_{(2, 46)}$ = 6.60, *p* = 0.004, η^2_p = 0.28). Follow-up paired-samples t-tests revealed that for negative pictures, variability of inhibition of avoidance was less than inhibition of approach (app: 246 ± 15 ms, avoid: 212 ± 18 ms, $t_{(23)}$ = 2.06, p = 0.05, Cohen's d = 0.49). For positive pictures, variability of inhibition for avoidance was less than for approach (app: 236 ± 13 ms, avoid: 179 ± 22 ms, $t_{(23)}$ = 3.07, p = 0.007, Cohen's d = 0.81). There was no effect of neutral pictures on the variability of inhibition of approach-avoidance actions.

There was also a significant main effect of *Movement type* ($F_{(2, 46)}$ = 5.16, *p* = 0.036, η^2_p = 0.23) indicating that the variability of inhibiting avoidance movements was less than inhibiting approach movements, irrespective of the valence. Follow-up paired-samples t-tests showed this difference was not significant (app: 224 ± 10 ms, avoid: 213 ± 15 ms, $t_{(23)}$ = 1.03, n.s).

Direction of action suppression: τ-Stop (skewness of the SSRT distribution)

Valence and *movement type* did not significantly affect the tail-end of the SSRT distributions.

Overall, the speed and variability of stopping was influenced by the valence of the stop-signal. Stopping approach was faster but more variable than stopping avoidance for positive and negative stop-signals. Crucially, there was no effect of neutral pictures on the speed or variability of approach-avoidance inhibition, suggesting that emotional valence does influence response inhibition.

5.3.2.3. Controlling for strategic slowing: hierarchical analysis on a subset of 13 participants using BEESTS

Data was re-analysed on a subset of participants to control for strategic slowing. Overall, the results did not change significantly with the exclusion of participants with high RTs, adding confidence to the whole group analysis.

5.3.2.3.1. Speed of action initiation: Reaction Times

Contrary to the whole group analysis showing an effect of the valence of the GO picture on the RTs, analysis on a subset of subjects indicated that there was no such influence. Results for the influence of the GO valence on RTs irrespective of *block type* did not show any significant differences.

Results for RTs for approaching and avoiding irrespective of the type of valence presented showed a main effect of the stop valence of the block ($F_{(2, 24)} = 5.47$, $p = 0.011$, $\eta^2_p = 0.31$). Subjects were faster to move in blocks where the stop-signal was negative (and therefore the go pictures were positive and neutral), compared to when the stop-signal was positive or neutral (stop-neg: 723 ± 21 ms, stop-pos: 751 ± 25 ms, stop-neu: 778 ± 34 ms; neg-pos: $t_{(12)} = -2.13$, $p = 0.055$, Cohen's d = -0.61; neg-neu: $t_{(12)} = -2.76$, $p = 0.018$, Cohen's d = -0.95). Similarly, subjects were faster to move in blocks where the stop-signal was positive relative to when it neutral but this was not significant. There was also a main effect of *Movement type*, $F_{(1, 12)} = 6.45$, $p = 0.026$, $\eta^2_p = 0.35$), with faster RTs for avoidance compared to approach (app: 760 ± 28 ms, avoid: 740 ± 24 ms; $t_{(12)} = 2.50$, $p = 0.028$, Cohen's d = 0.74). Action initiation was slower in emotional contexts.

5.3.2.3.2. Speed of action suppression: Stop-Signal Reaction Times

There was a trend towards a difference in the speed of inhibition of avoidance and approach movements when presented with emotional pictures (*Valence***Movement type*, $F_{(1, 24)} = 2.76$, $p = 0.083$, $\eta^2_p = 0.19$). Follow-up paired t-tests of this trend revealed that for negative pictures, inhibition was faster for approach than avoidance (app: 312 ± 56 ms, avoid: 450 ± 56 ms; $t_{(12)} = -4.04$, $p = 0.002$, Cohen's d = -1.12). No other effects were observed. Thus, contrary the whole-group analysis, there was no main effect of *Valence*. Thus, after removing participants who deliberately slowed down their responses, the SSRT results did not show faster inhibition when negative stop-signals were presented.

5.3.2.3.3. The certainty of parameter estimation: prior and posterior distributions, R statistic and goodness-of-fit

Figure 5.15A shows the posterior and prior distributions (left panel) for the group analysis for the condition where participants had to approach positive pictures. The prior distributions (black dotted lines) are adequately updated and the posteriors (black solid lines) are narrower than the priors, indicating a high degree of certainty in the parameters. **Figure 5.15B** shows the MCMC chains (right panel) for this particular condition converged adequately, and this was verified by the fact that the Gelman-Rubin R convergence diagnostic values were all lower than 1. All subjects had an R value lower than 1.1 for all conditions.

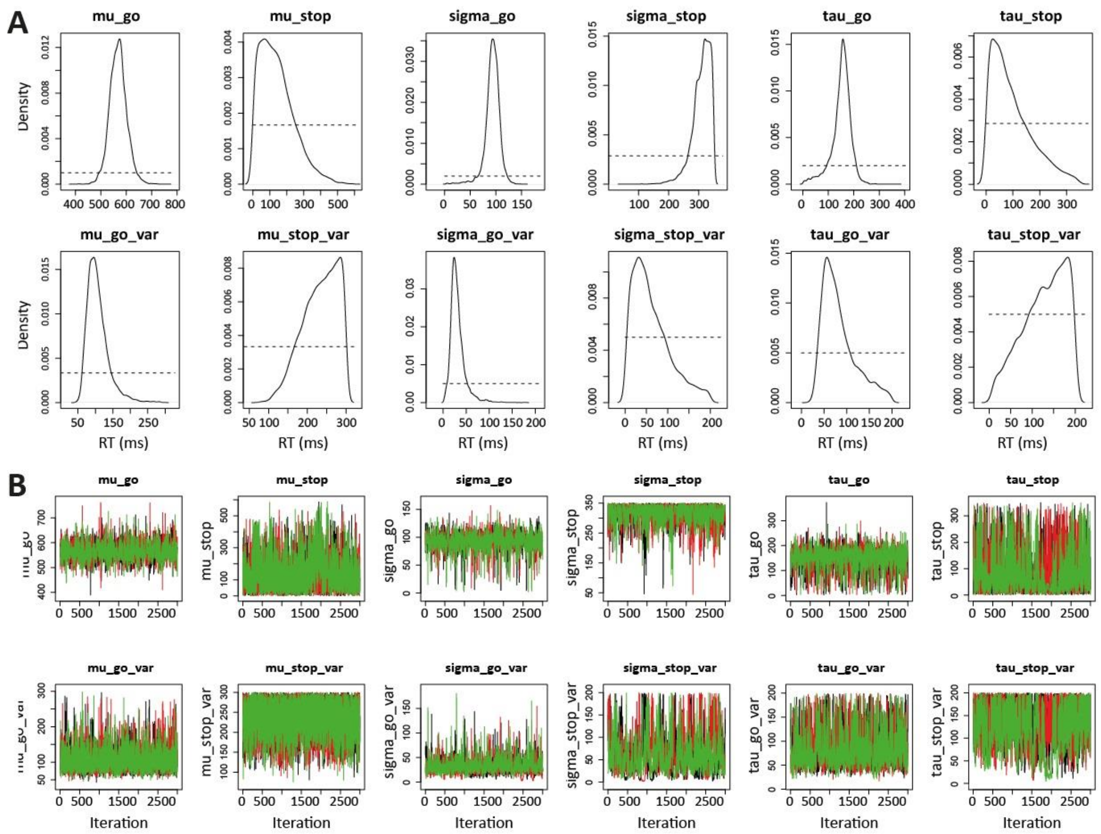


Figure 5.15. A) Posterior and prior distributions for the hierarchical analysis (n=13) when approaching positive pictures. The prior distributions (black dotted lines) are adequately updated and the posteriors (black solid lines) are unimodal both at the group-level mean (upper panel) and group-level variability (lower panel). **B)** MCMC chains. All three chains converged adequately for all parameters in the GO and STOP conditions for both the group-level mean (upper panel) and group-level variability (lower panel). Black, green and red reflect the results for each individual chain.

Figure 5.16 is a comparison of the posterior predictive model checks for individual and hierarchical BPA for Participant 15. This comparison also gives an idea of the goodness-of-fit. For the selected stop-signal delays (SSDs), the observed median signal-respond RTs (i.e. black triangles) are within the 2.5th and 97.5th percentile of the predicted median signal-respond RTs, and are approximated by the median of the predicted median signal-respond RTs (i.e. white circles). BEESTS appropriately accounted for the observed data, and the parameters are adequate.

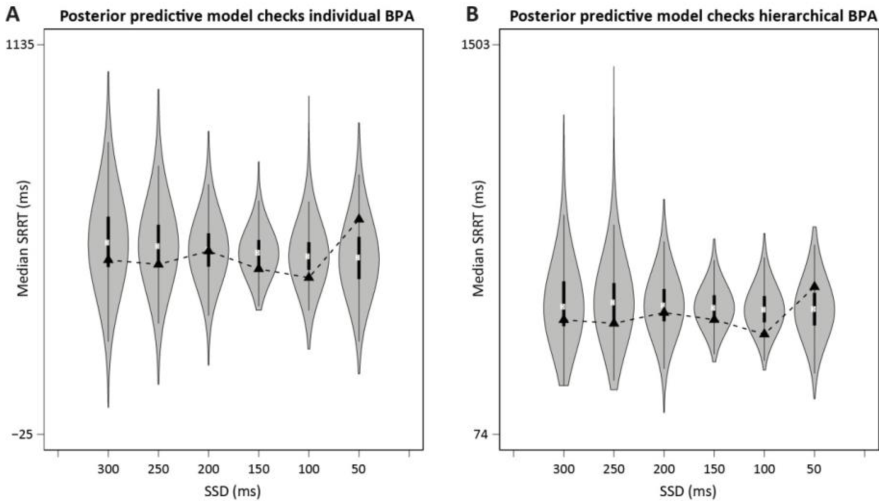


Figure 5.16. Posterior predictive model checks for A) individual and B) hierarchical BPA for participant 15. These checks give an idea of goodness-of-fit. The black triangles represent the observed median signal-respond RTs, whereas the white circles represent the predicted median signal-respond RTs. Both the individual and hierarchical BEESTS approximately accounted for the observed data.

5.3.2.3.4. Parameters of the RT and SSRT distributions: μ, σ, and τ

Speed of action initiation: μ-Go (mean of the RT distribution)

There was a main effect of the valence of the stop-signal on RTs ($F_{(1, 24)} = 8.46$, $p = 0.002$, $\eta^2_p = 0.41$), with participants being faster at initiating responses in blocks where the stop-signal was negative (570 ± 21 ms) compared to positive (611 ± 27 ms) and neutral (652 ± 35 ms) stop-signal blocks, irrespective of the type of movement made. Paired-sample t-tests revealed that RTs in stop-negative blocks were significantly faster than in stop-neutral blocks ($t_{(12)} = -3.45$, $p = 0.005$, Cohen's d = -1.11), and significantly faster than in stop-positive blocks ($t_{(12)} = -2.18$, $p = 0.05$, Cohen's d = -0.62). RTs in stop-positive blocks were also faster than stop-neutral blocks ($t_{(12)} = -2.46$, $p = 0.03$, Cohen's d = -0.77). Thus, the valence of the go-signal in each block affected how fast responses were initiated.

Variability of action initiation: σ-Go (spread of the RT distributions)

The *Block type* also significantly affected the variance in the RT distributions ($F_{(2, 24)} = 9.60$, $p = 0.004$, $\eta^2_p = 0.44$), with less variability in blocks with a negative stop-signal compared to positive and neutral stop-signal blocks (stop-neg: 96 ± 5 ms, stop-pos: 111 ± 7 ms, stop-neu: 141 ± 13 ms). Paired-samples t-tests revealed that RTs in negative stop-signal blocks were significantly less variable than positive stop-signal ($t_{(12)} = -2.25$, $p = 0.037$, Cohen's d = -0.97) and neutral stop signal blocks; $t_{(12)}$ = -3.38, p = 0.006, Cohen's d = -1.32). RTs in positive stop-signal blocks were also less variable than in neutral stop-signal blocks ($t_{(12)}$ = -2.86, p = 0.014, Cohen's d = -0.95). There was also a main effect of *Movement type* ($F_{(1,\ 13)}$ = 10.47, p = 0.007, η^2_p = 0.47), with less variability when avoiding compared to approaching (app: 125 ± 7 ms, avoid: 107 ± 7 ms; $t_{(12)}$ = 3.24, p = 0.007, Cohen's d = 0.90).

Direction of action initiation: τ-Go (skewness of the RT distribution)

There were no significant effects for the tail-end of the RT distributions.

Speed of action suppression: μ-Stop (mean of the SSRT distribution)

Similar to the whole-group data, there was a difference in the μ parameters for the speed on inhibition of avoidance- approach movements when presented with emotional pictures (**Figure 5.17**; *Valence***Movement type*, $F_{(2,\ 24)}$ = 4.46, p = 0.023, η^2_p = 0.27). Follow-up paired-samples t-tests revealed that for negative stop-signals, inhibition of approach was faster than inhibition of avoidance (app: 197 ± 42 ms, avoid: 274 ± 39 ms, $t_{(12)}$ = -2.67, p = 0.020, Cohen's d = -0.74). For positive stop-signals, inhibition of approach was not significantly faster than avoidance (app: 231 ± 50 ms, avoid: 318 ± 47 ms, p = n.s.). There was no difference between approach and avoidance for neutral pictures. Inhibition of approach was therefore faster for emotional pictures compared to neutral, suggesting that in general approach movements were prepared more slowly than avoidance movements but only in emotional contexts.

There was also a significant main effect of *Movement type* ($F_{(1,\ 13)}$ = 4.96, p = 0.046, η^2_p = 0.29) indicating that participants were faster at inhibiting approach compared to avoidance irrespective of the valence of the stop-signal. Follow-up paired-samples t-tests showed a significant difference between inhibition of approach and avoidance (app: 241 ± 39 ms, avoid: 279 ± 38 ms, $t_{(12)}$ = -2.23, p = 0.046, Cohen's d = 0.62).

Variability of action suppression: σ-Stop (spread of the SSRT distribution)

Similar to the hierarchical analyses for all participants, there was an effect of the valence of the stop-signal on the variability of inhibiting approach-avoidance actions (*Valence*Movement type;* $F_{(2, 24)} = 27.01$, $p < 0.001$, $\eta^2_p = 0.69$). For negative pictures, there was less variability when inhibiting avoidance compared to approach (app: 288 ± 5 ms, avoid: 199 ± 0.20 ms; $t_{(12)} = 5.10$, $p < 0.001$, Cohen's d = 2.04). For positive pictures inhibiting avoidance was less variable compared to approach (app: 297 ± 4 ms, avoid: 161 ± 28 ms; $t_{(12)} = 5.07$, $p < 0.001$, Cohen's d = 2.22). For neutral pictures, variability was less for approach compared to avoidance (app: 187 ± 18 ms, avoid: 257 ± 9 ms; $t_{(12)} = -4.50$, $p = 0.001$, Cohen's d = -1.46). There was a main effect of *Movement type* ($F_{(1, 12)} = 19.81$, $p = 0.001$, $\eta^2_p = 0.62$), with less variability in inhibiting avoidance movements compared to approach (app: 257 ± 8 ms, avoid: 206 ± 16 ms; $t_{(12)} = 4.43$, $p = 0.001$, Cohen's d = 1.46).

Direction of action suppression: τ-Stop (skewness of the SSRT distribution)

Contrary to the whole-group analysis, the hierarchical analysis revealed an effect of stop-signal valence on the tail-end of the inhibition distribution (Fig 17; *Valence***Movement type;* $F_{(2, 24)} = 9.32$, $p = 0.001$, $\eta^2_p = 0.44$). For negative pictures, the tail-end distribution was significantly smaller for approach than avoidance (app: 116 ± 16, avoid: 176 ± 20; $t_{(12)} = -5.34$, $p < 0.001$, Cohen's d = -1.56). For positive pictures there was an opposite trend (app: 177 ± 22, avoid: 117 ± 21; $t_{(12)} = 2.40$, *$p = 0.028$, Cohen's d = 0.69*). Neutral pictures had no effect on the shape of the distribution, suggesting that only emotional pictures impact the skew.

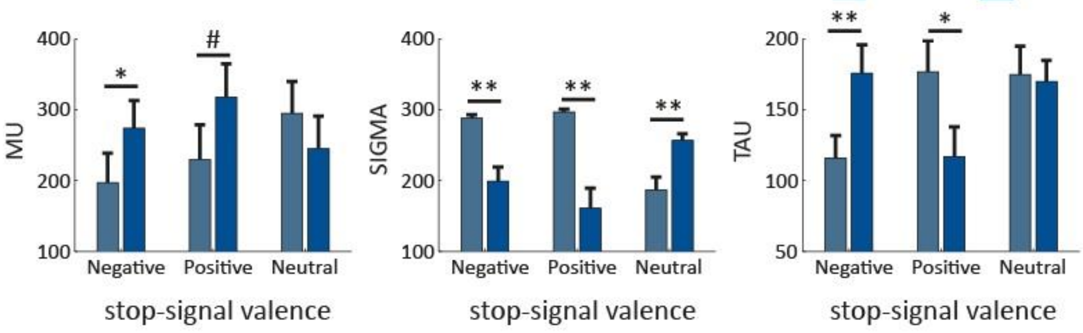


Figure 5.17. Mu, sigma and tau parameters for the STOP condition. Stopping latency (ms) when approaching was significantly faster than when avoiding (MU). Stopping (SIGMA) was less variable when avoiding emotional

stimuli compared to neutral. The tail-end distribution (TAU) was only influenced by valence. Light blue bars = approach; dark blue bars = avoidance. Error bars (+1 S.E.M.); ** significant at $p < 0.001$ level, * significant at $p < 0.05$ level.

Overall, after removing participants that did not deliberately slow down their responses, the results for the RT and SSRT distributions did not differ from the whole-group analysis.

5.3.2.4. Validating BEESTS: SSRTs calculated using the mean method analysis

As a control, SSRTs were re-calculated for individual subjects using the mean method. Because the mean method is susceptible to miscalculating the SSRT as a result of strategic slowing, it was important to calculate the SSRT for the subset of participants which did not display a strategic slowing of RTs throughout the experiment.

Results for the whole-group analysis showed similar results to those yielded by the BEESTS SSRTs. There was a significant main effect of *Movement type* ($F_{(1, 23)} = 8.06$, $p = 0.09$, $\eta^2_p = 0.26$), with faster inhibition of approach compared to avoidance irrespective of the stop valence. Follow-up paired t-tests showed a significant difference between inhibition of approach and avoidance (app: 358 ± 31 ms, avoid: 414 ± 27 ms, $t_{(23)} = -2.85$, p = 0.09, Cohen's d = -0.59). There was also a main effect of stop *valence* ($F_{(1, 23)} = 3.31$, $p = 0.046$, $\eta^2_p = 0.13$), with faster inhibition for negative pictures compared to positive (neg: 331 ± 37 ms, pos: 429 ± 35 ms, neu: 396 ± 33) and neutral. Follow-up paired t-tests confirmed that inhibition of negative pictures was significantly faster than positive ($t_{(23)} = -2.32$, $p = 0.030$, Cohen's d = -0.47). There was no difference in inhibition of positive and neutral, and negative and neutral pictures.

Results for the sub-group analysis, which removed participants with strategic slowing, showed a significant main effect of *Movement type* ($F_{(1, 23)} = 5.00$, $p = 0.045$, $\eta^2_p = 0.29$) indicating that participants were faster at inhibiting approach compared to avoidance irrespective of the stop valence. Follow-up paired-samples t-tests showed a significant difference between inhibition of approach and avoidance (app: 360 ± 39 ms, avoid: 419 ± 39 ms, $t_{(23)} = -2.24$, p = 0.045, Cohen's d = -0.61). In contrast to the whole group analysis, there was no significant main effect of *valence*.

The mean method analysis incorporating all participants corroborated the results from the whole-group BEESTS analysis by showing that participants were faster to inhibit actions when presented with negative stop-signals. This is not surprising given that there were no effects of the valence of the go-signal on the skewness of the RT distributions. Skewness has been suggested to affect the calculation of SSRT. Since the RT distributions used to calculate the SSRT were not skewed for the whole-group analysis, the mean method was less susceptible to miscalculations. However, when participants that deliberately slowed down their responses were removed, the main effect of *Valence* was no longer observed, corroborating the results of the sub-group BEESTS analysis which also did not show that stopping was faster for negative stop-signals. Thus, it seems that the removal of participants with strategic slowing eliminated the valence effect, suggesting that the faster you are at responding, the less time available for valence to influence inhibition.

5.3.2.5. *Regression analyses on RTs*

Regression analyses were conducted to assess how much of the variability on the RT distributions could be accounted for by *valence* and *arousal*. A 3-way RM-ANOVA with factors *Go-Valence*, *Variable type and Movement type* was conducted on betas obtained from the regression to assess the impact of the *valence* and *arousal* associated to each picture on the speed of initiation of approach and avoidance movements. Because approach and avoidance are movements typically triggered by positive and negative valences, and not associated with picture arousal, an interaction between *Go-Valence* and *Movement type* only was expected. Indeed, the results revealed an interaction between *Go-Valence* and *Movement type* (**Figure 5.18A**; $F_{(2,\ 46)} = 4.53, p = 0.025, \eta^2_p = 0.17$). This interaction was driven by differences in betas for the initiation of approach and avoidance when presented with positive go pictures (approach: -11.23 ± 3.69, avoidance: 3.41 ± 4.04), but only betas for approach differed from zero ($t_{(23)} = 3.08, p = 0.005$). For approach, as the valence of positive pictures increases, RTs decrease and for avoidance, there is a trend that as the valence of positive pictures increases, RTs increase. Thus, there is an effect of positive valence on action initiation of approach-avoidance responses, supporting the GO-RT analyses above.

There was also an interaction between *Valence* and *Variable type* ($F_{(2, 46)}$ = 3.88, p = 0.028, η^2_p = 0.15), driven by differences in betas for valence and arousal for negative pictures only **(Figure 5.18B)**. Thus, as negative pictures become less negative, RTs increase, and as the arousal of the negative pictures increase the RTs decrease (valence betas: 6.85 ± 3.58, arousal betas: -0.55 ± 4.17) although only the betas for valence differed from zero ($t_{(23)}$ = -1.92, p = 0.06). Therefore, the associated valence of negative pictures only affects movement initiation, but do not influence the speed of initiation of approach-avoidance responses.

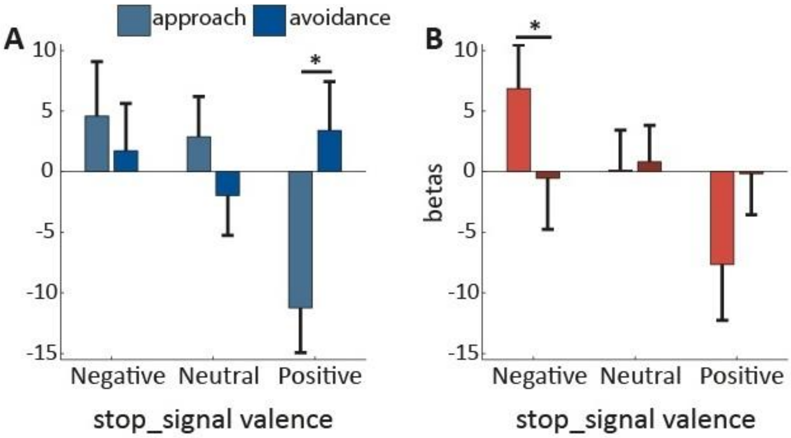


Figure 5.18. Regression showing the effect of valence on stopping. A) Interaction between *valence* and *movement type,* driven by difference in betas for approaching and avoiding positive pictures. As the valence of positive pictures increases, RTs decrease when approaching and decrease when avoiding. **B)** Interaction between *valence* and *variable type* driven by differences in betas for valence and arousal for negative pictures only. As negative pictures become less negative, RTs increase, whereas as the arousal of negative pictures increases, RTs decrease. Error bars (mean + S.E.M.); * significant at p < 0.05 level.

5.3.3. Discussion

Experiment 2 investigated if emotional stop-signals and their related response tendencies would bias the preparation of the "stop" process. I expected that for emotional pictures inhibition of predisposed tendencies would be harder compared to those that are not predisposed, and for neutral pictures there would be no difference on the inhibition of approach-avoidance responses. There was an influence of emotional valence, but not approach-avoidance tendencies, on the speed of action initiation, with slower responses when presented with emotional pictures relative to neutral pictures. There was an effect of valence, but not approach-avoidance tendencies, on the speed of inhibition, with faster inhibition of responses in negative relative to positive and neutral contexts, supporting previous work (Pessoa et al., 2012; Senderecka, 2016). Overall, the results show that approach-avoidance tendencies do not influence the preparation of “stop” processes during response inhibition, but emotional valence does.

Emotional valence influences the speed of action initiation

Results showed that when looking at the block-RTs (defined by the valence of the stop-signal), collapsed across the go-signal valences (e.g. negative stop-signal block, with positive and neutral go-signals), RTs were faster and less variable in blocks with positive and neutral go-signals, and slowest in blocks with positive and negative go-signals irrespective of whether an approach or avoidance was made. These data demonstrate that the presence of neutral content makes us respond faster, and that the presence of emotional stimuli slows down action initiation. This effect may occur due to the attention-grabbing properties of such stimuli, corroborating previous evidence demonstrating an interference with performance (Carretié, 2014; Herbert, 2011; Gawronski et al., 2005; Hartikainen et al., 2000; Schimmack, 2005; Schmidt, Belopolsky, & Theeuwes, 2012). Threat-related distractors, for instance, increase the number of errors when inhibiting a response (Hartikainen et al., 2000). Indeed, regression analyses confirmed that RTs are only influenced by the valence of the go-signal and not the arousal, suggesting that the slowing down of action initiation relative to blocks with neutral pictures resulted from the emotional content of positive and negative pictures. Therefore, the emotional content, particularly negative, influenced the speed and consistency of action initiation to abstract stimuli. These results concord with previous work that has shown that participants are slower to initiate responses in negative (i.e. high threat) contexts (Albert et al. 2010; Facchinetti et al. 2006; Stins et al., 2013). The slower initiation of responses in negative contexts may result from that fact threatening stimuli trigger “freezing-like” responses that lead to immobility (Facchinetti et al. 2006; Le Doux, 1996, 2000).

The level of threat in emotional stimuli biases the "stop" process

There was an effect of the valence of the stop-signal on the latency of stopping actions. Inhibition was faster when presented with negative stop-signals, compared to positive and neutral stop-signals. This demonstrates that the speed of inhibition is not modulated by arousal, in contrast to previous suggestions (Pessoa et al., 2012; Verbruggen & De Houwer, 2007), because there was no difference in inhibition between positive and neutral stop signals. Stopping was instead modulated by negative pictures.

The current results may offer some support for the hypothesis that negative pictures induce freezing-like behaviour and decrease the speed the inhibition of responses (Pessoa et al., 2012; Senderecka, 2016). The RT results above suggest a slowing down of action initiation, and presumably action preparation, when presented with threatening content, subsequently leading to faster inhibition. This slowing down of action initiation demonstrates that emotional pictures captured attention and interfered with performance, and suggests that the improved inhibitory performance observed in negative contexts cannot be attributed to enhanced perceptual processing and increased attention, contrary to previous suggestions (Pessoa, 2009). Instead, they reveal that better stopping in negative contexts is mediated via freezing (Facchinetti et al., 2006; Roelofs et al. 2010; Stins et al., 2013), a fast defensive response often deployed in threatening situations (LeDoux, 1996). Thus, negative stimuli may activate a defensive circuitry that results in freezing of responses, leading to slower action initiation and faster inhibition. In sum, negative stimuli speed up inhibition and low-threat stimuli (i.e. stimuli with no threat content) have no influence on inhibition.

Importantly, this faster inhibitory effect of negative pictures was not present when removing participants who slowed down their responses strategically, revealing that long RTs are capable of distorting distributions and impact on the calculation of SSRTs (see Verbruggen et al., 2013). In this case, the slowing down of RTs led to overestimating the impact of valence on stopping. Thus, it appears that emotional valence did not impact the speed of response suppression. Irrespective of this, however, the valence effect observed above is still interesting and should be followed up.

In sum, Experiment 2 demonstrated that approach-avoidance tendencies do not influence response inhibition by biasing the preparation of “stop” processes. Instead, negative valence may facilitate inhibition relative to neutral and positive pictures as a result of defensive freezing mechanisms.

5.4. General Discussion

This chapter investigated the process of response inhibition in emotional situations by determining if approach-avoidance tendencies influence the resolution of competing responses by biasing the preparation of “go” or the preparation of “stop” processes. Two experiments were conducted to assess this. Experiment 1 investigated whether emotional tendencies influence the preparation of approach and avoidance “go” responses, resulting in biasing response inhibition. Results showed a possible influence of “go” preparatory processes on inhibition. In contrast, Experiment 2 investigated whether approach-avoidance tendencies bias the preparation of “stop” processes. The data revealed that only valence determined inhibition, with faster inhibition for negative compared to positive and neutral stimuli. The preparation of “stop” processes therefore is biased by valence but not by approach-avoidance tendencies.

Overall, approach-avoidance tendencies influence inhibition by biasing the “go” preparatory processes but not the “stop” processes. This suggests that approach-avoidance tendencies influence preparatory processes that occur prior to action initiation, but not those that arise once an action has been executed. This corroborates the conclusions from previous chapters and confirms the effect that such tendencies have on selection processes. The current chapter therefore provides novel evidence on the underlying mechanisms whereby approach-avoidance tendencies influence response inhibition.

Action initiation is influenced by emotional valence and approach-avoidance tendencies

Both experiments confirmed that the emotional content of the go-signals influences our ability to initiate approach-avoidance actions. In Experiment 1, approach was initiated faster for positive compared to negative pictures, and avoidance was initiated faster for negative compared to positive pictures, corroborating previous work (Chen & Bargh, 1999; Roelofs et al., 2009) and other chapters in this thesis, and confirming the effect of approach-avoidance tendencies on action selection and initiation.

Experiment 2 demonstrated that response initiation was slower and less consistent in blocks containing positive and negative go-pictures relative to blocks which included neutral go-signals. This suggests prioritised attentional processing of emotional pictures relative to neutral (Ohman et al., 2001; Vuilleumier et al., 2001) that subsequently leads to slower response initiation. Indeed, relative to neutral pictures, emotional pictures interfere with task performance by slowing down RTs (Ambron & Foroni, 2015; Horstmann & Bauland, 2006) or increasing the number of errors (Hartikainen et al., 2000). This influence of valence on response initiation occurred irrespective of whether an approach or avoidance was made. This may be partly because, in Experiment 2, goals to approach and avoid emotional pictures were not made explicit like in Experiment 1. Previous work has highlighted the importance of task instructions and content evaluation in determining action selection (Eder & Rothermund, 2008; Eder & Klauer, 2009; Lavender & Hommel, 2007). Thus, Experiment 2 demonstrated that there is no implicit influence of approach-avoidance tendencies on action selection and initiation, corroborating the findings from Chapter Three.

In sum, emotional valence slows down action initiation relative to neutral stimuli, but within emotional stimuli some actions are more predisposed than others. The current chapter adds to the conclusion that approach-avoidance tendencies influence the speed of action selection and initiation, but only when explicit goal information is provided, confirming Chapters Two, Three and Four.

Response inhibition is influenced by valence

Both experiments demonstrated an effect of valence on inhibitory processes. Experiment 1 showed that inhibiting responses in negative contexts was less variable than in positive contexts. Experiment 2 demonstrated that inhibiting actions in negative contexts was faster than in positive or neutral ones. Thus, negative valence increased the speed and decreased variability of inhibition, supporting previous work (Pessoa et al., 2012; Senderecka 2016).

Mechanistically, faster inhibition in negative contexts may reflect “freezing-like” behaviour, whereby threatening information leads to immobility in order to minimise the cost of an action (Fanselow, 1994; Le Doux, 1996; Lang et al., 2000). Indeed, immobility (i.e. passive behaviour) has been suggested to be the first step in defensive behaviour, followed by active fight-or-flight (Fanselow, 1994; Mobbs et al., 2009). Immobility may result from a global inhibitory mechanism, whereby the prepared response and other response alternatives are suppressed simultaneously (Badry et al., 2009; Coxon et al., 2007; Majid et al., 2012). For instance, suppressing a finger movement, also results in suppression of neural excitability of the leg despite the leg being task-irrelevant (Badry et al., 2009). Thus, faster inhibition may result from a global stopping mechanism triggered by threatening information. This type of inhibition contrasts with selective mechanisms which suppress only specific effectors (Aron, 2011; Aron & Verbruggen, 2009). That is, one specific action may be inhibited but other effectors may still be active.

The speed of inhibition is therefore modulated by a defensive circuitry activated by the presence of negative information. Because there were no effects of positive stimuli on inhibition, the results argue against the hypothesis that task-relevant emotional stop-signals increase perceptual processing, thereby leading to facilitatory effects (Pessoa, 2009). Importantly, what seems clear from the results is that inhibition is not influenced by neutral pictures, confirming that behaviour is heavily influenced by emotional stimuli in our environment.

Can the level of threat influence inhibition?

Some work has suggested that inhibition is guided by the level of threat of emotional information (Pessoa et al., 2012). Neutral and positive stimuli can be classified as low-threat and negative stimuli as high-threat (Pessoa, 2009). The content of negative pictures contains a degree of threat. This degree of threat, however, may vary depending on the nature of the negative picture. For example, a negative picture of a dead animal may not necessarily have the same degree of threat as a negative picture of a violent dog displaying their teeth.

Indeed, a recent study suggested that negative stimuli with disgust and fearful properties have a differential impact on response inhibition (Xu et al., 2015), with disgust distractors interfering more with inhibition than fearful distractors. In the current chapter, pictures were not classified and were not formally assessed, for their threatening content because the goal was not to investigate how the level of threat influences stopping. However, given the established effect that negative pictures have on response inhibition, assessing the impact of different negative stimuli on the speed of inhibition seems imperative in order to understand if this is a general effect of negative valence or a more focused effect of threatening content. This is a very interesting question and one that should be formally assessed in the form of another experiment.

Conclusion

In sum, approach-avoidance tendencies appear to influence response inhibition by biasing the preparation of “go” processes prior to movement initiation. Approach-avoidance tendencies therefore only manifest prior to when an action needs to be executed. Furthermore, for these tendencies to impact action preparation and initiation, there needs to be an explicit goal to approach or avoid. In contrast, the preparation of “stop” processes is influenced by emotional valence, with faster inhibition in negative contexts. Stopping processes are therefore influenced by negative information, possibly modulated by a fast defensive circuit. This chapter dissociates the effect of valence and approach-avoidance tendencies by demonstrating their differential impact on “go” and “stop” processes. To my knowledge this is the first demonstration of this dissociation.

Chapter Six. Emotional valence updates motor plans during action execution

6.1. Abstract

Successful behaviour requires adapting to changes and new opportunities that may arise in the environment while we perform actions. Adapting to changes involves updating motor output in real time via feedforward and feedback mechanisms. Two mechanisms may be responsible for updating motor output: a fast, more automatic mechanism and slow, less automatic one. What remains unknown is whether the fast or slow mechanisms underlying visuomotor updating are influenced by emotional stimuli. More specifically, can approach-avoidance tendencies associated to emotional stimuli influence the speed at which these fast and slow mechanisms are engaged? If so, it would demonstrate that approach-avoidance tendencies and visuomotor corrections during execution are not independent processes. Two experiments were conducted to assess this. In Experiment One, participants made simple reach-to-target movements and emotional distractors were presented shortly after movement initiation. Emotional distractors and related response tendencies were expected to perturb reaching and cause spatiotemporal changes. The speed at which these changes occur should inform of fast or slow pathways. In Experiment Two, targets paired with emotional distractors jumped from the centre to the left or right shortly after reaching initiation. Participants corrected their movement towards or away from the new target location. Emotional distractors and associated approach-avoidance tendencies were expected to influence the speed of these corrections, revealing fast or slow mechanisms. Both experiments showed that only the end stage of reaching is influenced by emotional relative to neutral stimuli, affecting accuracy and precision. Furthermore, Experiment Two demonstrated that the speed of visuomotor corrections is influenced by valence. Overall, both experiments demonstrated that emotional stimuli, but not approach-avoidance tendencies, engage the slow mechanism, guided by top-down attentional modulation. Approach-avoidance emotional tendencies are independent of action execution.

6.2. Introduction

Successful behaviour requires the continuous monitoring of our environment for changes and new opportunities that may arise while we perform actions (Cisek, 2007; Shadmehr & Mussa-Ivaldi, 1994; Wolpert & Miall, 1996). These environmental changes update motor output via a system of feedforward and feedback mechanisms (Desmurget & Grafton, 2000), whereby monitoring of the environment adjusts movements in real time to accommodate new goals (Desmurget et al., 1999; Goodale et al., 1986). This quick re-planning most likely occurs via the parallel processing between motor planning and movement execution (Cisek & Kalaska, 2010). Emotional changes in the environment may influence how this motor re-planning occurs. More specifically, given that valence-related approach-avoidance tendencies influence how quickly we select and initiate actions, as has been demonstrated in Chapters Two, Three and Four, emotional changes in the environment may trigger approach-avoidance tendencies that influence movement execution by biasing the updating motor plans.

Visuomotor reaching corrections may inform of the underlying mechanisms in approach-avoidance

Arm reaching movements are especially suited to investigate both how our brain plans a goal-directed action (Kalaska & Crammond, 1992) and how unexpected changes in the environment influence the fast re-planning of actions via feedforward and feedback mechanisms while the movement is being executed (Desmurget & Grafton, 2000; Messier & Kalaska, 2000; Sabes, 2000). Within this framework, movements towards a target are initially planned, specifying the motor command (feedforward specification). While an action is executed, a forward model of movement dynamics is generated via information regarding the location of the effector in space, which simultaneously updates movements via feedback loops (Desmurget & Grafton, 2000). Changes in execution in response to environmental changes will therefore reflect the speed of feedforward and feedback mechanisms.

Visuomotor adaptation studies, whereby an arm perturbation or environmental change occurs while individuals perform an action, have also been critical for understanding the mechanisms involved in visually guided movement corrections (Day & Lyon, 2000; Desmurget et al., 1999; Paulignan et al., 1991; Prablanc & Martin 1992). These studies have added to models of movement control by revealing two further underlying mechanisms guiding visuomotor corrections: a fast, automatic pathway and a slower, less automatic pathway (Day & Lyon 2000; Pisella et al., 2000).

Day & Lyon (2000) implemented a task in which subjects moved towards or away from targets that “jumped” either to the left or the right of a central target. This target jump occurred 25 ms after movement initiation and in only 30% of trials, making it unexpected and meaning that subjects were not capable of preplanning a movement correction prior to movement initiation. Results showed that correcting towards the new target location occurred approximately 125 ms after the initiation of movement, whereas correcting away from the new target occurred at about 200 ms after movement initiation, despite the target jump in both situations occurring at the same time.

Thus, the authors dissociated two classes of responses during visually-guided movement. Early reaching corrections towards new targets were suggested to occur in a fast and automatic way, independently of conscious experience, supporting earlier work (Goodale et al., 1986; Jeannerod, 1988; Prablanc & Martin, 1992). In contrast, later corrections were assumed to be modifiable by the subjects’ intention to move in the opposite direction to the target and were classified as voluntary and less automatic than the early response. The shift from more automatic to less automatic is presumably influenced by the speed in which feedback loops can gather information during ongoing movements (Desmurget & Grafton, 2000; Gaveau et al., 2014; Striemer et al., 2010). Two models were proposed for driving these different classes of responses. The dual-pathway model proposes that visual input throughout execution is sent to either a cortical or subcortical pathway which ultimately dictates the flexibility of the correction (Day & Lyon, 2000). In contrast, the single-pathway model is generated by a single visuomotor mechanism driven by attention, whereby attention is automatically diverted to the new target triggering the early response, and the later response is driven by inhibition of attention, where higher processes redirect lower processes (Tipper et al., 1998).

The existence of two classes of responses for visuomotor corrections may suggest that, depending on the situation, one may prevail over the other. In emotional situations that require rapid action, for instance, the fast, more automatic response may be favoured over the slower, less automatic response. This sort of distinction exists in emotion processing (Pessoa & Adolphs, 2011), whereby prioritisation of emotional information can occur via fast, bottom-up networks (Tamietto & de Gelder, 2010) or driven by top-down attentional mechanisms (Pessoa et al., 2002). Thus, the question now is: can these fast and slow visuomotor mechanisms be influenced by emotional information? More specifically, can automatic emotional approach-avoidance tendencies influence the speed at which these mechanisms are engaged? For instance, correcting towards a positive target might occur faster than correcting towards a negative target. Similarly, correcting away from a negative target might be faster than correcting away from a positive target. This is because a positive stimulus automatically predisposes approach whereas a negative stimulus predisposes avoidance (Chen & Bargh, 1999). In essence, we may have two automatic systems at play: one related to the speed of visuomotor feedback (here referred to as *visuomotor automaticity*) and another related to approach-avoidance tendencies (here referred to as *valence automaticity*).

To the best of my knowledge, no study has investigated the potential relationship between these two automatic systems. If we observe an effect of *valence automaticity* on *visuomotor automaticity*, whereby predisposed tendencies trigger the fast or slow pathways earlier, it suggests that these two processes may not be independent from each other, potentially relying on similar underlying pathways. Importantly, if such corrections occur earlier in relation to neutral stimuli, it would demonstrate that emotional stimuli may have a privileged access to motor processes over non-emotional stimuli. It may be possible that the speed of visual feedback mechanisms during visuomotor corrections is influenced by the attentional prioritisation of emotional stimuli relative to neutral stimuli, driven by a fast and automatic visual pathway (LeDoux, 2000; Tamietto & de Gelder, 2010; West, Anderson, Bedwell, & Pratt, 2010). Indeed, visual pathways are extensively interconnected with emotional pathways at the cortical and subcortical level (Tamietto & de Gelder, 2010), which may in turn be connected to the fast pathways guiding early movement corrections.

Emotional influences on arm kinematics

While there is no evidence for an effect of approach-avoidance tendencies on the fast and slow mechanisms underlying reaching corrections, recent work has shown that the spatial characteristics of reaching execution are modulated by task-irrelevant emotional distractors (Ambron & Foroni, 2015; Ambron, Rumiati, & Foroni, 2016). Positive and negative distractors presented simultaneously with the target were shown to bias reaching toward the location of the distractor relative to neutral stimuli (Ambron & Foroni, 2015). This effect also occurred implicitly, even when the emotional dimension was not task-relevant (Ambron et al., 2016). This work demonstrates an effect of emotional stimuli on action execution and adds to the existing literature showing that task-irrelevant, non-emotional distractors cause changes in both the trajectory and the speed of movement (Buetti, Juan, Rinck, & Kerzel, 2012; Meegan & Tipper, 1998; Pratt & Abrams, 1994; Tipper et al., 1997; Welsh & Elliott, 2004). Mechanistically, these changes in spatiotemporal characteristics during movement may be driven by competition between the target and distractor, whereby the competing response elicited by the distractor is selectively inhibited by attentional mechanisms (Howard & Tipper, 1997; Tipper et al., 1997). The extent of inhibition biases the trajectory either towards (Welsh & Elliot, 2004) or away from the distractor (Howard & Tipper, 1997).

Other studies have shown that distractors influence how accurate and precise participants are at reaching a target (Messier & Kalaska, 1999; van den Dobbelsteen, Brenner, & Smeets, 2001). Accuracy and precision are characterised by the endpoint distribution. Forward modelling receives information of the location of the arm in space as movement occurs, and this information is used to predict the endpoint of the movement relative to target location (Desmurget & Grafton, 2000). Emotional distractors may therefore influence feedback mechanisms and bias the estimation of the endpoint location compared to the target.

While the above evidence demonstrates an effect of emotional stimuli on the spatiotemporal aspects of movement execution, the mechanisms underlying how emotional information influences the execution phase of movement remain undetermined. If changes that occur during action execution update motor output via a system of feedforward and feedback mechanisms (Desmurget & Grafton, 2000) presumably implemented via fast and slow pathways (Day & Lyon, 2000), it is possible that emotional distractors presented after movement initiation may affect movement re-planning by influencing when and which of these pathways is engaged. Early spatiotemporal changes during execution would reflect the implementation of a fast pathway, whereas late changes would suggest the activation of a slow pathway.

More specifically, emotional approach-avoidance tendencies may influence how and when these spatiotemporal changes occur. For instance, trajectories may veer towards or away from an emotional distractor depending on its valence: a positive stimulus could, for example, attract, and a negative stimulus could repel, the course of a reaching trajectory. Attract here would suggest an effect of approach tendencies, whereas repel would be a manifestation of avoidance. The extent to which emotion can “attract” or “repel” movement is most likely driven by the degree of response competition between the goal of the action and the emotional distractor (Tipper et al., 1997; Welsh & Elliott, 2004), which in turn may be influenced by approach-avoidance tendencies. Predisposed tendencies may need to be inhibited more than those that are not predisposed because they are presumed to be automatic (Chen & Bargh, 1999). The timing of when these attentional inhibitory mechanisms are engaged, evident in the timing of changes in speed and trajectory deviations, might provide a window into inferring the contribution of the underlying fast or slow processing pathways through which emotion influences movement. For instance, if any movement corrections in response to emotional distractors occur earlier in the movement, these will most likely be guided by fast pathways and would reveal a bottom-up movement influence of the distractor without yet being influenced by later top-down mechanisms. *Valence automaticity* may therefore influence *visuomotor automaticity*.

The influence of biomechanics on arm reaching movements

Movement corrections may not only be influenced by changes in context. The arm has joints, tendons and different mass distributions that may contribute to how an arm completes a movement towards a specific target. For example, to carry out a reaching movement the elbow, wrist and shoulders all have their individual torques (i.e. angle and force) that will allow the limb muscles to flex and extend from a resting position to a target.

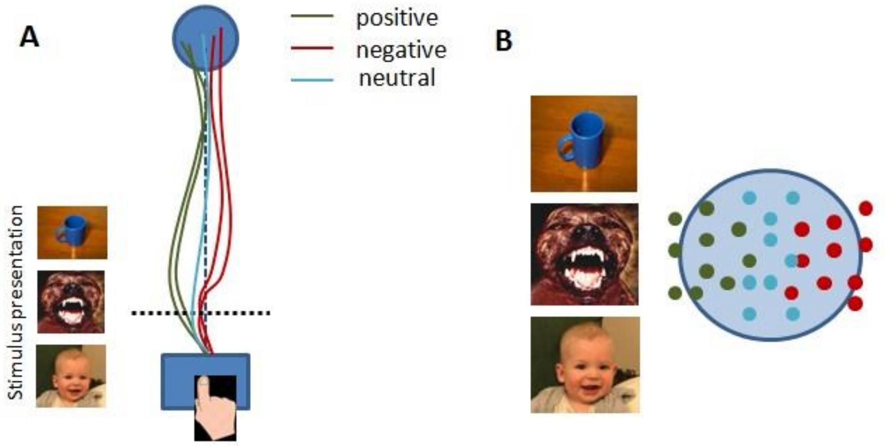
Motor plans typically determine these biophysical properties prior to the initiation of movement (Cos, Bélanger, & Cisek, 2011; Messier & Kalaska, 2000). These properties influence reaching, with participants making movements that are biomechanically easier to achieve (Cos et al., 2011; Marcos, Cos, Girard, & Verschure, 2015) and opting for the movement path that allows for greater arm mobility (Hogan, 1985b). Furthermore, biomechanical costs (i.e. the degree of difficulty of the movement) are computed very quickly, influencing decisions about actions at a very early stage of motor processing (Cos et al., 2014; Marcos et al., 2015). Thus, it is important to consider that changes in the parameters of action execution during reaching may not only reflect the influence of emotional changes, but also the biophysics of the arm.

Approach-avoidance tendencies and visuomotor corrections

This chapter aims to determine whether *valence automaticity* influences *visuomotor automaticity*. More specifically, do approach-avoidance tendencies influence the fast and slow pathways involved in updating motor plans and guiding movement corrections? An influence of *valence automaticity* on the fast pathway would demonstrate that valence and *visuomotor automaticity* are guided by similar fast, bottom-up pathways, possibly due to underlying primitive survival circuits. An influence of *valence automaticity* on the slow pathway would demonstrate a top-down and possibly goal-directed mechanism underlying emotional actions. To achieve this aim, two experiments were conducted.

Experiment 1 tested the hypothesis that action execution and concurrent motor planning are influenced by emotional distractors, which may guide movement re-planning via fast or slow pathways. Emotional distractors were presented to the left or right of the midline shortly after the initiation of a movement made towards a central non-emotional target. To distinguish between fast and slow pathways, I looked at changes in spatiotemporal properties throughout the movement, which may reveal early effects, and the accuracy and precision of the endpoints, which may reveal late effects of the distractor. Indeed, work has shown that the late stages of movement are independent from early kinematics and are more susceptible to top-down influences (Messier & Kalaska, 1999).

I expected that the appearance of a positive distractor would increase the speed of execution, while a negative distractor would decrease speed, according to previous evidence (Esteves et al., 2016). Furthermore, positive distractors should “attract” reaching movements (i.e. deviate trajectories towards the distractor, reflecting approach), whereas negative stimuli should “repel” trajectories (i.e. deviate trajectories away from the distractor, reflecting avoidance) **(Figure 6.1A)**. Given the prioritisation of emotional stimuli (Ohman et al. 2001; Vuilleumier et al. 2001), it was expected that these deviations would occur earlier for emotional stimuli relative to neutral. If, in contrast, emotional valence causes changes later in the movement, where conscious perception and top-down control take over, then accuracy and precision of where the finger lands were anticipated to reveal these influences compared to neutral distractors **(Figure 6.1B)**.



6.1. Schematic of predictions for Experiment 1. A) Positive distractors were expected to “attract” trajectories, causing deviations towards the distractor. Negative distractors were expected to “repel” trajectories, causing deviations away from the distractor. Neutral distractors were not expected to cause significant changes. Here the stimulus is presented on the left. **B)** Endpoints were expected to be further away from negative (red dots) relative to positive (green) and neutral (blue) distractors presented on the left. Similarly, endpoints were expected to be closer to positive relative to negative and neutral distractors. The blue circle is the target.

Experiment 1 demonstrated an effect of valence, but not approach-avoidance tendencies, on the late part of the reaching movement. There was therefore no influence of *valence automaticity* on *visuomotor automaticity*. A possible explanation for this is that the completion of the task did not rely on movement corrections. *Visuomotor automaticity* is only engaged during visuomotor adaptation (e.g. Day & Lyon, 2000). Unlike simple reaching where distractors are task-irrelevant, the success of visuomotor adaptation relies on responding to a task-relevant change. Thus, Experiment 1 was not a visuomotor adaptation task per se because it relied on movement “perturbations” caused by the appearance of a task-irrelevant distractor. Following this logic, it is possible that for such tendencies to influence visuomotor corrections they have to be task-relevant. Indeed, previous work has shown that task-instructions are necessary to trigger approach-avoidance tendencies (Eder & Rothermund, 2008; Lavender & Hommel, 2007). Importantly, the addition of task-instructions does not impede *valence automaticity* from arising. Chapter Four demonstrated that both top-down and bottom-up processes contribute to the selection of approach-avoidance actions. It is therefore possible to generate approach-avoidance goals and incorporate these into the on-going movement plan, yet still allow for a bottom-up influence of emotional tendencies.

As such, Experiment 2 investigated whether *valence automaticity* influenced *visuomotor automaticity* by making the emotional stimulus more task-relevant. Participants made visuomotor corrections towards or away from targets paired with emotional stimuli. The speed of movement corrections to emotional stimuli should reveal fast or slow pathways. If *valence automaticity* leads to faster responses, correcting towards positive stimuli should be faster compared to neutral or negative stimuli, and correcting away from negative stimuli should be faster than neutral or positive. Furthermore, if *valence automaticity* only influences the slow, top-down pathway, then this should be reflected in the later stages of movement. Accuracy and precision should be greater when moving towards positive stimuli and moving away from negative stimuli.

6.3. Experiment 1

6.3.1. Methods

6.3.1.1. Participants

16 healthy human subjects (nine males, mean age 24 ± 5 years) were recruited from the UCL psychology subject pool, with local ethical approval (UCL). All participants were right-handed and had normal or corrected-to-normal vision. Subjects gave written informed consent to participate in the study, and received monetary compensation for their time and travel (7.5£/h).

6.3.1.2. *Stimuli and experimental setup*

6.3.1.2.1. Target and distractor stimuli

Emotional pictures used as distractors were taken from the IAPS (Lang et al., 2008): 30 negative pictures with valences 1.6–3.8 (1.6 = most negative), 30 neutral pictures with valences 4.8 – 5.8 and 30 positive pictures with valences 6.2–8.2 (8.2 = most positive). All pictures (maximum 240 x 180 pixels) were matched for luminance. Arousal was matched as closely as possible despite positive and neutral pictures being naturally less arousing than negative stimuli. To standardise all the pictures, they were displayed as round by superimposing a black mask created in MATLAB (240 x 180; v.7.9.1.705; The MathWorks Inc.). By displaying the pictures as round they resembled the target.

Prior to choosing the pictures, a subset of pilot participants (n = 6) rated the pictures on their complexity on a scale of 1 – 5 (5 = most complex). Only pictures with a rating of 3 or less were chosen for the actual experiment. Pictures were presented to the left or the right of the target in a random order throughout the 8 blocks of trials.

A blue circle (176 x 176 pixels) was presented as the target at two different heights, separated by 1cm. It has been suggested that the brain can predict biomechcanical properties of potential actions before the initiation of movement (Cos et al., 2011; Messier & Kalaska, 1999), thereby influencing motor planning. For this reason, and to avoid over training, two target locations were chosen which were randomised throughout the experiment, meaning subjects also maintained attention throughout the task. Participants still planned movements to the two target locations in parallel, but the correct one was chosen once the target was displayed (see Cisek & Kalaska, 2005). All stimuli were presented on a 20-inch screen (SONY Trinitron, refresh rate: 120 Hz), using the Cogent 2000 toolbox (University College London, http://www.vislab.ucl.ac.uk/Cogent2000/index.html) and MATLAB.

The experiment consisted of twelve conditions depending on the position of the target (upper or lower), the position of the distractor (left or right of the target) and the valence of the distractor (negative, neutral or positive). There were a total of 480 trials, with 40 trials in each condition.

6.3.1.2.2. Recording reaching trajectories in the experimental 3D space

The three-dimensional (3D) coordinates of trajectories were recorded at a sample frequency of 800Hz using two Cartesian Optoelectronic Dynamic Anthropometer (CODA) sensor units (Codamotion Inc). The recordings derived from the composite of the two sensor units placed on each of the participant’s sides were used. CODA cameras record the X, Z (0.05mm standard deviation resolution) and Y (0.3mm standard deviation resolution) coordinates of the arm movement in real time (sub-millimetre resolution) by means of infrared emitting diode (IREDs) markers positioned on the participant’s arm. A total of 8 markers were used: 4 markers were placed the participants’ right arm and the remaining 4 on defined the screen boundaries, allowing continual measurement of the speed and location of the hand relative to the screen. Marker 1 was placed on the tip of the right index finger nail, marker 2 on its metacarpopharyngeal joint, marker 3 on the wrist bone, and marker 4 on the elbow. By recording from four locations on the arm, it allowed for visual inspection of movements to ensure participants were correctly completing the task. However, only data from marker 1 was used but the other markers were recorded as potential backups.

6.3.1.2.3. Calibration of the experimental setup

For each subject, the CODA cameras were calibrated prior to the main experiment to define the experimental 3D space and the position of the screen inside this space. The position of the target and distractors presented on the screen were subsequently defined relative to the 3D space. Participants placed their right index finger on a cross appearing on each of six previously defined locations on the screen for two seconds. Two locations corresponded to the target, and the remaining four locations corresponded to the position of the distractor. To define the starting position, subjects rested their finger on the touch sensor. To place all subjects' data in the same 3D space during analyses, data from each subjects' calibration session were used for normalising the starting point and endpoint coordinates.

6.3.1.2.4. Detection of movement onset

To test for an early effect of the distractor presentation on the reaching trajectory, it was of critical importance to use a time-sensitive approach to detect the initiation of the reaching movement. Using a customised current-sensor, the initiation of a movement was detected with millisecond precision. A trigger was sent to the computer to begin a new trial as soon as the participants' finger touched the sensor. The release of the finger from the sensor triggered the presentation of the emotional distractor at precisely 25ms after finger release. Using a customised touch plate allowed detecting the presence of the finger without requiring any additional force from the participant's arm (i.e. button press). This approach facilitated participants to reproduce a reaching movement as naturally as possible.

6.3.1.3. Experimental procedure and design

Participants were seated in a darkened room with their head supported on a chinrest and their eyes fixated on the centre of the screen. They were instructed to place their right index finger on a sensor located 40 cm in front of the screen. This initiated the trial. A blue target was presented on the screen 100 ms after the start of the trial for a duration of 500 ms. Participants were instructed to release their finger from the sensor upon the presentation of the blue target **(Figure 6.2)**, and to reach the target as accurately and as fast as possible. 25ms after the finger release, an emotional distractor picture was presented (duration 50 ms) to the left or right of the target. The blue target was presented for 500ms only, meaning participants did not get visual feedback of how accurate they were. The location of the distractor (left/right), target (up/down) and valence (positive/neutral/negative) of the picture were randomised from trial-to-trial. The early presentation of the emotional stimulus allowed for the possibility of engaging fast or slow pathways.

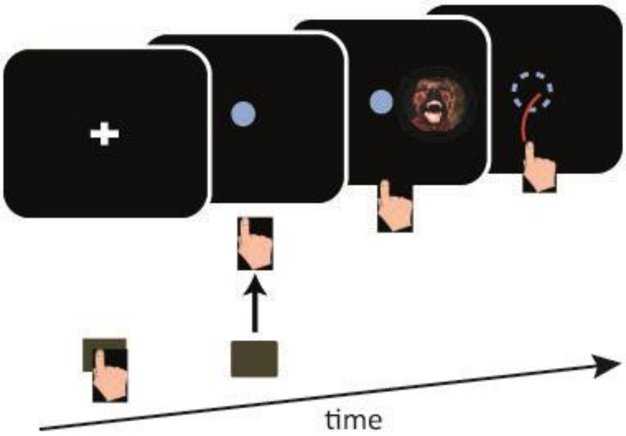


Figure 6.2. Task schematic for Experiment 1. Participants started with a fixation cross and with their right index finger resting on a touchplate (500 ms). Upon the presentation of a blue target, participants released their finger and reached towards the screen. The target remained on the screen for 500 ms. 25 ms after the release of the finger, an emotional distractor appeared either on the left or right side of the target for a duration of 50 ms. The target and distractor disappeared from the screen while participants completed their reaching movement (blue dotted line). A new trial would begin when the right index finger rested on the touchplate again.

Each participant performed a series of 8 blocks of 60 trials each, with a brief break between every block. Prior to the experiment they completed a training session of one block of 30 trials using blurred neutral pictures only to avoid pre-exposure to experiment pictures. Each picture was repeated 8 times in total.

6.3.1.4. *Picture ratings (valence/arousal/complexity)*

It is possible that each individual perceives an emotional picture in a different way (Bradley & Lang, 2007), and this may consequently affect how participants react to emotional distractors. To control for this, at the end of the experiment, each subject rated all the pictures presented according to their valence, arousal and complexity. They rated the valence and arousal on a scale of 1-9 on the computer keyboard. For valence, 1 represented extremely negative and 9 extremely positive. For arousal, 1 represented low arousing and 9 high arousing. To control for picture complexity, participants rated how easy or hard it was to perceive the content of every picture on a scale of 1 - 5; 1 being very simple and 5 very complex.

The subjective ratings for valence and arousal were subsequently compared against those of the IAPS (Lang et al. 2008). A paired-samples t-test was performed to compare subjective ratings to IAPS ratings. Results showed (see section 6.3.2.1) that subjective ratings were similar to the IAPS ratings. As such, the IAPS ratings were used for all analyses.

6.3.1.5. *Kinematic data analyses*

6.3.1.5.1. Data conversion and trajectory normalisation

For all analyses, CODA files were first exported into a text file and then imported into MATLAB (v. 7.10.0.499; the MathWorks) form. Time, position and velocity data were extracted for each X, Y and Z coordinate. Only data for marker one were used for the kinematics analysis. Data were analysed offline with custom written MATLAB code.

Trajectories were normalised to a common 3D space for all subjects. Because the calibration of the 3D space was done on an individual basis and because of the excellent spatial resolution of the sensor system (0.5 mm), the finger starting position for each subject differed between sessions and between trials, depending on the way the finger landed on the sensor. In order to calculate the average trajectory for each condition within each subject, trajectories were first normalised so that the starting point was always at zero (i.e. XYZ coordinates [0, 0, 0]). To do so each subject's sensor position coordinates of the 3D calibration session were subtracted from the starting point coordinates of every trial.

6.3.1.5.2. Kinematics of reaching trajectories

My central question was whether an emotional distractor can 'perturb' an ongoing movement, and lead to valence-specific fast corrections of the movement plan. These corrections are characterised by changes in the spatiotemporal parameters of movement set by the original movement plan, such as changes in the speed and magnitude of an arm movement.

To this end, several kinematic dependent variables were examined: peak velocity (PV), time of time of peak velocity (tPV), movement times (MT), and the integral (i.e. area under the curve) of each trajectory at three different time points (early, mid and late). Furthermore, because early movement properties are dissociated from later movement properties (Messier & Kalaska, 1999), the accuracy and precision of movement were also measured. How each of these variables contributes to investigating the main question is discussed further below.

6.3.1.5.3. Changes in the speed of execution: movement times and velocity

Two measures were expected to reveal influences on the temporal profile of reaching: movement times (MTs) and peak velocity (PV).

MT is defined as the total duration time of the movement, from movement initiation to reaching the screen. MT is affected by the spatiotemporal characteristics of reaching (Wong et al., 2015). The speed of movement completion may, for example, be slower or faster depending on the emotional content of the distractor. Similarly, a movement deviation caused by the appearance of the stimulus may mean the movement takes longer to complete. MT therefore indexes the speed and magnitude of movement. The starting point of the movement was calculated from when the tangential velocity exceeded 0.1 m/sec. The end of the movement was defined as the time point that the finger reached a virtual screen, calculated as 1 cm in front of the computer screen (Day & Lyon, 2000). MT was calculated by subtracting the starting time from the end time. To observe possible effects of distractor presentation, 25 ms were subtracted from all the times obtained (i.e. MT and tPV). All times are presented in milliseconds. Differences in the MT give an overall indication of the influence of emotion on action execution but do not inform of differences that occur early in the movement (e.g. influences on bottom-up mechanisms) and how these compare to later stages (e.g. influences on top-down mechanisms).

To assess influences on early vs. late kinematics during movement, I measured time of the PV. For example, a positive stimulus may speed up a movement because participants were making what is considered to be an “approach” action towards the screen. In contrast, negative pictures may slow down movement by activating a defensive system that leads to freezing (Stins et al., 2011). Importantly, unlike the MT, the PV is not affected by spatial properties of movement. That is, MTs account for the length of the movement, whereas PV doesn't. The time at which PV is reached is particularly important to answer whether re-planning is guided by fast vs. slow pathways. The PV and tPV were derived by measuring the tangential velocity to accommodate for the curvature of reaching movements. Tangential velocity refers to the instantaneous linear velocity of a body on a curved path and it is calculated by taking the linear velocity at every x and y coordinates. The units for PV are m/sec. The equation below displays how tangential velocity was calculated:

$$TV = sqrt(x\_velocity^2 + y\_velocity^2).$$

6.3.1.5.4. Changes in the magnitude of execution

Reaching deviations that occur as a result of presenting a distractor may not reflect motor planning processes that occur prior to the initiation of a movement, but may reflect motor planning that occurs in parallel with action execution. As suggested by other studies (Ambron & Foroni, 2015; Ambron et al., 2016; Welsh & Elliott, 2004), the emotional valence of a distractor may cause arm deviations either towards or away from the distractor location. These deviations may occur early or later in the movement, which can provide indication about the contribution from fast or slow pathways guiding visuomotor corrections (Day & Lyon, 2000). Early movement corrections may be guided by fast bottom-up pathways that are not yet influenced by later top-down mechanisms (McSorley, Haggard, & Walker, 2006). In contrast, if they occur later in the movement, they would reflect top-down mechanisms which are under the control of participants intentions (Day & Lyon, 2000).

Because previous work has shown that participants are able to correct their movement automatically in response to an environmental change at an early latency of 130-160 ms (Day & Lyon, 2000), each reaching trajectory was split into three sections (i.e. early [start of movement until 33.3% of total trajectory], mid [early until 66.6% of total trajectory] and late [mid until 100% of total trajectory] portions). This allowed me to observe at which point in the trajectory any movement deviations occurred following the appearance of the distractor. To quantify for differences in deviations across conditions the integral (i.e. area under the curve) was calculated on a trial-by-trial basis for each condition in each of the split portions. A mean across all trials for each condition was subsequently calculated. This was complemented by visual inspection of the laterality of these deviations for each subject for any significant results, following Day & Lyon (2000).

6.3.1.5.5. Accuracy, precision and arm biomechanics

Reaching accuracy and precision to target locations has been shown to be independent of the initial kinematics of a movement (Messier & Kalaska, 1999), instead reflecting top-down control. The later stage of movement therefore reflects conscious and top-down biases potentially guided by the subjects' intention (Day & Lyon, 2000).

Accuracy and precision were quantified by the distribution of the endpoints (i.e. where the index finger lands on the screen). Accuracy reflects how close the distribution of the endpoints is to the target, whereas precision reflects how spread out the distribution of the endpoints is. For example, the appearance of a negative distractor early in the movement may cause the endpoint of the movement to be further away from the target (i.e. an avoidance movement) thereby reducing the accuracy of reaching. Similarly, the appearance of emotional distractors may cause the distribution of endpoints to be more spread out than neutral distractors suggesting that emotional distractors disrupt the precision of reaching movements. The distribution of endpoints may also have an orientation that gives an indication of the direction of the spread of the endpoints. The orientation is important for revealing the "attract-repel" effect of emotional distractors. For instance, the orientation of the endpoint distribution may be in the opposite direction of where a negative distractor was presented, or closer to where a positive distractor was presented.

Prior to calculating accuracy, precision and movement orientation, each individual endpoint was first normalised to a common 3D space. Both target positions were normalised to have position coordinates (X0, Z0) and endpoint coordinates were subsequently normalised according to the new target position coordinates. To normalise the endpoint position according to a common target for all subjects, the target position coordinates defined during the subject's calibration session were subtracted from the coordinates of the endpoint in every trial and respectively for different conditions. This normalisation procedure was repeated to normalise the endpoint distribution according to the distractor position and hence using the subject's calibration coordinates for the distractor in the respective condition. The above normalisation process yielded new position coordinates of the trajectory endpoints, on a trial-by-trial basis, and created a common 3D space for all trials and all subjects. For simplicity's sake, because both targets were now (0, 0), endpoint data was collapsed between upper and lower targets, reducing the number of conditions to 6 (left distractor: positive, negative, neutral; right distractor: positive, negative, neutral).

To account for the accuracy of the movement, the Euclidean distance, that is the "straight-line" distance between two points, was calculated. Here, the Euclidean distance from the target was calculated by subtracting the target x and z coordinates taken from the calibration from the endpoint x and z coordinates. The distances are presented in mm.

Movement precision and the orientation of the spread of the endpoints were determined by fitting an ellipsoid (i.e. linear transformation of hyperspheres) over the distribution of the endpoints within a given condition (e.g. all the endpoints when a positive distractor was presented on the left), giving two variables: area and angle **(Figure 6.3)**. The area (i.e. spread of the endpoints) reflects the precision of reaching, whereas the angle reflects the orientation of the area relative to a vertical line on the target (horizontal vs. vertical). Negative angles indicate that the distribution of the endpoints lie clockwise from the vertical line, whereas positive angles are anticlockwise from a vertical line. The larger the angle, in positive and negative directions, the more horizontal a distribution is. This is important because if there is a deviation of the trajectory away from the target caused by the appearance of a distractor, then the ellipses should become more horizontal. Confidence ellipsoids were fitted onto the endpoint distributions using the x and z coordinates of all the endpoints within a given condition for each participant individually. A confidence ellipsoid assumes a multivariate normal distribution and a probability of 0.95; therefore the ellipses encompassed 95% of the endpoint population. The area and angle of the distributions for each condition for each participant were subsequently used to compare between different valences. The endpoint distributions were calculated in reference to the target and the distractor separately (van den Dobbelsteen et al., 2001). The units for area and angle are mm^2 and degrees, respectively.

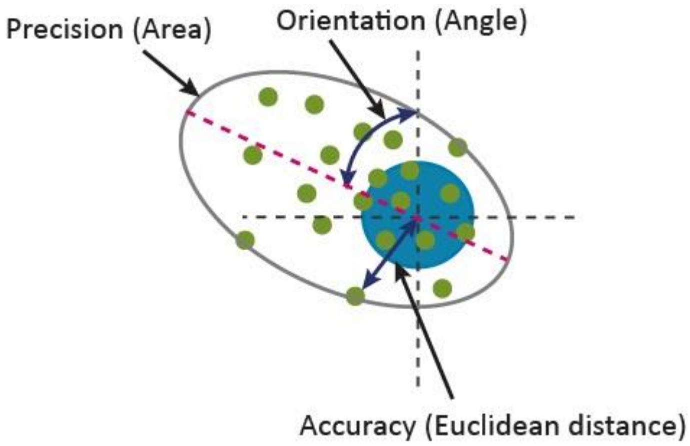


Figure 6.3. Schematic of an ellipsoid fitted over the endpoint distribution. The precision is given by the area of the ellipsoid (grey oval). The orientation of the ellipsoid (red dotted line) relative to the target reveals the direction of the distribution (either to the left or the right). Accuracy was calculated as the distance between the centre of each endpoint (green dots) and the centre of the target (blue circle).

6.3.1.6. Statistical analysis and trial exclusion

To include only complete trajectories in our dataset, a virtual screen was defined, calculated as 1 cm in front of the y-coordinate of the target (Day & Lyon, 2000). Trajectories that started before the presentation of the target (0.7%), 500 ms after the target presentation (3.5%) or where there was no movement at all (0.1%) were excluded from the analysis. Trials in which the trajectory deviated from a straight line by more than two standard deviations were considered outlier trajectories and were excluded from the data (6.7%). Outliers from the means for PV, tPV, Euclidean distance and integrals obtained from the analysis were calculated for each variable, per condition and for each individual subject using Grubb’s test, α = 0.05 (7.3%). In total, 18.2% of trials were excluded from the data analysis.

For the statistical analysis, the mean value of all the trajectories was first obtained, for each condition and every subject for the variables examined (PV, tPV, integral, Euclidean distances, ellipsoid angle and area). Statistical analysis was conducted using SPSS statistics software (v 22).

To investigate the effects of emotional valence and distractor location on reaching trajectories, a within-subjects 3x4 repeated-measures ANOVA (RM-ANOVA) with factors *Picture Valence* (Negative vs. Neutral vs. Positive) and *Presentation* (Target above-Distractor left vs. Target above-Distractor right vs. Target below-Distractor left vs. Target below-Distractor right) was performed. Mauchly's test of sphericity was measured to validate the ANOVA. If the assumption of sphericity was violated, a Greenhouse-Geisser correction was applied. For all analyses, partial-η^2 is reported as a measure of effect size. Statistical threshold was fixed at 0.05. Post-hoc Bonferroni corrections were made to correct for multiple comparisons. Significant interactions were followed up using two-tailed paired-sample t-tests. RT means and standard error of the mean (SEM) are given, and for paired-samples t-tests Cohen's *d* is reported.

To compare the effects of *Valence* only (positive vs. neutral; negative vs. neutral), a separate analysis was conducted with all measures normalised relative to the Neutral distractors, which were used as a baseline condition. Normalisation took place by subtracting values for each variable for the neutral distractors from those for positive and negative distractors. As such, all dependent variables for Positive and Negative distractors were normalised according to this baseline for comparison purposes. Paired sample t-tests were carried out between the normalised measures.

6.3.1.7. Control analyses: influence of the arousal of the distractors

It has been previously suggested that arousing pictures capture attention and influence the trajectory of goal-directed movements (Day, Shyi, & Wang, 2006; Most, Smith, Cooter, Levy, & Zald, 2007). Based on previous evidence, it was expected that highly arousing emotional stimuli would increase the speed of the trajectories whilst decreasing their accuracy (Coombes, Higgins, Gamble, Cauraugh, & Janelle, 2009). To investigate the effect of the arousal of the distractors on reaching trajectories, a median-split of the data was conducted, separating pictures into highly arousing distractors (pictures rated above 5 in the IAPS arousal scale) and low arousing distractors (pictures rated below 5 in the IAPS arousal scale).

Data were then re-analysed as above for low vs. high distractors. An RM-ANOVA with factors *Arousal* (high vs. low) and *Presentation* (Target above-Distractor left vs. Target above-Distractor right vs. Target below-Distractor left vs. Target below-Distractor right) was performed.

6.3.2. Results

6.3.2.1. *Individual picture ratings*

To control for individual differences, participants rated each picture on their valence and arousal. Paired samples t-tests revealed that negative and neutral pictures were not rated differently from the IAPS (neg-IAPS = 2.63 ± 0.00, neg-rate = 2.67 ± 0.19; neut-IAPS = 5.00 ± 0.00, neut-rate = 5.07 ± 0.07). Positive pictures were rated significantly less positive than the IAPS ratings (pos-IAPS: 7.57 ± 0.00, pos-rate: 6.77 ± 0.21; $t_{(15)} = 6.33$, $p < 0.001$) but positive nonetheless (all positive pictures were considered to have a ratings of 6.7 or above). The results suggest that subjects perceived pictures as being their correct valence.

For arousal, paired t-tests revealed that negative pictures were not rated differently from the IAPS (neg-IAPS = 6.00 ± 0.00, neg-rate = 5.80 ± 0.38). However, both neutral (neut-IAPS = 3.00 ± 0.00, neut-rate = 2.07 ± 0.38; $t_{(15)} = 2.43$, $p = 0.029$) and positive (pos-IAPS: 5.00 ± 0.00, pos-rate: 3.80 ± 0.36; $t_{(15)} = 3.38$, $p = 0.004$) pictures were rated as being significantly less arousing than the IAPS ratings. In general, subjects perceived low-threatening stimuli (i.e. neutral and positive) as less arousing.

6.3.2.2. *Effects of Valence on reaching kinematics*

All of the results below represent effects of distractor *valence* and the target/distractor location on arm reaching movements.

6.3.2.2.1. Kinematic measures (PV, tPV, MT)

Movement speed: Average Peak Velocity of arm reaching

Differences in the PV reveal if the valence of the distractor affected how fast participants reached towards the target. PV was affected by the location of presentation of the distractor and the target (**Figure 6.4**; *Presentation*, $F_{(3, 42)} = 4.01$, $p = 0.013$, $\eta^2_p = 0.22$).

When the distractor was presented on the left side, PV was lower for the upper compared to the lower target (upper: 1.10 ± 0.05 m/sec, lower: 1.11 ± 0.05 m/sec; $t_{(15)} = -2.18$, $p = 0.047$, Cohen's d = -0.48). Participants were therefore faster when the target was presented in the upper positive compared to the lower position irrespective of the distractor location. This difference is most likely attributable to the biophysical properties of the arm and not an experimental manipulation. That is, participants follow a path that allows for the easiest and greatest arm mobility (Hogan, 1985a, 1985b). By essentially following the easiest movement path, participants presumably are also faster. Valence therefore did not impact how fast participants moved.

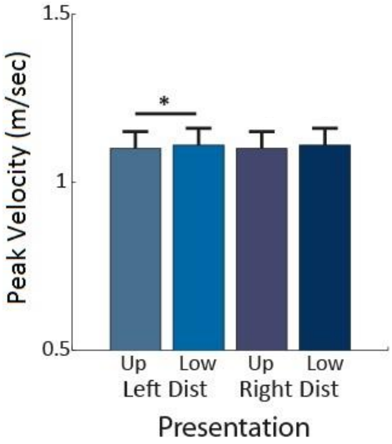


Figure 6.4. Influence of presentation on peak velocity. Reaching was faster when moving to upper targets when left and right distractors were presented. Error bars (+1 S.E.M) * significant at p < 0.05 level.

Time of Peak Velocity

There was no significant effect of the *Valence* of the distractor or the side of *Presentation* of the target and distractor on the time at which PV was reached.

Movement time (duration) of arm trajectories

There was no significant effect of *Valence* or *Presentation* on the duration of the trajectory. The average overall MT was 358 ± 24 ms. MT was therefore not affected by speed or changes in the trajectory.

In sum, the lack of effects of valence on all kinematic variables above demonstrates that emotional distractors and their associated response tendencies do not influence the early or late kinematics of action execution.

6.3.2.2.2. Effects of valence on trajectory deviations: Integral of the trajectory (area under the curve)

Early and mid-trajectory deviations from a straight line

There was no effect of *Valence* or *Presentation* on the area of the early or middle part of the trajectory.

Late trajectory deviations from a straight line

There was an effect of *Valence* of the distractor and the type of *Presentation* on the area of the late part of the trajectory (*Valence*Presentation*, $F_{(6, 84)} = 2.09$, $p = 0.063$, $\eta^2_p = 0.13$). When split for each presentation, results showed that this interaction was primarily driven by a *Valence* effect when the target was above and the distractor was on the right ($F_{(2, 28)} = 3.97$, $p = 0.030$, $\eta^2_p = 0.22$). Follow-up tests showed that the integral area for negative distractors was significantly larger than the area for positive distractors (neg: 37382 ± 1993 mm^2, pos: 36630 ± 1878 mm^2; $t_{(14)} = 2.75$, $p = 0.016$, Cohen's d = 0.70). There was no difference in the integral between emotional and neutral distractors. Thus, negative distractors appeared to cause a large deviation of the trajectory in comparison to positive distractors, but only during the late phase of a movement. Visual inspection of trajectories for all subjects when negative distractors were presented on the right confirmed that this deviation was indeed larger than positive distractors (**Figure 6.5A and C**). However, visual inspection also showed that this deviation was always to the right, irrespective of whether the distractor was presented on the left or right, demonstrating biophysical effects of the arm (**Figure 6.5**).

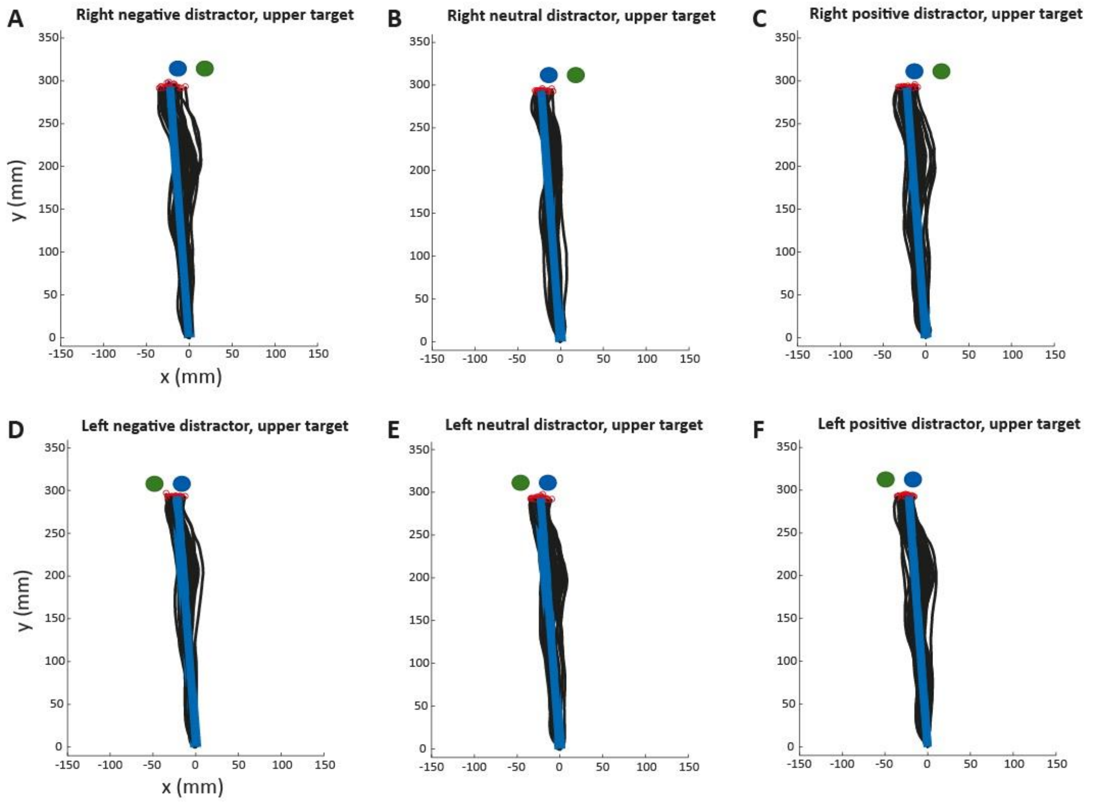


Figure 6.5. Raw trajectories for subject 1. A, B, C) Trajectories when the distractor was presented in the right demonstrating a larger deviation towards the right for negative distractors on the later part of the trajectory. Blue line depicts a straight-line trajectory for comparison. Raw trajectories are drawn in black. Blue circle represent the target, green circle represents the distractor. **D, E, F)** Comparison trajectories when the distractor was presented on the left demonstrating a deviation towards the right. Late trajectory deviations all occur towards the right irrespective of distractor location.

In sum, there were no trajectory deviations in the early part of reaching, whereas the latter part appeared to be affected by the valence of the distractor. In line with Day & Lyon (2000), these results suggest that top-down, cortical mechanisms were likely to be responsible for negative stimuli influencing action execution. Changes in the later portion of the trajectory however, did not show an “attract” or “repel” effect of emotional distractors, demonstrating no incidental effects of approach-avoidance tendencies on action execution.

6.3.2.2.3. Effects of Valence on reaching accuracy, precision and endpoint orientation

Accuracy of reaching: Euclidean distance of the endpoint from the target

The Euclidean distance reflects the accuracy of reaching movements. Results showed that accuracy was affected by the location of presentation of the distractor and the target

(**Figure 6.6**; *Presentation*, $F_{(1.04,\ 14.6)} = 20.94$, $p < 0.001$, $\eta^2_p = 0.60$). The distance from the target was smaller when the upper target was presented compared to the lower target, but this distance was unaffected by the side of distractor presentation. When the distractor was presented on the left side, the distance from the upper target was smaller compared to the lower target (upper: 22± 1 mm, lower: 35 ± 2 mm; $t_{(14)} = -4.61$, $p < 0.001$, Cohen's d = -1.21). Equally, when the distractor was presented on the right side, the distance from the upper target was also shorter compared to the lower target (upper: 21 ± 1 mm, lower: 35 ± 2 mm; $t_{(14)} = -4.63$, $p < 0.001$, Cohen's d = -1.20). Accuracy was better when reaching to the upper target. Thus, there was no effect of emotional valence on the accuracy of reaching, and instead any differences presented here may be attributable to the biophysical properties of the arm and not an experimental manipulation.

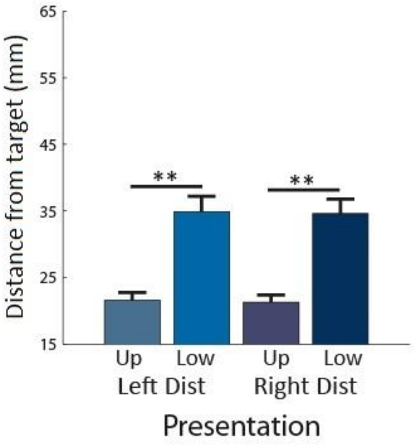


Figure 6.6. Effect of target and distractor presentation on the accuracy. Distance of the endpoints from the target was smaller for the upper target, irrespective of where the distractor was presented. Error bars (+1 S.E.M.); ** significant at the p <0.001 level.

Area of the ellipse: Precision of reaching

The area of the ellipse reveals the precision of reaching movements. The greater the area, the less precise movements are. For precision there was a significant main effect of *Valence* ($F_{(1.2,\ 18.4)} = 9.02$, $p = 0.005$, $\eta^2_p = 0.38$), indicating that the emotional content of the distractors influenced the precision of reaching trajectories **(Figure 6.8A)**. Both negative and positive distractors significantly improved the precision of reaching towards the targets relative to neutral distractors (negative: 1260 ± 101 mm^2, neutral: 1303 ± 93 mm^2, positive: 1279 ± 94 mm^2; neg-neutral: $t_{(15)} = -3.17$, $p = 0.006$, Cohen's d = -1.01; pos-neutral: $t_{(15)} = 2.87$, $p = 0.012$, Cohen's d = 0.72). The area when negative distractors were presented was also significantly smaller than when positive distractors were presented ($t_{(15)} = -2.57$, $p = 0.022$, Cohen's d = -0.34). This main effect was qualified by a 2-way *Valence*Presentation* interaction (**Figure 6.7;** $F_{(1.7,\,25.2)} = 19.30$, $p < 0.001$, $\eta^2_p = 0.56$). This interaction was broken down for each *Valence*.

For negative distractors, there was a significant main effect of *Presentation* ($F_{(1.5,\,21.8)} = 4.19$, $p = 0.040$, $\eta^2_p = 0.22$). When distractors were presented on the left, precision differed between the upper and lower targets, with greater area for lower compared to upper targets (upper: 1185 ± 78 mm^2, lower: 1260 ± 93 mm^2; $t_{(15)} = -3.89$, $p = 0.001$, Cohen's d = -1.54). However, when the distractor was presented on the right, there was no difference in the area between the upper and lower targets.

For neutral distractors, there was no significant main effect of *Presentation* on the area of the ellipse.

For positive distractors, there was a significant main effect of *Presentation* ($F_{(1.4,\,21.0)} = 7.28$, $p = 0.008$, $\eta^2_p = 0.33$). When the distractor was presented on the left side, there was no difference in precision between the upper and lower targets. However, when the distractor was presented on the right side, precision differed between upper and lower targets (upper: 1365 ± 128 mm^2, lower: 1125 ± 104 mm^2; $t_{(15)} = 9.42$, $p < 0.001$, Cohen's d = 2.12).

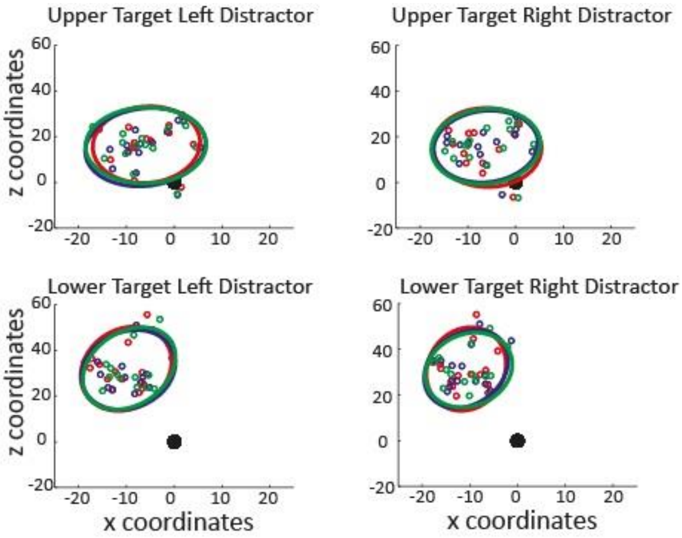


Figure 6.7. Ellipses for reaching precision split into valence and each presentation. Endpoints were generally closer to the upper target relative to lower target (black dots). For negative (red dots) distractors, movements were more precise (i.e. area of red ellipse was smaller) when reaching to upper targets, whereas for positive pictures (green dots) reaching was more precise towards lower targets. There were no effects for neutral (blue dots).

Orientation of the spread of the endpoints: angle of the ellipse

The angle of the ellipse reflects the orientation of the spread of the endpoints which may inform about the biomechanics of the arm, taking into account measures such as, for example, the elbow torque and joint angles (Hogan, 1985). If the valence of the distractor causes an online deviation of the trajectory away from the target, then the angle of the ellipses should be as horizontal as possible (e.g. larger). Negative angles demonstrate that the endpoints lie mostly clockwise from a vertical line, whereas positive angles demonstrate the endpoints lie anticlockwise.

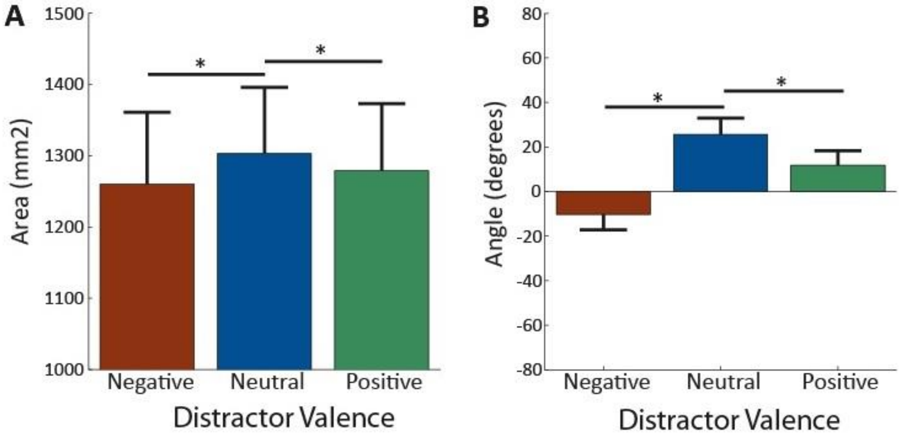


Figure 6.8. Area (precision) and angle (orientation) of the endpoint distributions. A) Main effect of valence on reaching precision. The spread of the endpoints was significantly smaller for emotional relative to neutral pictures. **B)** Main effect of valence on the orientation of the ellipses. When negative distractors were presented, orientation was negative (clockwise from a vertical line), for neutral and positive distractors, orientation was positive (anticlockwise from a vertical line). Error bars (+1 S.E.M.); * significant at the p <0.05 level

The results showed that angles were significantly affected by the *Valence* of the distractor ($F_{(2, 30)} = 13.87$, $p < 0.001$, $\eta^2_p = 0.48$), with negative angles for negative, and positive angles for positive and neutral distractors **(Figure 6.8B)**. Angle was also influenced by the location of *Presentation* of the target and distractor ($F_{(1.5, 22.9)} = 16.47$, $p < 0.001$, $\eta^2_p = 0.52$), with negative angles for upper and positive angles for lower targets. However, these main effects were qualified by a 2-way *Valence*Presentation* interaction ($F_{(2.8, 41.6)} = 3.31$, $p = 0.032$, $\eta^2_p = 0.18$). This interaction was broken down for each *Valence*.

For negative distractors, there was a significant main effect of *Presentation* ($F_{(1.3, 18.7)} = 12.77$, $p < 0.001$, $\eta^2_p = 0.46$). Overall, for left distractors, the angle was negative compared to the positive angle of the ellipse when the right target was presented (left: -57.88 ± 13.11 deg, right: 37.38 ± 15.58 deg), indicating that the endpoints were located in the opposite direction to the location of the distractor, suggesting an avoidance mechanism. Furthermore, when the upper target was presented, there was a difference in angle between the left and right (left: -56.43 ± 14.86 deg, right: 32.23 ± 16.62 deg; $t_{(15)} = -3.17$, $p = 0.006$, Cohen's d = -0.79). Equally, when the distractor was presented on the right side, there was a difference in the angles between the upper and lower targets (upper: -59.46 ± 12.23 deg, lower: 42.58 ± 16.20 deg; $t_{(15)} = -4.28$, $p = 0.001$, Cohen's d = -1.09).

For neutral distractors, there was a significant main effect of *Presentation* ($F_{(3, 45)} = 14.91$, $p < 0.001$, $\eta^2_p = 0.50$). In contrast to above, the presentation of the distractor did not influence the angle. Instead, angle was influenced by the upper or lower target presentations only. In general, when the upper target was presented, the angle was negative compared to the positive angle when the lower target was presented (upper: -7.69 ± 12.74 deg, lower: 59.12 ± 6.28 deg; $t_{(15)} = -4.73$, $p < 0.001$, Cohen's d = -1.25). When the left distractor was presented, there was a difference in the angles between the upper and lower targets (upper: -53.86 ± 14.93 deg, lower: 38.27 ± 19.41 deg; $t_{(15)} = -3.93$, $p = 0.001$, Cohen's d = -0.99). However, when the right distractor was presented, there was no difference in angle between the upper and lower targets.

For positive distractors, there was a significant main effect of *Presentation* ($F_{(1.9, 28.5)} = 7.59$, $p = 0.003$, $\eta^2_p = 0.34$). When the upper target was presented, the angle was negative compared to the positive angle of the ellipse when the lower target was presented (upper: -22.44 ± 14.81 deg, lower: 45.88 ± 13.43 deg; $t_{(15)} = -2.72$, $p = 0.016$, Cohen's d = -0.68). When the left distractor was presented, there was a difference in the angles between the upper and lower targets (upper: -56.00 ± 15.01 deg, lower: 11.33 ± 20.76 deg; $t_{(15)} = -3.21$, $p = 0.006$, Cohen's d = -0.83). However, when the right distractor was presented, there was no difference in angle between the upper and lower targets.

In sum, accuracy was guided by the biomechanics of the arm. Accuracy was greater when reaching for the upper target (i.e. endpoints were closer to the upper target) and endpoints being closer to the left distractor. Indeed, when thinking about the easiest movement path the right hand can make, due to the elbow joint torque properties, the right arm inevitably tends to land on the left of a straight line. Previous work has demonstrated that the arm follows a movement path that is biomechanically viable and easier (Cos et al., 2011; Cos et al., 2014). Unlike accuracy, precision was influenced by the valence of the distractor. Participants were more precise (i.e. less spread out) when presented with negative compared to positive and neutral pictures. Precision was also influenced by the valence and biophysics of the arm, with precision being different between the upper and lower targets depending on the valence of the distractor. In terms of the orientation of the endpoints, the results show that only negative distractors influenced the location of the endpoints, with endpoints located away from left distractors (i.e. clockwise from a vertical line) and away from right distractors (i.e. anticlockwise from a vertical line). Both precision and orientation of the endpoints were influenced by negative valence, demonstrating an influence of negative stimuli on action execution, in line with Chapter Four.

6.3.2.2.4. Measures normalised to the baseline (Neutral) condition

There were no differences between *positive* or *negative* valence in any of the above measures (tPV, PV, MT, Target Euclidean distance, Distractor Euclidean distance and area under the curve) when normalised relative to the *neutral* (baseline) condition, demonstrating no effect of valence on kinematic measures relative to neutral distractors.

6.3.2.3. Effects of Arousal on movement kinematics

Similar to the results presented above, all of the results below represent effects of distractor *arousal* (high vs. low) and the target/distractor location on the kinematics, accuracy and precision of arm reaching movements.

6.3.2.3.1. Kinematic measures (PV, tPV, MT)

Movement speed: Average Peak Velocity of arm reaching

PV was affected by the presentation of the distractor and the target (*Presentation*, $F_{(3, 42)} = 3.74$, $p = 0.018$, $\eta^2_p = 0.21$). PV was lower when reaching for upper targets compared to lower targets (upper: 1.10 ± 0.05 m/sec, lower: 1.11 ± 0.05 m/sec; $t_{(15)} = -2.23$, $p = 0.043$, Cohen's d = -0.59). When the distractor was presented on the left side, PV was lower for the upper compared to the lower target (upper: 1.10 ± 0.05 m/sec, lower: 1.11 ± 0.05 m/sec; $t_{(15)} = -2.18$, $p = 0.047$, Cohen's d = -0.48). Movements were therefore faster when reaching for the upper target. This difference may be attributable to the biophysical properties of the arm and not an experimental manipulation.

Time of Peak Velocity

There was no significant effect of *Arousal* or *Presentation* on the time at which PV was reached.

Movement time (duration) of arm trajectories

There was no significant effect of *Valence* or *Presentation* on the duration of the trajectory.

6.3.2.3.2. Trajectory deviations from a straight line: Integral of the trajectory (area under the curve)

There was no effect of *Arousal* or *Presentation* on the area of the early, middle or late part of the trajectory, indicating that arousal did not cause any significant deviations.

In sum, kinematic measures were not affected by the arousal of the distractors but were instead influenced by the biophysical properties of the arm.

6.3.2.3.3. Effects of Arousal on accuracy, precision and angle

Accuracy of reaching: Euclidean distance of the endpoint from the target

Accuracy was affected by the presentation of the distractor and the target (**Figure 6.9**; *Presentation*, $F_{(1.03, 14.5)} = 22.24$, $p < 0.001$, $\eta^2_p = 0.61$). The distance of the endpoints was smaller for upper targets compared to lower targets (upper: 21 ± 1 mm, lower: 35 ± 2 mm; $t_{(14)} = -4.72$, $p < 0.001$, Cohen's d = -1.25), but this distance was unaffected by the side of distractor presentation. Thus, when the distractor was presented on the left, accuracy was better for upper compared to lower targets (upper: 22 ± 1 mm, lower: 35 ± 2 mm; $t_{(14)} = -4.76$, $p < 0.001$, Cohen's d = -1.27). Equally, when the distractor was presented on the right, accuracy was better for upper compared to lower targets (upper: 21 ± 1 mm, lower: 35 ± 2 mm; $t_{(14)} = -4.64$, $p < 0.001$, Cohen's d = -1.23).

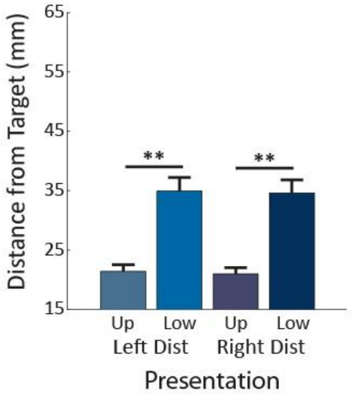


Figure 6.9. Accuracy of reaching towards upper and lower targets. Participants were more accurate in reaching to upper than to lower targets, as shown by the smaller Euclidean distance to the target. Error bars (+1 S.E.M.); ** significant at the p <0.001 level

Precision of reaching: area of the ellipse

There was a significant main effect of *Presentation* ($F_{(1.5, 20.8)} = 10.17$, $p = 0.002$, $\eta^2_p = 0.42$) on the area of the ellipse that was qualified by a 2-way *Arousal*Presentation* interaction ($F_{(1.4, 20.0)} = 4.83$, $p = 0.029$, $\eta^2_p = 0.26$). This interaction was broken down for each *Arousal*.

For distractors with low arousal, there was a significant main effect of *Presentation* ($F_{(1.3, 18.3)} = 9.58$, $p = 0.004$, $\eta^2_p = 0.41$). When the distractor was presented on the left, there was no difference in precision between the upper and lower targets. However, when the distractor was presented on the right, precision was better for upper targets compared to lower targets (upper: 3175 ± 462 mm^2, lower: 3398 ± 500 mm^2; $t_{(15)} = -4.26$, $p = 0.001$, Cohen's d = -1.55).

For distractors with high arousal, there was a significant main effect of *Presentation* ($F_{(1.9, 26.1)} = 9.76$, $p = 0.001$, $\eta^2_p = 0.41$). When the distractor was presented on the left, there was no difference in the area between the upper and lower targets. However, when the distractor was presented on the right, the area for upper targets was smaller compared to lower targets (upper: 3066 ± 446 mm^2, lower: 3490 ± 531 mm^2; $t_{(15)} = -4.63$, $p < 0.001$, Cohen's d = -3.54). Precision was better when reaching for upper targets but only when the distractors were presented on the right.

Orientation of the spread of the endpoints: angle of the ellipse

For the angle of the ellipse there were no significant effects of *Arousal* or *Presentation*, indicating no effect of the biomechanics of the arm on reaching endpoints.

In sum, the data did not show any effects of arousal on the early or late phases of movement. Movement properties were instead influenced by the biophysical properties of the arm, with participants following the easiest and most achievable movement paths. Participants were faster, more accurate and more precise when reaching for upper targets compared to lower targets.

6.3.3. <u>Discussion</u>

Experiment 1 tested the hypothesis that action execution and concurrent motor planning are influenced by emotional changes in the environment. More specifically, it investigated whether automatic approach-avoidance tendencies (*valence automaticity*) may influence the fast vs. slow pathways (*visuomotor automaticity*) underlying movement re-planning. If emotion indeed has privileged access to the motor system, then I would predict that such distractors have the potency to 'alter' ongoing movement. To this end I conceived an experiment that allowed for quantifying the influence of emotional distractors on movement kinematics.

Positive distractors were expected to "attract" trajectories and negative distractors to "repel" trajectories, relative to neutral distractors. Given the proposed prioritisation of emotional stimuli by the visual system (Ohman et al., 2001; Vuilleumier et al. 2001), I expected that any influences on ongoing movement would occur earlier for emotional relative to neutral stimuli. Earlier changes should reflect bottom-up processes. If instead, corrections are guided by top-down influences, then changes should be observed towards the end of the movement, reflected by the accuracy and precision of movement.

The results showed that the later, but not early, stage of execution was influenced by emotional valence: negative distractors led to greater deviations at the end of the movement, and accuracy and precision were better in emotional relative to neutral contexts. Furthermore, action execution was influenced by the biophysical properties of the arm, indicating that participants made movements that were easier to achieve and allowed for greatest arm mobility. Overall, there was no evidence for *valence automaticity*, that is, approach-avoidance tendencies were not triggered by emotional distractors, and this did not manifest in the spatiotemporal characteristics of movement. This result suggests an independence of response tendencies and motor execution. Changes in execution are therefore driven by emotional valence but not by emotional approach-avoidance tendencies, in line with the results reported in Chapter Four.

Valence influences the end-stage of action execution

Valence, but not approach-avoidance tendencies, affected the latter stage of movement. Greater movement deviations occurred when negative relative to positive and neutral distractors were presented and positive and negative distractors improved the precision of execution relative to neutral distractors. Importantly these effects were not observed for arousal, confirming that the valence of the emotional picture was responsible for the effects. In contrast, there was no evidence of valence effects on the early or middle parts of the trajectory.

The effect of valence argues against privileged access of emotional information to the motor system driven by fast, bottom-up processes. Instead, the later effects reflect the engagement of top-down attentional mechanisms which subsequently may have guided feedback mechanisms at the end stage of execution (Pessoa et al., 2002). Indeed, the speed of feedback mechanisms has been suggested to be reliant on the speed of sensory processing during ongoing movement (Desmurget & Grafton, 2000; Striemer et al., 2010). Importantly, the results suggest that emotional stimuli were prioritised relative to neutral stimuli, possibly due to increased perceptual processing and the engagement of top-down attentional processes driven by the conscious perception of emotional content (Pessoa et al. 2002; Pessoa &, 2010). Indeed, the late effects on execution probably arose from the conscious perception of emotional information. For instance, work has shown that the earliest emotional processing can occur is 100 ms (Pizzagalli, Regard, & Lehmann, 1999), although neural data shows that this is closer to 200 ms (Oya, Kawasaki, Howard, & Adolphs, 2002). Emotional stimuli are therefore typically processed 100-200 ms after their initial presentation (Olofsson, Nordin, Sequeira, & Polich, 2008; Schupp, Junghöfer, Weike, & Hamm, 2004). Speculatively, in this context, emotional information may have been prioritised relative to neutral but only consciously perceived towards the end of the movement.

Valence also influenced the orientation of the spread of the endpoints compared to neutral stimuli. For example, for both positive and negative distractors presented on the left, the majority of the endpoints were found to the right of the targets, whereas for distractors presented on the right, the endpoints were found to the left of the targets. Importantly, orientation was not influenced by arousal, implying that this is a purely valence-driven effect. Coupled with precision, the results suggest that valence also causes movements to end up further away from the emotional stimulus. This is supportive of previous work showing that movements are biased away from distractors due to attentional inhibition (Howard & Tipper, 1997). Here, the emotional distractor was prioritised and competed for attention with the target as the movement was on-going, according to earlier proposals (Howard & Tipper, 1997; Welsh, Elliott, & Weeks, 1999; Welsh, 2011; Welsh & Elliott, 2004). A top-down attentional mechanism has been suggested to “lock” attention to the target and be involved in suppressing the natural tendency to move towards competing targets (Tipper et al. 1998). Thus, because emotional distractors were prioritised by attention, a higher degree of top-down control was necessary to suppress the tendency to move to the competing distractor. This resulted in greater deviations away from the distractor, and trajectories ending up further away from the target than was originally intended. The extent of the deviation away depends on the relative activation of the response elicited by the emotional distractor (Tipper et al., 1997).

The current results demonstrate an influence of valence, but not approach-avoidance tendencies, on motor re-planning during action execution driven by higher-order processes. The results suggest a slow and intentional mechanism underlying motor updating during execution in emotional contexts, driven by conscious top-down attentional control

(Day & Lyon, 2000; Tipper et al., 1998). This slower, intentional mechanism is likely guided by prioritised emotional information. These results are also supportive of previous chapters that showed conscious evaluation of the emotional stimulus is essential for driving emotional influences on the motor system. Importantly, the results complement results from Chapters Two and Three which had suggested the involvement of top-down mechanisms on action selection. The results suggest top-down mechanisms influenced by emotional information that serve to update movements in response to emotional changes in the environment. However, these top-down mechanisms are not influenced by approach-avoidance tendencies, suggesting different emotional top-down influences on action selection and execution.

The biomechanics of the arm influences reaching kinematics, accuracy and precision

While valence seems to affect reaching movements, it is possible that the biophysics of the arm may have also contributed. I therefore controlled for this. The results show that many of the effects observed were indeed influenced by biophysical properties. That is, movements that are biomechanically easier to make, combined with the different target and distractor locations, resulted in differences in action execution. Overall, reaching movements were faster, more accurate and more precise when reaching to upper targets, suggesting that planning of movements to upper targets was biased by what was considered biomechanically easier for participants. There is evidence that biomechanical costs (i.e. the degree of difficulty of the movement) (Cos et al., 2011, 2014; Marcos et al., 2015; Sainburg & Kalakanis, 2000) are incorporated into movement planning prior to initiation and influence the kinematics of arm reaching.

Movements were also faster for distractors presented on the right than the left. This suggests that the side that the distractor is presented in makes a difference to how quickly and accurate execution is. Faster movements when distractors were presented on the right might have been due to the fact that visual information processed on the left did not have to cross to motor areas. Thus, feedback was influenced faster for right distractors. For example, when reaching towards the right with the right arm, movements are faster than when reaching towards the left, presumably due to the time taken to transfer information between hemispheres (Day & Lyon, 2000). However, given that in the current experiment participants only reached with their right arm, one cannot conclusively determine that interhemispheric crossing may account for the results.

These data therefore reveal two different elements of planning during reaching. Firstly, movement planning takes biomechanical costs into account. Secondly, these plans are updated in real time throughout the movement.

Active approach and avoidance in emotional contexts may influence reaching trajectories

In sum, Experiment 1 demonstrated an influence of valence, but not approach-avoidance tendencies, on motor re-planning during action execution driven by higher-order processes. However, Experiment 1 also suggested that there is no effect of *valence automaticity* on early, bottom-up pathways. There was therefore no influence of *valence automaticity* on bottom-up or top-down processes during execution.

A possible reason for this may be because the completion of the task did not rely on movement corrections. Visuomotor automaticity is only engaged during visuomotor adaptation (e.g. Day & Lyon, 2000). Unlike simple reaching where distractors are task-irrelevant, the success of visuomotor adaptation relies on responding to a task-relevant change. Participants may therefore be required to correct relative to emotional stimuli. If approach-avoidance tendencies are to influence movement trajectories, the context may need to require participants to engage in approach and avoidance movements. Indeed, work has shown that approach-avoidance is goal-directed, and that task-instructions may be responsible for driving whether an approach or avoidance is activated by the emotional stimulus (Bradley & Lang, 2013; Eder & Rothermund, 2008; Lavender & Hommel, 2007). Thus, participants may need to be given explicit goals to reach towards or away from a stimulus in order to generate such tendencies and possibly impact reaching execution.

As such, Experiment 2 was designed to ask how the approach and avoidance of emotional targets influences known approach-avoidance effects on movement execution. Two experiments were conducted (see section 6.4.1.3). In both experiments, the participant was required to generate an approach-avoidance goal to an emotional picture. An adapted version of the task in Day & Lyon (2000) was used in which participants reached towards a central target and in 30% of the trials the target jumped either to the left or the right shortly after movement initiation. Above the new target an emotional picture was presented. Participants either moved towards or away from the new target location. Thus, a correction in response to a target jump from the centre was required.

The timing of *when* this correction occurs is crucial for determining any fast and slow underlying processes mediating such corrections (*visuomotor automaticity*). The goal was therefore to determine whether approach-avoidance tendencies to emotional pictures are capable of influencing the speed of visuomotor corrections. If the fast and slow mechanisms are influenced by valence-related approach-avoidance tendencies it would demonstrate that these two processes are not autonomous and that emotional information has privileged access to the motor system. Corrections made towards a new target were expected to be faster when the new target was paired with a positive picture compared to a negative or neutral picture. Similarly, corrections made away from a new target were expected to occur faster when the new target was paired with a negative relative to positive or neutral picture. Accuracy and precision of reaching was also expected to be influenced by emotional valence but not neutral pictures.

6.4. Experiment 2

6.4.1. Methods

6.4.1.1. Participants

16 healthy participants (four males, mean age 23 ± 3 years) were recruited as in Experiment 1. All subjects participated in Experiment 2A and B.

In Experiment 2A, 5 subjects were excluded from the analysis. 2 participants were excluded due to an excessive number of errors as a result of not understanding the task. 3 participants were excluded due to faulty recordings. Data analyses were conducted on 11 subjects.

In Experiment 2B, 7 subjects were excluded from the analysis. 4 participants were excluded due to an excessive number of errors as a result of not understanding the task. 3 participants were excluded due to faulty recordings. Data analyses were conducted on 9 subjects.

6.4.1.2. Stimuli and experimental setup

6.4.1.2.1. Target and emotional stimuli

The same pictures used in Experiment 1 were used in Experiments 2A and 2B.

An unfilled blue circle (130 x 105 pixels) was presented at three different locations on the same plane: centre (control target), left and right. Only the circle that served as the target became filled, with the remaining two circles unfilled. All stimuli were presented as in Experiment 1.

The experiment consisted of 12 experimental conditions depending on the position of the target (centre, left, right), the type of movement participants had to make (approach vs. avoid), and the valence of the distractor (negative, neutral or positive). Additionally, there was a control condition. In total, there were 13 conditions. In total there were 8 blocks with 60 trials each, giving a total of 640 trials and 40 trials in each condition.

6.4.1.2.2. Recording in the experimental 3D space & calibration of the experimental setup

Recording of reaching movements and calibration of the 3D space for Experiments 2A and 2B was the same as in Experiment 1.

6.4.1.3. Experimental procedure and design

The experiment was divided into two sessions: Experiment 2A in which the target jumped *after* the reaching movement was initiated and Experiment 2B in which the target jumped *before* the initiation of movement. Expt 2A investigated how emotional valence influenced the online correction of an already initiated movement, whereas Expt 2B investigated how emotional valence influenced the planning of a movement prior to initiation and whether this would influence the speed of visuomotor corrections. Expt 2B therefore acted as a “control”. This should reveal any differences in the influence of *valence automaticity* on *visuomotor automaticity* between movements that take emotional changes into account prior to movement initiation and those that only take it into account after movement initiation. In Expt 2B, the valence and the target jump should be incorporated into the movement plan meaning that effects of *valence automaticity* on *visuomotor automaticity* may arise earlier. Thus, the current experiment will assess if action initiation, motor planning and execution are influenced by valence-related approach-avoidance tendencies.

For both experiments, participants were seated in the experimental room as in Experiment 1. In Experiment 2A **(Figure 6.10)**, trials started with a fixation cross (jittered, mean 500 ± 100 ms). Subsequently, a filled blue circular target was presented at the centre of the screen along with two unfilled circles on the left and right sides (70% of trials) and participants were instructed to reach the central target as accurately and fast as possible. This control condition was used as a comparison against the remaining experimental conditions. On trials in which a target jump occurred (30% of trials), the filled blue circular target “jumped” either to the left or right along the same plane 25 ms after the release of the right index finger from the touch plate. The target “jump” was simulated by filling either the left or the right unfilled circles, and making the central target unfilled. On approach trials, an emotional picture was always presented above the new target (duration 300 ms) and participants were instructed to reach towards the new circular target as fast and accurately as possible. On avoidance trials, an emotional picture was always presented above one of the circles, but subjects were instructed to reach for the target opposite to that with the picture above it. Approach and avoidance were blocked: one block with approach trials and another block with avoidance trials. Trials were randomised so that subjects did not know when a target jump would occur or which direction the target would jump to. In all cases, the arm began reaching for the central target *before* the target jump.

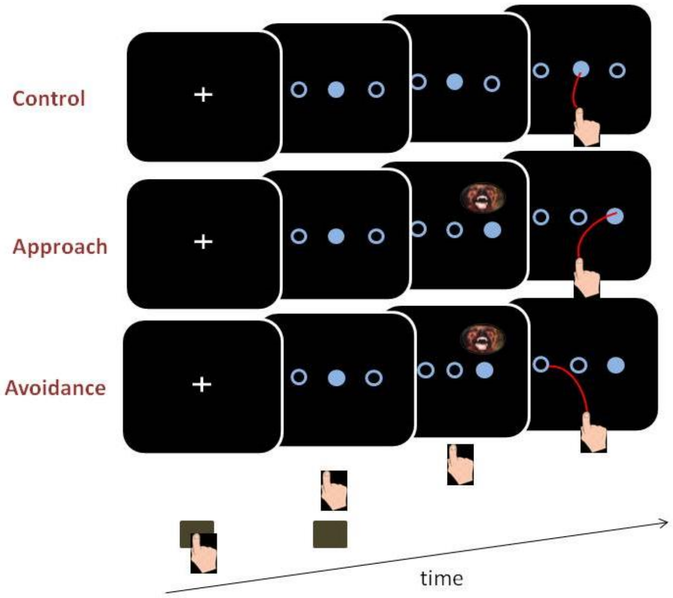


Figure 6.10. Task schematic of three trials for Experiment 2. Upper panels show a trial sequence when participants were required to reach to the central target only and when no jump occurred (**control**). Middle panels show a trial sequence when participants had to reach to the new target location (**approach**). A target "jumped" from the centre to one of the lateral circles and an emotional picture was displayed above the new target simultaneously. After 300 ms the emotional picture disappeared. Bottom panels show a trial sequence when participants moved in the opposite direction of the new target (**avoidance**).

The new targets were paired with emotional stimuli in order to keep the design as similar as possible and avoid target confounds. The central target was a blue circle. In order to keep the targets as homogeneous as possible, the new target also had to be a blue circle. Furthermore, because emotional distractors were expected to be prioritised by attentional mechanisms, they were still expected to elicit approach-avoidance tendencies.

In Experiment 2B, the task was identical except that participants had two touch plates, placed side-by-side 40 cm away from the screen. Participants placed their left index finger on the same touch sensitive plate used in Experiment 1 and released to initiate a trial, but were instructed to leave their left arm in place. Instead, they reached with their right index finger that was located on another plate. Thus, the left finger release triggered the start of the trial, but the reaching task was completed with the right arm. Contrary to Experiment 2A, the arm reaching for the target was released *after* the target jump.

The location (left/right) and valence (positive/neutral/negative) of the picture were randomised from trial-to-trial, as was the frequency of the target jumps. Each participant performed a series of 8 blocks with a brief break between every block. Prior to the experiment they received a training session of two blocks of 30 trials using blurred neutral pictures only, one for approach and one for avoidance.

6.4.1.4. *Picture ratings (valence/arousal/complexity)*

Participants rated the valence, arousal and complexity of the emotional pictures as in Experiment 1. Ratings only occurred at the end of the second session (Experiment 2B).

6.4.1.5. *Data analyses*

Data analyses followed the same procedure as in Experiment 1. The same dependent variables were analysed and for the same reasons. The only exception is that reaction time (RT) was also analysed. RT is the time between the onset of a stimulus and initiation of movement. In Experiment 2B, the presentation of the emotional stimulus occurred before the initiation of movement and therefore it may have had an influence on the RT. For this reason, RTs were analysed for both Experiment 2A and 2B, although RTs were only expected to be influenced in Experiment 2B.

6.4.1.6. *Statistical analysis*

As in Experiment 1, only complete or correct trajectories were included. Trajectories in which participants did not reach the screen (1.2%) and moved too early (i.e. before the target presentation) or 500 ms after the target presentation (1.4%) were excluded from the analysis. Outliers were calculated for each variable, per condition and for each subject using Grubb's test (1.5%). In addition, trajectories where participants did not reach towards the correct target were excluded (i.e. made the wrong movement). To quantify this, circular boundaries were defined for each target using the x and z coordinates. These boundaries were calculated by taking the median of all the endpoints (across all conditions) corresponding to that specific target (after excluding outliers) and adding or subtracting 3 S.D from this median. Any endpoints, and therefore trajectories, that fell outside of these circular boundaries (depending on the condition) were excluded (6.3%). In total, 10.4% of trials were excluded from the analysis.

An average control trajectory was computed prior to all analyses by calculating the mean across all correct control trajectories. This average trajectory was subsequently used to calculate the time point at which corrections to the left or the right occurred in the remaining conditions, for each participant individually, by taking all trials in each condition and subsequently running t-tests. Each t-test calculation consisted of 50 observations. For example, taking 50 time points from the control condition and 50 time points from the condition when you had to move towards the new target with a positive picture displayed, t-tests were run across each time point. Any significant differences from zero were considered as significant deviations from the control trajectory and the time point was logged. T-tests were conducted with correction for multiple comparisons (i.e. FDR correction) for the lateral velocity (i.e. x-velocity because it logged the position of the arm on a horizontal plane) in accordance with Day & Lyon (2000). FDR correction was used instead of Bonferroni due to the high number of comparisons that needed to be made here (in Experiment 1 the number of multiple comparisons was far less and Bonferroni was deemed sufficient). FDR is less conservative than Bonferroni, and has been shown to have greater power at reducing the probability of false positives.

Statistical analyses were conducted on the same dependent variables defined in Experiment 1, in addition to the time point of the trajectory deviations. A within-subjects 2x2x3 RM-ANOVA was performed with *Movement type* (approach vs. avoidance), *Target side* (Left vs. Right) and *Picture Valence* (Negative vs. Neutral vs. Positive) as factors on all dependent variables obtained. All analyses and follow-up statistics are presented as in Experiment 1.

6.4.1.7. Control analyses on the arousal of the distractors

As in Experiment 1, all analyses were repeated using the *arousal* (high vs. low) of the emotional pictures instead of the valence. A within-subjects 2x2x2 RM-ANOVA was performed with *Movement type* (approach vs. avoidance), *Target side* (left vs. right) and *Picture Arousal* (high vs. low) as factors on all dependent variables obtained.

6.4.2. Results

6.4.2.1. Individual picture ratings

To control for individual differences, participants rated the valence and arousal of each picture. Paired samples t-tests revealed that negative and neutral pictures were not rated differently from the IAPS (neg-IAPS = 2.63 ± 0.00, neg-rate = 2.36 ± 0.23; neut-IAPS = 5.00 ± 0.00, neut-rate = 5.22 ± 0.11). Positive pictures were rated significantly less positive than the IAPS ratings but were still perceived as positive (pos-IAPS: 7.57 ± 0.00, pos-rate: 7.04 ± 0.16; $t_{(10)} = 6.33$, $p = 0.007$). The results suggest that subjects perceived pictures as being their correct valence.

For arousal, paired samples t-tests revealed that negative (neg-IAPS = 6.20 ± 0.00, neg-rate = 3.60 ± 0.27; $t_{(10)} = -9.62$, $p < 0.001$) and positive (pos-IAPS: 4.90 ± 0.00, pos-rate: 3.21 ± 0.46; $t_{(10)} = -3.64$, $p = 0.005$) pictures had a lower arousal that the IAPS arousal ratings. The arousal of neutral pictures did not differ from the IAPS ratings (neut-IAPS = 3.15 ± 0.00, neut-rate = 3.04 ± 0.46). Overall, pictures were rated as being less arousing than the IAPS ratings.

6.4.2.2. Effects of Valence on reaching trajectories

All of the results below represent effects of distractor *valence* (positive, negative, neutral), target location (left vs. right) and the type of movement made (approach vs. avoid).

6.4.2.2.1. Speed of processing and movement initiation: Reaction times (RTs)

The initiation of movement was expected to be influenced by the valence of the emotional pictures but only in Experiment 2B, since movement initiation occurred after the appearance of the emotional picture. In both Experiment 2A and 2B there was no effect of emotional valence on the initiation of movement.

6.4.2.2.2. Kinematic measures (tPV, PV, MT)

Movement speed: Average Peak Velocity of arm reaching

The velocity of approaching or avoiding may be influenced by valence, with faster movements towards positive pictures and away from negative pictures. In Experiment 2A, results showed that PV was affected by whether participants had to approach or avoid (*Movement type*, $F_{(1, 10)} = 5.96$, $p = 0.035$, $\eta^2_p = 0.37$) and whether they had to reach to the left or the right (*Side*, $F_{(1, 10)} = 8.64$, $p = 0.015$, $\eta^2_p = 0.46$). Participants were faster to reach to the right compared to when moving to the left (left: 1.54 ± 0.03 m/sec, right: 1.58 ± 0.04 m/sec; $t_{(10)} = -2.94$, $p = 0.015$, Cohen's d = -0.89). Participants were also faster to approach than to avoid the new target (approach: 1.57 ± 0.04 m/sec, avoidance: 1.54 ± 0.03 m/sec; $t_{(10)} = 2.17$, $p = 0.05$, Cohen's d = 0.59). There was no influence of valence on PV.

In Experiment 2B, PV was affected by both the movement type and side (**Figure 6.11A**; *Movement type*Side*, $F_{(1, 8)} = 6.47$, $p = 0.034$, $\eta^2_p = 0.45$). When approaching, moving to the left was slower than when moving to the right (left: 1.42 ± 0.04 m/sec, right: 1.54 ± 0.04 m/sec; $t_{(8)} = -6.00$, $p < 0.001$, Cohen's d = -1.93). Equally, when avoiding, moving to the left was slower than to the right (left: 1.46 ± 0.04 m/sec, right: 1.52 ± 0.03 m/sec; $t_{(8)} = -3.35$, $p = 0.010$, Cohen's d = -1.14).

In addition, PV was affected by whether participants reached to the left or the right (*Side*, $F_{(1, 8)} = 34.83$, $p < 0.001$, $\eta^2_p = 0.81$) and by the valence of the emotional picture (**Figure 6.11B**; *Valence*, $F_{(2, 16)} = 3.89$, $p = 0.042$, $\eta^2_p = 0.33$). Participants moved faster to the right than to the left (left: 1.44 ± 0.04 m/sec, right: 1.53 ± 0.03 m/sec; $t_{(8)} = -6.11$, $p < 0.001$, Cohen's d = -1.99). For *valence*, participants moved faster when presented with positive pictures, followed by neutral and negative (negative: 1.48 ± 0.03 m/sec, neutral: 1.48 ± 0.04 m/sec, positive: 1.50 ± 0.04 m/sec). However, only the PV between neutral and positive pictures differed from each other ($t_{(8)} = -2.71$, $p = 0.027$, Cohen's d = -0.96). Moving in positive contexts was significantly faster than moving in neutral contexts. There was a trend for faster reaching in positive relative to negative contexts ($t_{(8)} = -2.16$, $p = 0.062$, Cohen's d = -0.94). Valence therefore affected movement speed when moving to the left or the right.

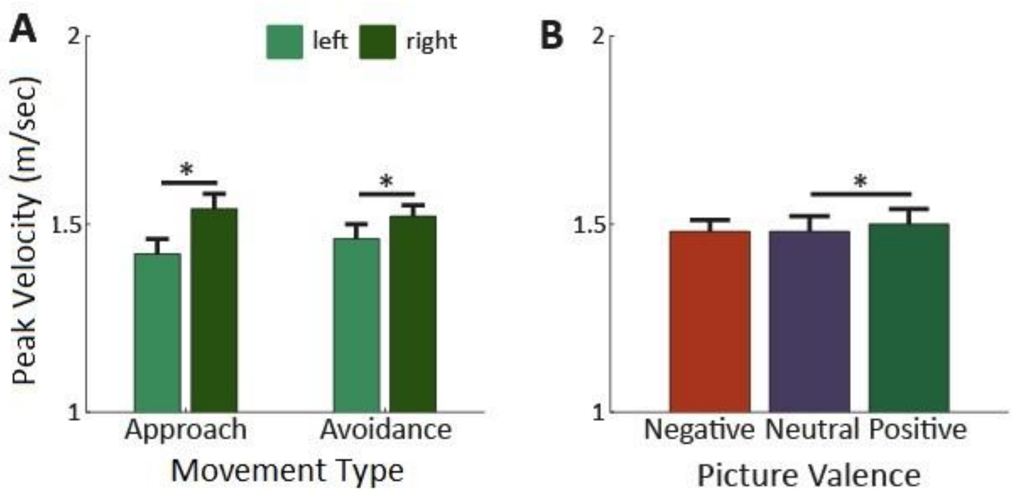


Figure 6.11. Peak velocity while approaching and avoiding A) Interaction between movement type and side, showing that participants were faster to reach to the left than to the right. **B)** Main effect of valence showing that reaching was faster when presented with positive pictures relative to neutral and negative. Error bars (+1 S.E.M.); * significant at the p <0.05 level.

Time of Peak Velocity

In Experiment 2A, both the *valence* of the emotional picture and the *side* that participants moved to influenced the time at which PV was reached (**Figure 6.12A**; *Valence*Side*, $F_{(2, 20)} = 4.72$, $p = 0.021$, $\eta^2_p = 0.32$). When a negative picture was presented, PV was reached faster when moving to the left compared to the right (left: 179 ± 10 ms, right: 196 ± 10 ms; $t_{(10)} = -3.06$, $p = 0.012$, Cohen's d = -0.94). Equally, when a positive picture was presented, PV was reached faster when moving to the left than to the right (left: 179 ± 10 ms, right: 191 ± 10 ms; $t_{(10)} = -2.87$, $p = 0.017$, Cohen's d = -0.87). There was no difference between moving to the left and right when a neutral distractor was presented.

Furthermore, whether subjects had to approach or avoid the target and the side also influenced the time of PV (**Figure 6.12B;** *Movement type*Side*, $F_{(1, 10)} = 5.22$, $p = 0.045$, $\eta^2_p = 0.34$). For approach, participants were faster to reach PV when moving to the left than to the right (left: 173 ± 11 ms, right: 190 ± 10 ms; $t_{(10)} = -2.84$, $p = 0.018$, Cohen's d = -0.87). However, when avoiding there was no difference when moving to the left or the right.

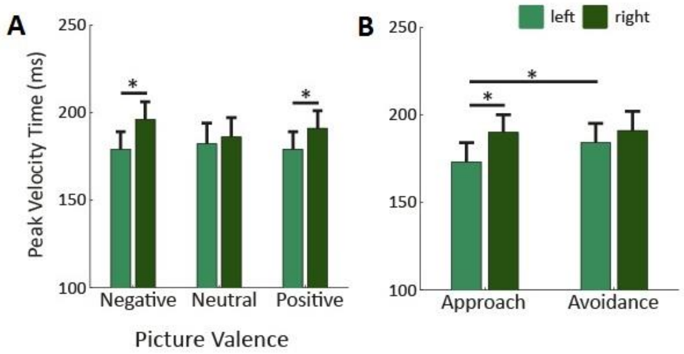


Figure 6.12. Influence of valence and movement type on time to peak velocity. A) Interaction between valence and side, showing that when negative and positive pictures were displayed, participants reached peak velocity faster when moving to the left. **B)** Interaction between movement type and side showing that when approaching, reaching peak velocity to the left was faster than when moving to the right. Error bars (+1 S.E.M.); * significant at the p <0.05 level.

There was a main effect of *side*, ($F_{(1, 10)} = 5.57, p = 0.040, \eta^2_p = 0.36$). When participants moved to the left, they reached PV faster than when they moved to the right (left: 180 ± 11 ms, right: 190 ± 10 ms; $t_{(10)} = -2.36$, $p = 0.040$, Cohen's d = -0.68).

In Experiment 2B, there was only a main effect of the side to which participants had to move to on the time of PV (*Side*, $F_{(1, 8)} = 8.75$, $p = 0.018$, $\eta^2_p = 0.52$). When participants moved to the left, they were faster to reach maximum speed than when they moved to the right (left: 191 ± 17 ms, right: 211 ± 16 ms; $t_{(8)} = -2.99$, $p = 0.017$, Cohen's d = -1.03).

Movement time (duration) of execution

Similar to the above variables, valence did not influence how fast a movement was completed. Instead, in Experiment 2A, movement time was affected by whether participants had to approach or avoid (*Movement type*, $F_{(1, 10)} = 22.90$, $p = 0.001$, $\eta^2_p = 0.70$) and by whether they moved to the left or right (*Side*, $F_{(1, 10)} = 120.32$, $p < 0.001$, $\eta^2_p = 0.92$). Participants were faster to complete their trajectory when moving to the right compared to the left (left: 417 ± 10 ms, right: 354 ± 9 ms; $t_{(10)} = 10.94$, $p < 0.001$, Cohen's d = 3.25). Participants were also faster to complete their movement when approaching compared to avoiding the target (approach: 373 ± 11 ms, avoidance: 398 ± 9 ms; $t_{(10)} = -4.78$, $p = 0.001$, Cohen's d = -1.49).

In Experiment 2B, movement time was affected by whether participants had to approach or avoid (*Movement type*, $F_{(1, 8)} = 8.73$, $p = 0.018$, $\eta^2_p = 0.52$) and by the side (*Side*, $F_{(1, 8)} = 83.75$, $p < 0.001$, $\eta^2_p = 0.91$). Participants were faster when moving to the right compared to the left (left: 427 ± 16 ms, right: 359 ± 14 ms; $t_{(8)} = 9.03$, $p < 0.001$, Cohen's d = 4.73). Participants were also faster to move when approaching compared to avoiding the target (approach: 386 ± 15 ms, avoidance: 400 ± 15 ms; $t_{(8)} = -2.96$, $p = 0.018$, Cohen's d = -0.65).

6.4.2.2.3. Speed of visuomotor corrections: Lateral velocity deviations from the control

The main goal of Experiment 2 was to investigate the influence of valence on visuomotor corrections, giving insight into bottom-up and top-down processes. Corrections to new targets were expected to be faster when paired with positive pictures. Corrections away from new targets should be faster when presented with negative pictures. In Experiment 2A, the timing of corrections was affected by whether subjects approached or avoided the target (**Figure 6.13A;** *Movement type*, $F_{(1, 10)} = 7.79$, $p = 0.019$, $\eta^2_p = 0.44$), and by the side they had to reach to (**Figure 6.13B;** *Side*, $F_{(1, 10)} = 9.89$, $p = 0.010$, $\eta^2_p = 0.50$). Corrections occurred earlier when participants approached targets compared to when they avoided targets (approach: 202 ± 8 ms, avoidance: 239 ± 7ms; $t_{(10)} = -2.80$, $p = 0.019$, Cohen's d = -0.95). Corrections also occurred earlier when reaching towards targets on the right side relative to the left (left: 237 ± 7 ms, right: 204 ± 6 ms; $t_{(10)} = 3.14$, $p = 0.010$, Cohen's d = 0.95).

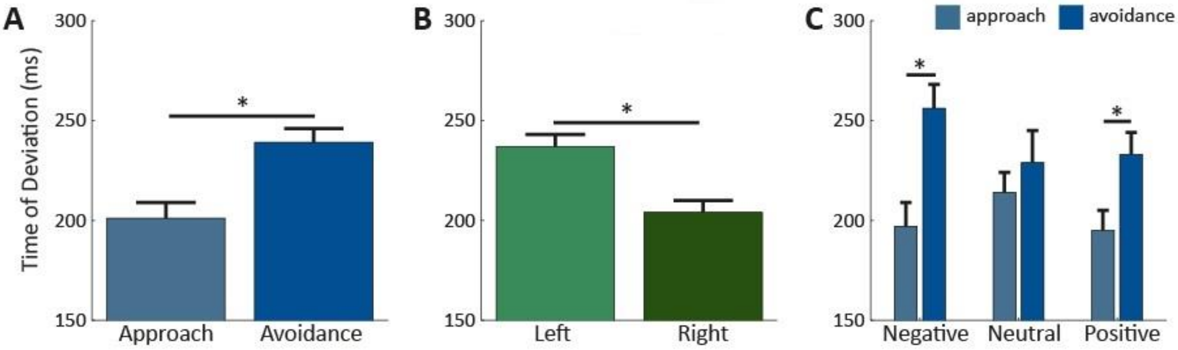


Figure 6.13. Influence of movement type, side and valence on the speed of visuomotor corrections. A) Effect of movement type showing that deviations occurred significantly earlier when approaching than when moving away from new targets. **B)** Effect of the side of reaching showing that deviations occurred earlier when reaching to targets presented on the right compared to the left. **C)** Effect of valence and movement type indicating that for emotional pictures, deviations to the targets occurred significantly earlier compared to when neutral pictures were presented. Error bars (+1 S.E.M.); * significant at the p <0.05 level.

Movement type and *valence* appeared to influence the timing of visuomotor corrections (**Figure 6.13C**; *Movement type*Valence*, $F_{(1,20)} = 3.18$, p = 0.063, ηp2 = 0.24). This interaction revealed that when emotional pictures were shown, visuomotor corrections to the respective target were earlier when approaching than when avoiding. Approaching was faster than avoidance when presented with negative (app: 196 ± 12 ms, avoid: 256 ± 12 ms; $t_{(10)} = -3.12$, $p = 0.011$, Cohen's d = -0.93) and positive (app: 195 ± 10 ms, avoid: 233 ± 11 ms; $t_{(10)} = -2.56$, $p = 0.028$, Cohen's d = -0.76) pictures. There was no difference in the timing of these corrections when neutral pictures were shown. Valence therefore influenced the timing of visuomotor corrections to respective targets. For visualisation purposes, **Figure 6.14A** shows the lateral velocities for subject 11 for all conditions for Expt 2A.

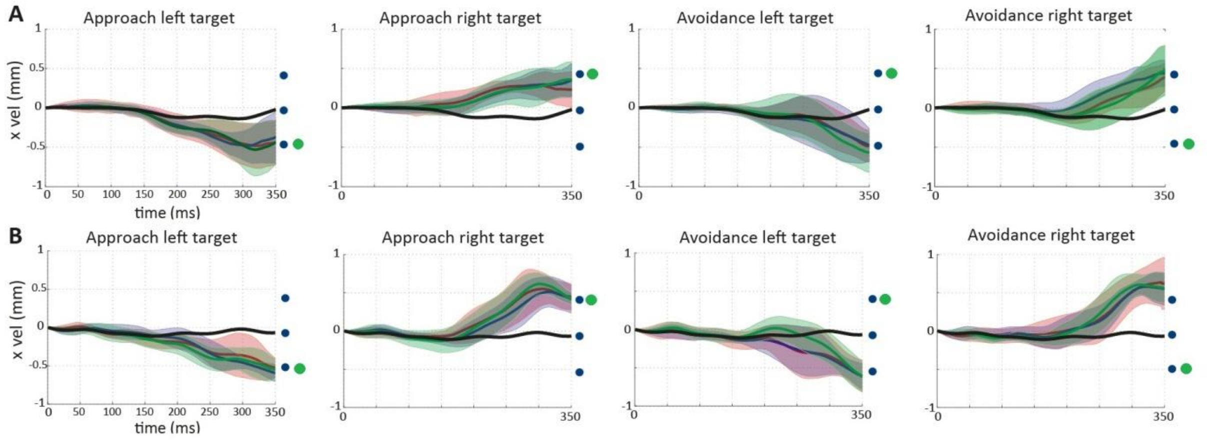


Figure 6.14. Mean lateral velocities showing the speed of visuomotor corrections for subject 11. A) Lateral velocities for Expt 2A. First two upper panels show the mean lateral velocities compared against the control trajectory (± 1 standard deviation represented by the shaded area) for approaching left and right targets when positive (green lines), negative (red) and neutral (blue) pictures were shown. Blue circles represent targets, green circles represent the picture. The last two upper panels show the mean lateral velocities for moving away from the target with the emotional picture. **B)** Comparison mean lateral velocities for Expt 2B. These velocities appear to be more direct and less variable than those for Expt 2A. Lateral velocities for approaching and avoiding targets when positive (green lines), negative (red) and neutral (blue) pictures were shown.

In Experiment 2B, corrections were affected by whether subjects approached or avoided the target (*Movement type*, $F_{(1,8)} = 13.88$, $p = 0.006$, $\eta^2_p = 0.63$), and by the side they had to reach to (*Side*, $F_{(1,8)} = 22.99$, $p = 0.001$, $\eta^2_p = 0.74$). Corrections occurred earlier when participants approached targets compared to when they avoided targets (**Figure 6.14B;** approach: 196 ± 16 ms, avoidance: 241 ± 13 ms; $t_{(8)} = -3.73$, $p = 0.006$, Cohen's d = -1.27). Corrections also occurred earlier when reaching towards targets on the right side relative to the left (left: 245 ± 12 ms, right: 192 ± 16 ms; $t_{(8)} = 4.79$, $p = 0.001$, Cohen's d =

1.69). Movements to respective targets for subject 1 were more direct compared to Expt 2A, as shown in **Figure 6.15**.

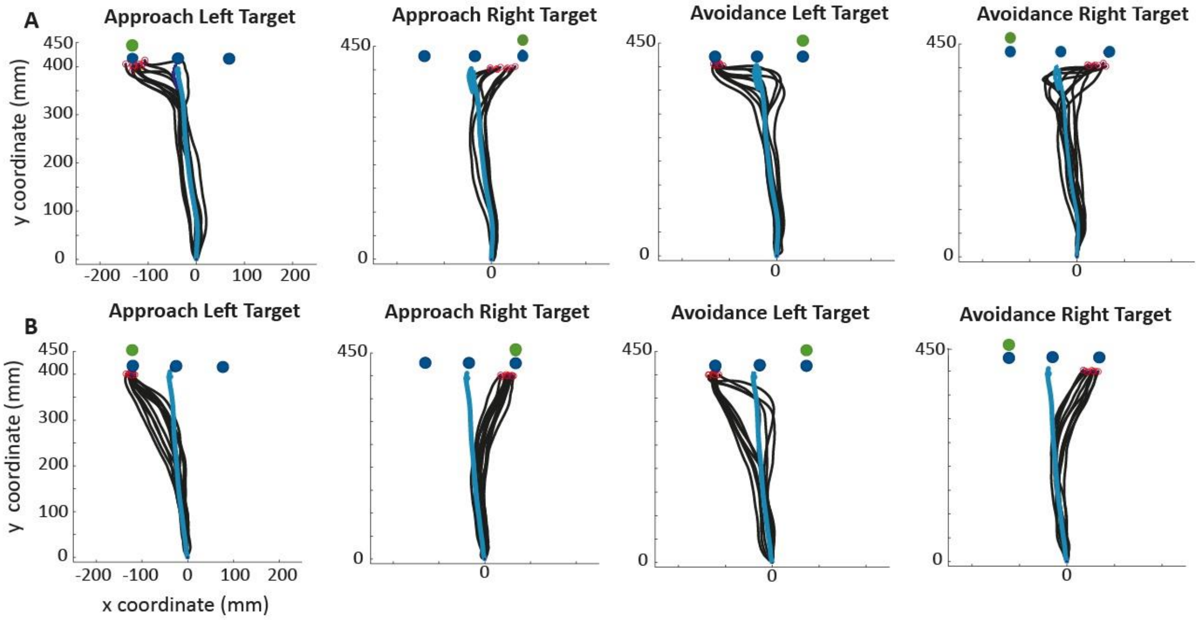


Figure 6.15. Raw trajectories for participant 1 when a negative picture was presented. A) Raw trajectories (black lines) when approaching and avoiding new targets in Expt 2A showing corrections towards or away from new targets relative to the control condition (dark blue line). Blue circles represent targets, green circles represent the picture. **B)** Raw trajectories when approaching and avoiding in Experiment 2B. Trajectories appeared to be more direct in Expt 2B compared to 2A.

The above results did not alter for Experiment 2A and 2B when the lateral velocities were split into early and late epochs. No significant effects were found in the early part of the trajectory, whereas deviations occurred in the late part of the trajectory, similar to Experiment 1.

In sum, the results for the kinematics of a movement indicate an influence of the type of movement to be made (approach vs. avoid) and the biophysical properties of the arm (moving to the left vs. right). Overall, moving towards a target is faster than moving away from a target, and moving to the left is faster than moving to the right. There was an influence of valence on the timing of visuomotor corrections when approaching and avoiding but there was no influence of approach-avoidance tendencies.

6.4.2.2.4. Effects of Valence on accuracy, precision and angle

Accuracy of reaching: Euclidean distance of the endpoint from the target

As in Experiment 1, the Euclidean distance gave insight into the accuracy of the movement relative to the target. In Experiment 2A, the accuracy was affected by whether subjects approached or avoided and by the side (**Figure 6.16A**; *Movement type*Side*, $F_{(1, 10)} = 21.95$, $p = 0.001$, $\eta^2_p = 0.58$). When approaching the target, endpoints were closer to the target when moving to the left compared to the right (left: 20 ± 2 mm, right: 40 ± 4 mm; $t_{(10)} = -5.63$, $p < 0.001$, Cohen's d = -1.84). Similarly, when avoiding, endpoints were closer to the target when moving to the left compared to the right (left: 22 ± 2 mm, right: 48 ± 4 mm; $t_{(10)} = -8.62$, $p < 0.001$, Cohen's d = -3.11). Participants were also more accurate when moving to the right when approaching versus avoiding ($t_{(10)} = -4.77$, $p = 0.001$, Cohen's d = -1.47).

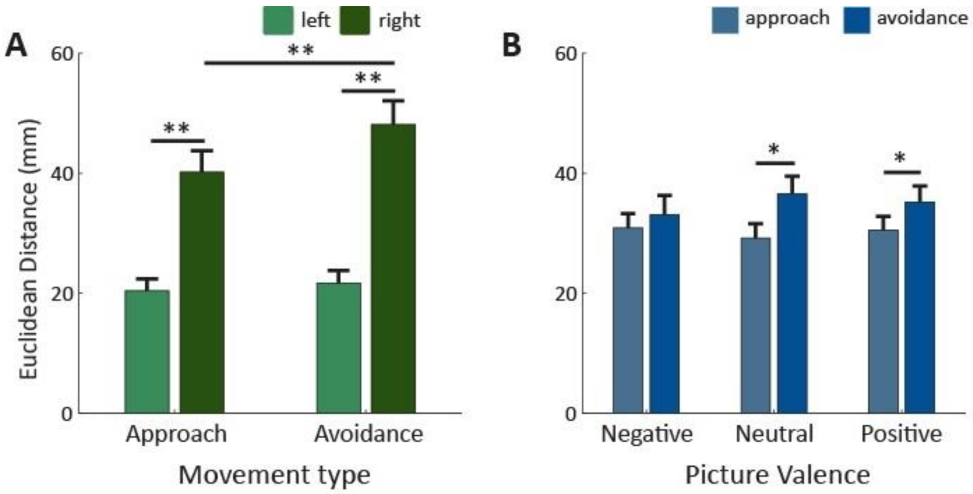


Figure 6.16. Influence of valence and movement type on reaching accuracy. A) Interaction between the movement type and side, showing that moving to the left was more accurate than moving to the right. **B)** Interaction between movement type and valence, showing that accuracy was better when approaching than avoiding when neutral and positive pictures were shown. Error bars (+1 S.E.M.); ** significant at the p <0.001 level; * significant at the p <0.05 level.

The valence of the emotional pictures and the type of movement made (e.g. towards or away) was expected to influence movement accuracy. Indeed, the results showed an influence of movement type and the valence on the endpoint distance (**Figure 6.16B**; *Movement type*Valence*, $F_{(2, 20)} = 4.54$, $p = 0.024$, $\eta^2_p = 0.31$). When negative pictures were presented, there was no difference in the distance to the target between approach and avoidance movements. When neutral pictures were presented, the distance from the target was shorter when approaching compared to avoiding (approach: 29 ± 2 mm, avoidance: 37 ± 3 mm; $t_{(10)} = -3.77$, $p = 0.004$, Cohen's d = -1.27). Similarly, for positive pictures, the distance was shorter when approaching compared to avoiding (approach: 31 ± 2 mm, avoidance: 35 ± 3 mm; $t_{(10)} = -2.71$, $p = 0.022$, Cohen's d = -0.71), suggesting greater accuracy for neutral and positive pictures relative to negative.

In addition to the above interaction, the endpoint distance relative to the targets was also affected by whether participants approached or avoided (*Movement type*, $F_{(1, 10)} = 10.95$, $p = 0.008$, $\eta^2_p = 0.52$) and by the side of the movement (*Side*, $F_{(1, 10)} = 51.22$, $p < 0.001$, $\eta^2_p = 0.84$). Endpoints were in general closer to the target when subjects approached (approach: 30 ± 2 mm, avoidance: 35 ± 3 mm; $t_{(10)} = -3.26$, $p = 0.009$, Cohen's d = -1.11). Equally, endpoints were closer to the target when participants reached to the left compared to the right (left: 21 ± 2 mm, right: 44 ± 4 mm; $t_{(10)} = -6.99$, $p < 0.001$, Cohen's d = -2.39).

In Experiment 2B, the Euclidean distance relative to the targets was affected by whether participants approached or avoided (*Movement type*, $F_{(1, 8)} = 18.31$, $p = 0.003$, $\eta^2_p = 0.70$) and by the side of the movement (*Side*, $F_{(1, 8)} = 18.50$, $p = 0.003$, $\eta^2_p = 0.70$). Endpoints were closer to the target when subjects approached (approach: 30 ± 3 mm, avoidance: 32 ± 3 mm; $t_{(8)} = -4.43$, $p = 0.002$, Cohen's d = -1.58). Equally, endpoints were closer to the target when participants reached to the left compared to the right (left: 21.67 ± 4.05 mm, right: 40.50 ± 2.76 mm; $t_{(8)} = -4.31$, $p = 0.003$, Cohen's d = -1.45). There was no effect of valence on accuracy.

Precision of reaching: area of the ellipse

In Experiment 2A, the precision of the movement was influenced by approach and avoidance (*Movement type*, ($F_{(1, 10)} = 6.88$, $p = 0.025$, $\eta^2_p = 0.41$) and by the side (*Side,* ($F_{(1, 10)} = 11.79$, $p = 0.006$, $\eta^2_p = 0.54$), supporting the results for the Euclidean distance. The area of the ellipse surrounding the endpoints was smaller when subjects approached the target than when they avoided (approach: 579 ± 78 mm^2, avoidance: 887 ± 138 mm^2; $t_{(10)} = -2.34$, $p = 0.041$, Cohen's d = -0.078). Similarly, the area was smaller when reaching toward left compared to right targets (left: 556 ± 116 mm^2, right: 911 ± 101 mm^2; $t_{(10)} = -4.27$, $p = 0.002$, Cohen's d = -1.29). Participants were more precise in correcting when approaching relative to avoiding the targets, and more precise when reaching to left targets, the latter possibly as a result of the biophysical properties of the arm. **Figure 6.17A** shows the mean endpoints for all subjects when approaching and avoiding when positive, negative and neutral pictures were presented.

These main effects were qualified by a 3-way interaction between the movement type, the side of reaching and the valence of the emotional picture (*Movement type*side*valence*, $F_{(1,10)} = 3.73$, p = 0.042, ηp2 = 0.27). This interaction was split for each side. When participants reached to the left, picture valence did not significantly affect the precision of approaching or avoiding. When participants reached to the right, participants were more precise when approaching or avoiding ($F_{(1,10)} = 5.42$, p = 0.042, ηp2 = 0.35). Overall, valence did not impact the precision of reaching.

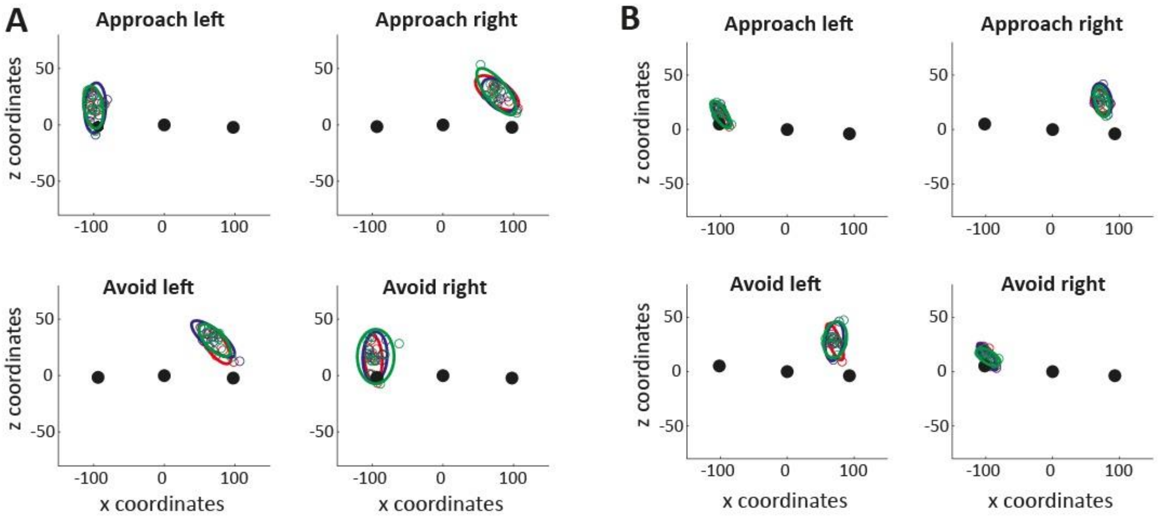


Figure 6.17. Influence of valence on reaching precision. A) Ellipses fitted around the mean endpoints for all subjects when positive (green), negative (red) and neutral (blue) pictures were presented for Expt 2A. **B)** Ellipses fitted around the mean endpoints for all subjects in Expt 2B. Ellipses in Expt 2B are smaller, and therefore more precise, than ellipses in Expt 2A. Precision was greatest when participants planned their correction prior to the initiation of movement.

In Experiment 2B, precision was also influenced by approach and avoidance (*Movement type*, ($F_{(1, 8)} = 5.51$, $p = 0.047$, $\eta^2_p = 0.41$) and by the side (*Side,* ($F_{(1, 8)} = 10.77$, $p = 0.011$, $\eta^2_p = 0.57$). The area of the ellipse was smaller when subjects approached the target than when they avoided (approach: 562 ± 93 mm^2, avoidance: 765 ± 149 mm^2; $t_{(8)}$ = -

2.35, $p = 0.047$, Cohen's d = -1.00). Similarly, the area was smaller when reaching toward left compared to right targets (left: 445 ± 58 mm^2, right: 881 ± 180 mm^2; $t_{(8)} = -3.28$, $p = 0.011$, Cohen's d = -2.42). Participants were therefore more precise when approaching and when moving to the left. **Figure 6.17B** shows the mean endpoints for approaching and avoiding in Expt 2B. Visual inspection shows that precision was greater in Expt2B than Expt 2A. Precision was greatest when participants planned their correction prior to the initiation of movement.

Orientation of the spread of the endpoints: angle of the ellipse

In both experiment 2A and 2B, there was no effect of approach or avoidance, the side of reaching or the valence on the angle of the ellipse surrounding the endpoints.

To sum up, the accuracy of reaching movements was influenced by valence, but precision and orientation of reaching movements was not. Valence only affected accuracy when it was presented after the initiation of movement (Experiment 2A) and not before (Experiment 2B). Furthermore, participants were more accurate when approaching low-threat stimuli. In both experiments accuracy was influenced by the type of movement made and the biophysics of the arm. Precision was affected by the type of movement made, with better precision for approaching compared to avoiding, and by the side of reaching.

6.4.2.3. Effects of Arousal on action execution

All of the results below represent effects of distractor *arousal* (high vs. low), target location (left vs. right) and the type of movement to be made (approach vs. avoid). In general, the results for arousal did not differ from those for valence.

6.4.2.3.1. Kinematic measures (PV, tPV, MT)

Movement speed: Average Peak Velocity of arm reaching

In Experiment 2A, PV was affected by the side (*Side*, $F_{(1, 10)} = 11.29$, $p = 0.008$, $\eta^2_p = 0.57$). Participants were slower when moving to the left compared to the right (left: 1.50 ± 0.05, right: 1.55 ± 0.04; $t_{(10)} = -2.77$, $p = 0.008$, Cohen's d = -0.45).

In Experiment 2B, PV was affected by both the movement type and side (*Movement type*Side*, $F_{(1, 8)} = 5.97$, $p = 0.040$, $\eta^2_p = 0.43$). When approaching, moving to the left was slower than when moving to the right (left: 1.42 ± 0.04 m/sec, right: 1.55 ± 0.04 m/sec; $t_{(8)} = -4.89$, $p = 0.001$, Cohen's d = -1.68). Equally, when avoiding, movements were slower when moving to the left than to the right (left: 1.45 ± 0.04 m/sec, right: 1.51 ± 0.03 m/sec; $t_{(8)} = -3.20$, $p = 0.013$, Cohen's d = -1.04). In addition, participants were slower when moving to the left compared to the right (*Side*, $F_{(1, 8)} = 25.26$, $p = 0.001$, $\eta^2_p = 0.76$; left: 1.43 ± 0.04 m/sec, right: 1.53 ± 0.03 m/sec; $t_{(8)} = -5.07$, $p = 0.001$, Cohen's d = -1.78).

Time of Peak Velocity

In Experiment 2A, there was no effect of *arousal, movement type* or the *side* of reaching on the time at which PV was reached.

However, in Experiment 2B, there was a main effect of side (*Side*, $F_{(1, 8)} = 6.53$, $p = 0.034$, $\eta^2_p = 0.45$). When participants moved to the left, they reached PV faster than when they moved to the right (left: 191 ± 17 ms, right: 209 ± 16 ms; $t_{(8)} = -2.53$, $p = 0.035$, Cohen's d = -0.88).

This main effect was qualified by an effect of both the *arousal* and the *side* (Arousal**Side*, $F_{(1, 8)} = 5.99$, $p = 0.040$, $\eta^2_p = 0.43$). When arousal was low participants reached PV faster when moving to the left than the right (left: 188 ± 18 ms, right: 212 ± 16 ms; $t_{(8)} = -3.37$, $p = 0.010$, Cohen's d = -1.14).

Movement time (duration) of execution

In Experiment 2A, movement time was affected by whether participants approached or avoided (**Figure 6.18A**; *Movement type*, $F_{(1, 10)} = 35.84$, $p < 0.001$, $\eta^2_p = 0.80$) and by moving to the left or the right (*Side*, $F_{(1, 10)} = 82.01$, $p < 0.001$, $\eta^2_p = 0.90$). Participants were faster when approaching compared to avoiding the target (approach: 372 ± 12 ms, avoidance: 421 ± 11 ms; $t_{(10)} = -5.96$, $p < 0.001$, Cohen's d = -1.89). Participants were also faster when moving to the right compared to the left (left: 415 ± 10 ms, right: 379 ± 11 ms; $t_{(10)} = 8.99$, $p < 0.001$, Cohen's d = -5.03).

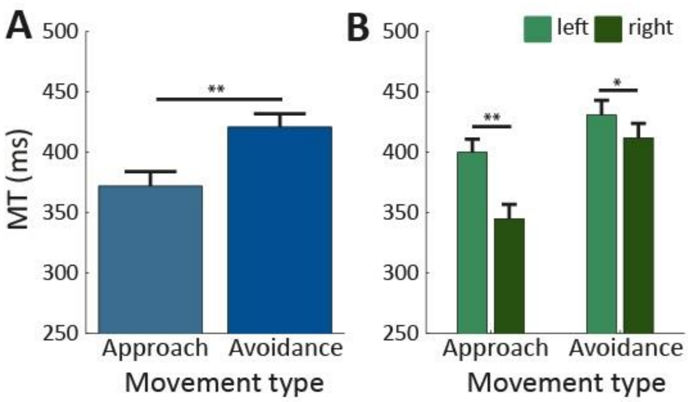


Figure 6.18. Influence of movement type on movement times. A) Duration of the trajectories was significantly short when approaching than when avoiding. **B)** Duration of the trajectories was shorter when moving to right than to left targets. Error bars (+1 S.E.M.); ** significant at the p <0.001 level; * significant at the p <0.05 level.

These effects were qualified by an effect of *movement type* and *side* (**Figure 6.18B**; *Movement type*Side*, $F_{(1, 10)} = 31.17$, $p < 0.001$, $\eta^2_p = 0.78$). When approaching, moving to the right was faster than moving to the left (left: 400 ± 11 ms, right: 345 ± 12 ms; $t_{(10)} = 20.69$, $p < 0.001$, Cohen's d = 7.35). Similarly, when avoiding, moving to the right was faster compared to the left (left: 431 ± 12 ms, right: 412 ± 12 ms; $t_{(10)} = 2.70$, $p = 0.024$, Cohen's d = 0.88).

In Experiment 2B, movement time was also affected by approaching and avoiding (*Movement type*, $F_{(1, 8)} = 43.21$, $p < 0.001$, $\eta^2_p = 0.84$) and by moving to the left or the right (*Side*, $F_{(1, 8)} = 63.67$, $p < 0.001$, $\eta^2_p = 0.89$). Participants were faster when approaching compared to avoiding the target (approach: 384 ± 15 ms, avoidance: 421 ± 16 ms; $t_{(8)} = -6.61$, $p < 0.001$, Cohen's d = -2.26) and faster when moving to the right compared to the left (left: 428 ± 16 ms, right: 377 ± 15 ms; $t_{(8)} = 7.89$, $p < 0.001$, Cohen's d = 2.71).

These effects were qualified by a combined effect of *movement type* and *side* (*Movement type*Side*, $F_{(1, 8)} = 10.56$, $p = 0.012$, $\eta^2_p = 0.60$). When approaching, moving to the right was faster than moving to the left (left: 418 ± 17 ms, right: 350 ± 14 ms; $t_{(8)} = 9.67$, $p < 0.001$, Cohen's d = 3.60). Similarly, when avoiding, moving to the right was faster compared to the left (left: 437 ± 15 ms, right: 405 ± 18 ms; $t_{(8)} = 3.42$, $p = 0.009$, Cohen's d = 1.15).

6.4.2.3.2. Speed of visuomotor corrections: Lateral velocity deviations from the control

The arousal of the pictures may also impact visuomotor corrections. In Experiment 2A, the time point of the deviations from the control was affected by whether subjects approached or avoided the target (*Movement type*, $F_{(1, 9)} = 23.64$, $p < 0.001$, $\eta^2_p = 0.70$), and by the side they had to reach to (*Side*, $F_{(1, 9)} = 15.47$, $p = 0.003$, $\eta^2_p = 0.61$). Corrections occurred earlier when participants approached targets compared to avoidance (approach: 198 ± 8 ms, avoidance: 242 ± 7 ms; $t_{(9)} = -4.25$, $p < 0.001$, Cohen's d = -0.99) and when reaching towards targets on the right side relative to the left (left: 229 ± 7 ms, right: 208 ± 9 ms; $t_{(9)} = 3.79$, $p = 0.004$, Cohen's d = 0.52).

In Experiment 2B, the time point of corrections was affected by whether subjects approached or avoided the target (*Movement type*, $F_{(1, 8)} = 11.34$, $p = 0.008$, $\eta^2_p = 0.58$), and by the side they had to reach to (*Side*, $F_{(1, 8)} = 19.65$, $p = 0.001$, $\eta^2_p = 0.68$). Corrections occurred earlier when approaching targets compared to avoidance (approach: 186 ± 17 ms, avoidance: 237 ± 14 ms; $t_{(8)} = -3.09$, $p = 0.009$, Cohen's d = -1.32), and when reaching towards targets on the right relative to the left (left: 238 ± 12 ms, right: 196 ± 15 ms; $t_{(8)} = 3.36$, $p = 0.003$, Cohen's d = 1.36).

In sum, the kinematic results indicate an influence of the type of movement made (approach vs. avoid) and the biophysical properties of the arm (moving to the left vs. right). These results did not differ from the valence results above demonstrating that the arousal of the pictures also does not have an influence on early and late processes.

6.4.2.3.3. Effects of Arousal on accuracy, precision and the angle

Accuracy of reaching: Euclidean distance of the endpoint from the target

In Experiment 2A, the accuracy of reaching was affected by whether subjects approached or avoided and by the side they had to move to (**Figure 6.19**; *Movement type*Side*, $F_{(1, 10)} = 40.73$, $p < 0.001$, $\eta^2_p = 0.82$). When approaching, endpoints were closer to the target when moving to the left compared to the right (left: 20 ± 2 mm, right: 39 ± 4 mm; $t_{(10)} = -4.73$, $p < 0.001$, Cohen's d = -1.59). However, when avoiding, there was no difference in the accuracy between left and right targets.

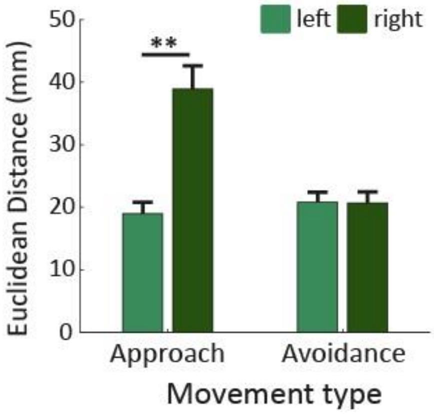


Figure 6.19. Influence of movement type on reaching accuracy. Accuracy was greater when reaching to the left than to the right when approaching. Error bars (+1 S.E.M.); ** significant at the p <0.001 level.

Accuracy was also affected by whether participants approached or avoided (*Movement type*, $F_{(1, 10)} = 39.15$, $p < 0.001$, $\eta^2_p = 0.81$) and by the side of the movement (*Side*, $F_{(1, 10)} = 11.28$, $p = 0.008$, $\eta^2_p = 0.56$). Endpoints were closer when subjects avoided compared to approach (approach: 29 ± 2 mm, avoidance: 21 ± 1 mm; $t_{(10)} = 6.01$, $p < 0.001$, Cohen's d = 2.01). Equally, endpoints were closer to the target when participants reached to the left compared to the right (left: 20 ± 2 mm, right: 30 ± 3 mm; $t_{(10)} = -3.33$, $p = 0.009$, Cohen's d = -1.18).

In Experiment 2B, accuracy was affected by approaching or avoiding (*Movement type*, $F_{(1, 8)} = 137.75$, $p < 0.001$, $\eta^2_p = 0.95$). Endpoints were closer to the target when subjects approached compared to avoid (approach: 30 ± 3 mm, avoidance: 22 ± 3 mm; $t_{(8)} = 12.38$, $p < 0.001$, Cohen's d = 4.52). This effect was qualified by a combined effect of both the movement type and the side (*Movement type*Side*, $F_{(1, 8)} = 74.77$, $p < 0.001$, $\eta^2_p = 0.90$).

When approaching, accuracy was better when moving to the left than to the right (left: 22 ± 4 mm, right: 39 ± 3 mm; $t_{(8)} = -3.71$, $p = 0.006$, Cohen's d = -1.22). However, when avoiding, there was no difference in accuracy between left and right targets.

Precision of reaching: area of the ellipse

In Experiment 2A, precision was influenced by the side to which movement had to be made (*Side,* ($F_{(1, 10)} = 5.20$, $p = 0.049$, $\eta^2_p = 0.37$). The area was smaller when reaching toward left targets compared to right (left: 562 ± 94 mm^2, right: 806 ± 131 mm^2; $t_{(9)} = -2.28$, $p = 0.049$, Cohen's d = -0.77). Thus, participants were more precise in correcting when approaching targets relative to avoiding the targets, and more precise when reaching to left targets, the latter possibly as a result of the biophysical properties of the arm. For illustration purposes, **Figure 6.20A** shows ellipses fitted around the mean endpoints for high and low arousal for Expt2A.

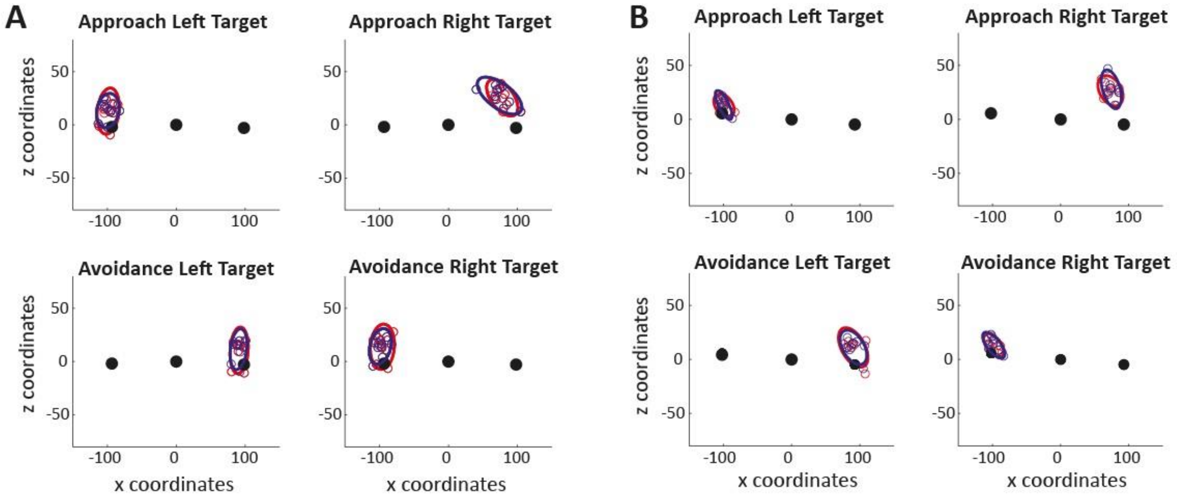


Figure 6.20. Precision of reaching as a function of the arousal of the emotional picture. A) Ellipses fitted over the mean endpoint distribution for all subjects in Expt 2A.Reaching was more precise when reaching to the left than to the right. **B)** Ellipses for Expt 2B. There was no effect of low (blue dots) or high (red dots) arousal on reaching precision. Like for valence, reaching appeared to be more precise for Expt 2B than 2A.

In Experiment 2B, there was no effect of *arousal, movement type* or the *side* on the area of the ellipse around the endpoint distribution. Precision, however, did appear to be better in Expt 2B than 2A **(Figure 6.20B)**.

Orientation of the spread of the endpoints: angle of the ellipse

In Experiment 2A, angle was influenced by approaching and avoiding and the side of reaching for the target (*Movement type*Side*, *(*$F_{(1,\ 10)}$ = 12.49, p = 0.006, η^2_p = 0.58). When approaching, there was no difference in the angle between left and right targets. When avoiding, the angle of the ellipse was more negative when moving to the right compared to the left (left: 0.80 ± 8.94 deg, right: -38.20 ± 10.21 deg; $t_{(10)}$ = 3.33, p = 0.009, Cohen's d = 1.06).

Similarly, in Experiment 2B, there was an effect of both approach and avoidance and the side of reaching for the target (*Movement type*Side*, *(*$F_{(1,\ 8)}$ = 7.43, p = 0.026, η^2_p = 0.48). When approaching, there was no difference in the angle between left and right targets. When avoiding, the angle of the ellipse was more negative when moving to the right compared to the left (left: 15.50 ± 12.36 deg, right: -35.51 ± 9.99 deg; $t_{(8)}$ = 3.32, p = 0.011, Cohen's d = 1.11).

To sum up, accuracy, precision and the orientation of the spread of the endpoints were influenced by the type of movement made and the biophysics of the arm but not by arousal. Arousal therefore did not impact early or late processes in visuomotor corrections.

6.4.3. Discussion

Experiment 2 investigated the influence of *valence automaticity* on *visuomotor automaticity*. Using a design in which participants made approach and avoidance actions in response to emotional target "jumps", it was expected that emotional pictures and their associated response tendencies would influence the speed of visuomotor corrections, in addition to influencing other movement kinematics. The timing of *when* participants made movement corrections was expected to reveal possible underlying fast or slow mechanisms driving emotional influences.

Two experiments were conducted to assess if action execution and motor re-planning are influenced by approach-avoidance tendencies. In the first experiment, the target jumped after movement initiation, and in the second experiment the target jumped before movement initiation. In the former, there was no planning prior to movement initiation, whereas in the latter participants planned corrections prior to initiation. Corrections were expected to be more attenuated in the second experiment. Surprisingly, irrespective of these planning differences, both experiments revealed that correcting towards new targets occurs earlier than correcting away from new targets, demonstrating fast and slow mechanisms underlying reaching corrections that are independent of planning processes. Importantly, there was an influence of emotional valence on visuomotor corrections and on the accuracy of reaching. Overall*, valence automaticity* did not influence *visuomotor automaticity*, confirming the results from Experiment 1.

Valence only affects the kinematics of movements initiated after the presentation of the emotional picture

The current results demonstrate that emotional valence, but not approach-avoidance tendencies, influence the updating of motor plans. However, unlike in Experiment 1, emotional valence did not influence movement kinematics when reaching was initiated before the appearance of the emotional stimulus. Instead, temporal characteristics were influenced by valence when the emotional picture was presented before action initiation. In Expt 2B velocity was greater when presented with positive relative to neutral pictures, irrespective of moving towards or away. Valence therefore appeared to influence motor planning that took place prior to movement initiation, supporting previous work (de Oliveira et al., 2012; Esteves et al., 2016).

Speculatively, because participants made reaching movements towards the screen, and therefore in the direction of the emotional stimuli, movements may have been faster due to underlying approach tendencies associated to positive stimuli. Indeed, recent evidence has shown that peak velocity is higher when approaching positive stimuli relative to neutral or negative (Esteves et al., 2016). Similarly, it has been demonstrated that participants are faster to move in positive contexts (Albert et al., 2010; Chiu et al., 2014). Thus, faster movements when positive pictures were shown suggest that positive contexts are conducive to faster movement execution, but only when valence is incorporated into the movement plan prior to initiation. Positive pictures therefore influenced the planning of reaching movements prior to their initiation, demonstrating an effect of valence on motor planning. This result is supportive of Chapter Four, which demonstrated a valence effect on the planning of action parameters prior to action execution, and goes against previous work that had demonstrated that movement execution is not influenced by the valence of stimuli presented before action initiation (Coombes et al., 2006; Stins et al., 2015).

Early versus late trajectory corrections are influenced by emotional valence

One of the main goals of this experiment was to determine if emotional approach-avoidance tendencies influenced the speed of visuomotor corrections. According to previous work (Day and Lyon, 2000), the timing of when these corrections occur should reveal differences between underlying fast and slow mechanisms. Indeed, both experiments showed that corrections occurred earlier when participants moved towards targets compared to when they moved in the opposite direction, irrespective of valence. This suggests that reaching movement is under the control of two mechanisms: a fast and highly automatic process and slower, less automatic process that can be modified by the subjects' intention (Pisella et al., 2000; Striemer et al., 2010).

Unlike the predictions, these fast and slow mechanisms were not influenced by approach-avoidance tendencies, even when pictures were presented before the initiation of movement. In contrast, there was a potential valence effect that suggested that corrections to approach when presented with emotional pictures were faster than corrections to avoid. Crucially, this difference was not present when neutral pictures were shown. Speculatively, faster approach than avoidance when presented with emotional pictures may be driven by the fast prioritisation of emotional information relative to neutral information even when it is task-irrelevant (Vuilleumier, 2005; Vuilleumier et al., 2001). Given that the earliest visuomotor corrections towards a stimulus occurred at around 200 ms, by this time emotional information was fully processed (Olofsson et al., 2008) and top-down attentional mechanisms (Pessoa et al., 2002) may have been employed to guide faster corrections to approach compared to avoidance.

Indeed, top-down attentional mechanisms have been suggested to play a role in guiding the fast and slow responses in visuomotor corrections (Day & Lyon, 2000). This attentional model suggests that moving to a target engages and locks attention, whereas moving away from a target requires inhibiting this attention shift and redirecting it to the opposite location of the target (Tipper et al., 1998). If emotional pictures are prioritised, it may be possible that emotional stimuli facilitated the “locking in” of attention to the new target and disrupted inhibition when moving away from the new target. In contrast to models proposing the existence of fast or slow pathways guiding visuomotor corrections, attentional models suggest the existence of fast and slow responses under one unified top-down single pathway (Day & Lyon, 2000; Tipper et al., 1997). Interestingly, this effect of valence was not present when the emotional picture was presented prior to the initiation of movement. In this case, motor planning had already occurred, meaning there was no need for attentional prioritisation during an on-going movement because participants had already been exposed to the emotional information. Emotional valence therefore influences visuomotor automaticity via attentional prioritisation during, but not prior to, action execution, supporting attentional models guiding visuomotor corrections (Day & Lyon, 2000; Tipper et al., 1998).

Despite the results being similar for both experiments, it is clear that movements made towards or away from new targets were more direct in Expt 2B, with less dragging of the arm towards the central target, as had also been observed in Day & Lyon (2000). Furthermore, movement corrections were numerically faster in Expt 2B than 2A. These discrepancies in trajectory and timing of corrections are not surprising given that in Expt 2B participants began the movement *after* the target jump and could plan a movement to the respective target area in advance, whereas in Expt 2A participants had planned a movement to the central target before knowing where they would have to move to. Thus, the timing of when this target jump occurs (before or after movement initiation) reveals differences in motor planning. This difference however, did not seem to impact the fact that deviations made towards targets occurred earlier than those away from the targets, suggesting that irrespective of when the target jump occurs, the same visuomotor process was available for both tasks, although the strength of this process may be task-dependent.

Thus, the data are supportive of attentional models (Rushworth et al., 1997; Tipper et al., 1998) that show that top-down attentional mechanisms are responsible for guiding visuomotor corrections. Importantly, these attentional mechanisms appear to be enhanced in emotional contexts. To the best of my knowledge, this is the first evidence of a link between emotional information and the speed of visuomotor corrections, indicating an influence of emotional valence on mechanisms underlying motor updating during action execution.

Reaching accuracy may be influenced by valence-related approach-avoidance tendencies

There was an effect of valence-related approach-avoidance tendencies on accuracy, with better accuracy when approaching in low threat (i.e. positive and neutral) situations compared to when negative pictures were presented. Like in Experiment 1, the end stage of the movement was influenced by valence. Better accuracy in low-threat contexts may be explained by two possible mechanisms. Firstly, negative pictures may have caused response interference and disrupted accuracy due to threatening visual information capturing attention and consuming resources for completing the task (Erthal et al., 2005; Hartikainen et al., 2000; Hartikainen, Siiskonen, & Ogawa, 2012). Secondly, moving towards the screen in low threatening contexts may have been compatible with tendencies associated to positive stimuli, leading to more accurate movements. Thus, these results suggest a possible effect of approach tendencies on the end stage of reaching. Moving towards positive stimuli is predisposed, whereas approaching is incongruent negative stimuli. The lack of accuracy when approaching could reflect an underlying avoidance tendency during negative contexts. Overall, the end stage of a reaching movement may be susceptible to a top-down attentional effect guided by approach-avoidance tendencies.

Moving towards targets was more accurate and precise than when moving in the opposite direction. Thus, even though moving towards targets is considered a fast and automatically guided mechanism (Day & Lyon, 2000), it produced more accurate movements towards the targets in comparison to movements entirely controlled by the participants' intention to move in the opposite direction. This could be related to the uncertainty of moving away. Moving to a target is more certain because feedback mechanisms know the exact location to where the finger needs to move to. Instead, moving in the opposite direction requires redirecting attention, which is slower and introduces uncertainty into the movement. That is, the subject is not entirely sure of where the finger is going to land because they need to redirect attention away from the new target. Indeed, feedback mechanisms inform of the location of the arm in space which is used to estimate the endpoint relative to the target location (Desmurget & Grafton, 2000). If the finger is far away from the location to where it needs to move to (as is the case in the away condition), the comparison between the endpoint and the new target location introduces uncertainty which biases the estimation of where the finger needs to land. The delay in correcting to the opposite direction of the target, combined with decreased precision and accuracy of the endpoints, suggests that moving away was under the influence of high uncertainty and was counterintuitive to reaching towards.

Alternative influences on reaching

In both experiments, accuracy and precision were better when moving to left targets compared to right targets, suggesting that moving to the left was biomechanically easier to make with the right arm (Cos et al., 2011; Cos et al., 2014; Hogan, 1985). Because the target jump occurred after movement initiation in Expt 2A, it suggests that biomechanical costs appear to be incorporated into feedback mechanisms during visuomotor corrections. Biomechanical costs are incorporated into the decision-making process before movement initiation (Cos et al., 2014; Marcos et al., 2015). However, to my knowledge, there is no evidence showing that biomechanical costs are incorporated into feedback mechanisms during ongoing movement.

Furthermore, in both experiments, participants initiated a movement correction to the right approximately 30 seconds before a correction to the left. This result corroborates previous evidence showing that corrections made to right targets occur roughly 18 ms before corrections made to left targets showing that moving to the right is faster than moving to the left (Day & Lyon, 2000; Welsh & Elliott, 2004). Evidence for this delay is also observed when looking at the raw trajectory corrections from the control condition **(Figure 6.15)**, in which corrections made to the right occurred earlier than corrections to the left. Such discrepancies are due to a delay in the transfer of information between hemispheres. When the target jumped to the left, the right visual field would have detected this jump. All subjects reached with their right arm and therefore a jump to the left would have required information to be transferred from the right to the left hemisphere in order to guide the right arm. These results highlight the importance of considering arm properties in the experimental design. This problem has been largely ignored by the reaching literature, as most reaching studies typically only use one arm for reaching and do not incorporate the location of the targets into their analyses. To truly control for this issue, an additional control group reaching with their left arm should have been used.

In sum, Experiment 2 replicated previous work showing that reaching movements can be influenced by fast and slow mechanisms (Day & Lyon, 2000; Day & Brown, 2001) and by the biophysical properties of the arm (Hogan, 1985). There was an influence of valence on *visuomotor automaticity*, with emotional stimuli influencing top-down attentional mechanisms engaged in driving fast and slow visuomotor corrections. Furthermore, there was an effect of approach-avoidance tendencies on the end stage of a movement, possibly guided by approach-avoidance tendencies. As was the case with Experiment 1, there was no evidence for an influence of *valence automaticity* on *visuomotor automaticity*.

6.5. General Discussion

This chapter aimed to shed light on the influence of emotional approach-avoidance tendencies on the ability to update motor plans in the face of ever changing environments. More specifically, I investigated whether approach-avoidance emotional tendencies (i.e. *valence automaticity*) influenced fast and slow pathways involved in correcting movements during action execution (i.e. *visuomotor automaticity*).

Two experiments were conducted to determine this influence. Both experiments demonstrated that emotional valence, but not their related approach-avoidance tendencies, influenced the latter stages of reaching, indicating a possible top-down influence of emotion on action execution. Importantly, Experiment 2 showed that emotional valence, but not emotional tendencies, influenced *visuomotor automaticity*. Thus, the main contribution of this chapter was to show that emotional valence influences top-down attentional mechanisms involved in motor updating during action execution and confirm that approach-avoidance tendencies do not influence action execution and on-going motor planning, supporting Chapter Four.

Valence automaticity does not influence visuomotor automaticity

There was no influence of valence-related approach-avoidance tendencies on mechanisms underlying motor updating. This suggests that approach-avoidance tendencies are limited to influencing action selection and do not influence feedback mechanisms involved in guiding visuomotor updating during execution. The current experiments are supportive of evidence demonstrating no effect of emotions and their related approach-avoidance tendencies on the execution of actions (Coombes et al., 2007; Stins et al., 2011) and argue against previous suggestions of a possible influence of emotional tendencies on action execution (Esteves et al., 2016; Stins et al., 2015).

A possible reason for a lack of an effect of *valence automaticity* may be because in both experiments, participants did not form the explicit goal to approach or avoid the emotional stimulus. Thus, emotional pictures were considered task-irrelevant and participants did not apply the task-instructions to emotional information. Common-coding models had suggested that approach-avoidance tendencies arise not from the evaluation of the stimulus but as a result of intended action effects which consequently triggers the action most suited to achieve the goal (Eder & Rothermund, 2008; Eder & Hommel, 2011; Hommel et al., 2001; Lavender & Hommel, 2007). A specific goal to approach a stimulus may activate a positive code which will overlap with the code for a positive stimulus. This overlap on the codes is what ultimately leads to one action being faster than another. Thus, goals are formed by contextual requirements such as, for example, task-instructions.

In Experiment 1 participants formed a goal about moving towards the target and the emotional stimulus was presented as a task-irrelevant distractor. Thus, individuals were not instructed to respond to the emotional distractor. Indeed, previous work has suggested that for emotional distractors to have an impact on task performance they necessarily need to be task relevant (Lichtenstein-Vidne, Henik, & Safadi, 2012; Okon-Singer, Tzelgov, & Henik, 2007). In Experiment 2, participants were instructed to approach or avoid non-emotional targets paired with emotional information. The task instructions did not explicitly state to approach or avoid emotional stimuli and therefore individuals did not form approach-avoidance goals.

The current results are therefore supportive of common-coding models (Lavender & Hommel, 2007) by highlighting the importance of task-instructions in triggering approach-avoidance tendencies. These data are also supportive of Chapter Three which had already demonstrated that task-instructions are needed for eliciting approach-avoidance, in support of other work (Liefooghe et al., 2012; Waszak et al., 2013) and that there are no implicit effects of such tendencies on action selection. This chapter confirms that emotional approach-avoidance tendencies do not (implicitly) influence action execution. *Valence automaticity* and *visuomotor automaticity* therefore appear to be independent processes.

Emotional valence influences action execution via top-down mechanisms

Both experiments provided evidence for an influence of valence on the later stage of the reaching movement, when emotional content was likely to have already been processed. Emotional stimuli therefore did not influence execution via fast, bottom-up processes, but instead biased motor updating through slower, top-down influences (Pessoa et al., 2002). Furthermore, the effect of emotional valence on the latter part of movement suggests that awareness of the emotional stimulus was necessary to update motor plans. Work has demonstrated that emotional information is typically processed 100-200 ms after it is initially presented (Olofsson et al., 2008; Oya et al., 2002; Pizzagalli et al., 1999). If movement times for both experiments were between 350-450 ms, it is highly likely that later stages of reaching movements were influenced by the conscious evaluation of the emotional pictures. The processing of emotional information was likely mediated via conscious, top-down attentional processes (Pessoa et al., 2002; Pessoa & Adolphs, 2011).

Importantly, emotional valence interacts with *visuomotor automaticity* and influences the speed of fast and slow responses, most likely via a higher-order attentional mechanism. This is supportive of the *single pathway model* proposed by Day & Lyon (2000) whereby discrepancies between early vs. late corrections are guided by the extra time taken for top-down areas to overcome the initial attention directed to the new target and redirect attention to move in the opposite direction, resulting in slower corrections (Tipper et al., 1998; Welsh & Elliot, 2004; Welsh, 2011; Rushworth et al., 2007). Importantly, these attentional mechanisms are influenced by the prioritisation of emotional stimuli (Vuilleumier et al. 2001; Ohman et al. 2001; Pessoa et al. 2002), which facilitated the "locking in" of attention to the new target and disrupted attentional inhibition when moving away from the new target. For instance, in Experiment 2 when moving towards the new target location there was no competition for attention and attention was automatically directed towards the new stimulus, facilitated by emotional content. In contrast, in the avoidance condition, participants moved away from the new target, therefore creating a new competing target located in the opposite direction. The target with emotional content becomes the non-target, whereas the target in the opposite direction is upgraded to target status. Thus, when moving away we have a target and non-target competing with each other, and this requires that the attention initially directed to emotional content is inhibited and redirected to the new target. Due to prioritisation, this process was disrupted. Furthermore, the effects observed were present even when the target jump occurred before the initiation of arm reaching (Expt 2B) and when motor planning to the new target was most likely complete, supporting the attentional model.

Contrary to Experiment 2, in Experiment 1 only one target was presented at a time. However, emotional distractors (i.e. non-target stimuli) were presented in the periphery, possibly creating competition with the actual target. Indeed, because emotional distractors were prioritised by attention, a higher degree of top-down control was necessary to suppress the tendency to move to the competing distractor. The completeness of the inhibitory process is what determines if trajectories deviate towards or away from a distractor (Welsh & Elliott, 2004). In this case trajectories ended up further away from the target than was originally intended (Tipper et al., 1997).

In sum, the data support the single-pathway model whereby higher-order attentional mechanisms guide visuomotor corrections and bias the end stage of reaching movements. Importantly, emotional stimuli appear to interact with how fast this attentional mechanism is deployed as a result of prioritisation of emotional information. Emotional valence therefore influences feedback mechanisms during motor updating. Moreover, the lack of an influence of approach-avoidance tendencies suggests that, despite emotional content being consciously perceived, approach-avoidance tendencies were not incidental.

Conclusion

In sum, this chapter aimed to demonstrate in a novel manner whether emotional approach-avoidance tendencies influence motor re-planning during action execution. More specifically, do automatic predisposed tendencies influence the fast and slow mechanisms underlying visually guided movement? The data from both experiments showed that motor plans are updated by a top-down, attentional mechanism (Tipper et al., 1997, 1998) that serves to direct attention to competing targets during execution. These attentional mechanisms are influenced by the prioritisation emotional information relative to neutral stimuli and by conscious awareness of the emotional content of the stimuli. Approach-avoidance tendencies did not implicitly influence mechanisms underlying visuomotor corrections, demonstrating independence between these processes. Overall, the results show that emotional stimuli impact action execution and suggest that mechanisms underlying emotional processing and online motor updating are not independent from each other.

Chapter Seven. Discussion

In this section, I will discuss how the above experiments have contributed to our understanding of how emotion and motor processes interact. More specifically, the main goal of this thesis was to determine the influence that emotional approach-avoidance tendencies have on different motor stages, from action selection and planning to action execution, and whether the conscious evaluation of emotional stimuli is necessary for these tendencies to impact movement generation. In the following, I discuss the significance of the current work, highlight outstanding questions and future experiments that could be conducted to add to the above evidence. I also speculate on clinical applications of the studies in this thesis.

7.1. Approach-avoidance tendencies and emotional context flexibly influence action selection

The generation of movement is constituted of two separate phases: the “what” phase, concerned with the selection of a motor goal, and the “how” phase, which determines the selection and specification of an action that will fulfil the motor goal (Cisek & Kalaska, 2010; Wong et al., 2015; Zhu & Thagard, 2002). What determines how actions are selected to approach and avoid emotional stimuli remains the subject of much debate. For instance, previous work has suggested that such actions are selected in a hardwired manner, independent of context and tied to specific arm movements which activate certain muscle groups (e.g. pulling/muscle flexion to approach a positive stimulus) (Cacciopo et al. 1993; Chen & Bargh, 1999). In contrast, approach-avoidance may be goal-directed (Eder & Rothermund, 2008; Eder & Klauer, 2009; Lavender & Hommel, 2007; Markman and Brendl, 2005), activated as a function of the task instructions and contextual demands (i.e. the reference-frame; should I move away from the stimulus or move the stimulus away from me?). Chapter Two contrasted these proposals to determine how selection of approach-avoidance actions occurs. This work was motivated by the observation that the idea that emotional actions are selected according to specific movements that activate certain muscle groups, such as those used for pulling (i.e. flexion) and pushing (i.e. extension), seemed too rigid and incompatible with the idea of a flexible motor system that responds to different contexts and updates itself as the environment changes, as proposed by the *affordance competition hypothesis* (ACH; Cisek, 2007; Cisek & Kalaska, 2010). Although previous work had already suggested that approach and avoidance are not tied to specific arm movements (Eder & Rothermund, 2008; Rotteveel & Phaf, 2004), the determinant factors in the selection of such actions remained unknown.

Chapter Two demonstrated that selection of approach-avoidance actions is influenced by both the reference-frame and approach-avoidance tendencies. That is, the goal to approach and avoid was determined by whether an agent moved relative to an emotional stimulus or whether the stimulus moved relative to the agent, and by approach-avoidance emotional tendencies. How fast this goal was determined influenced the speed of action selection and initiation, with faster actions to approach positive and avoid negative stimuli. Crucially, action selection could not be explained by specific arm movements or muscle groups.

The evidence presented here supports ecological and flexible frameworks that consider the numerous possibilities for action in a given environment, such as the *ACH* (Cisek & Kalaska, 2010), and proposals that the evaluation of action goals and anticipated consequences determine approach-avoidance behaviour (Eder & Rothermund, 2008, Eder & Klauer, 2009; Lavender & Hommel, 2007). This “evaluative-coding” framework (Eder & Klauer, 2009; Lavender & Hommel, 2007) postulates that both the emotional stimulus presented *and* the goal have an affective coding (e.g. a positive stimulus and an approach goal coded positively). When these codes are compatible, a faster response will occur. For example, an action “towards”, such as moving the self towards a stimulus, is in itself associated with a positive valence. When the goal is a positive stimulus, the shared positive coding of the stimulus and the action goal will lead to faster selection of approach. Thus, there is an overlap between perceptual and action codes. The work presented here provides some critical reappraisal of the long standing idea that approach-avoidance tendencies are ‘hardwired’. I thus confirmed the concept of flexible approach-avoidance actions: an identical action (e.g. towards/approach) can be positively or negatively coded depending on the valence of the stimulus and the context in which action is executed.

Importantly, while evaluative-coding frameworks had suggested that task instructions and goals determine affective coding, it had not been demonstrated that affective coding of actions is also determined by the reference-frame. What the work presented here adds to current theory is that the reference-frame is an important determinant of the context of behaviour and actions goals, and that approach-avoidance tendencies interact with the context. Since this work was published (Saraiva et al. 2013), other chapters (Chapters Three, Four and Five) have shown similar results (**Table 7.1**) and other studies have confirmed the flexibility of approach-avoidance actions in emotional situations (Beatty, Cranley, Carnaby, & Janelle, 2016; Eder, Rothermund, & Hommel, 2016; Laham, Kashima, Dix, & Wheeler, 2015; Ly, Huys, Stins, Roelofs, & Cools, 2014; Phaf, Mohr, Rotteveel, & Wicherts, 2014; Rotteveel et al., 2015).

		Approach		**Avoid**		**Pos-Neg RT Difference**	
		Negative	**Positive**	**Negative**	**Positive**	**App**	**Avoid**
Chapter Two	Object Ref.	692 ± 24	655 ± 21	671 ± 24	703 ± 23	-37	32
	Self Ref.	668 ± 25	639 ± 20	673 ± 23	703 ± 23	-29	30
Chapter Three		628 ± 16	587 ± 14	650 ± 16	663 ± 16	-41	13
Chapter Four		735 ± 19	721 ± 19	769 ± 23	803 ± 22	-14	34
Chapter Five		601 ± 19	578 ± 16	609 ± 19	630 ± 16	-23	21

Table 7.1. Effects of approach-avoidance tendencies on action selection. Reaction times for approaching and avoiding positive and negative stimuli across four chapters. When participants were required to approach positive stimuli, RTs were always significantly faster than when approaching negative stimuli. When participants initiated avoidance for negative stimuli, RTs were significantly faster than avoiding positive stimuli. This effect was consistent and significant across different experiments, showcasing the replicability of this result. Approach-avoidance tendencies influence the speed of action selection and initiation. All RTs are presented in ms ± 1 S.E.M.

Selecting approach-avoidance: interactions between top-down and bottom-up processes?

The current work supports the idea that approach-avoidance behaviour is predisposed and goal-directed, suggesting that approach-avoidance selection is not a purely "bottom-up" driven process, but that top-down areas are also involved. Thus, while the current data do not question the role that bottom-up, subcortical areas such as the amygdala and the basal ganglia play in triggering fast reactions to emotional stimuli, as has been shown previously (LeDoux, 1996, 2000; Rolls, 1999), they do suggest the involvement of top-down cortical areas in approach-avoidance behaviour. Speculatively, it is possible that in some emotional situations the influence from top-down areas is weaker, for instance in contexts where fast and urgent action is required to an unexpected threatening stimulus. In contrast, other situations that are deemed less urgent, such as avoiding a small spider on the ceiling, top-down areas evaluate contextual demands and “overrule” bottom-up processes. Some work has shown support for this. For instance, the OFC is activated during the selection of valence-related approach-avoidance actions, demonstrating that this area is essential to override predisposed response tendencies and guide the selection of actions contrary to these tendencies (Roelofs et al., 2009). Similarly, other studies have shown that the OFC is involved in overriding learned reward associations (Elliott et al., 2000; Rushworth et al., 2007). Furthermore, other work showed that disruption to the anterior PFC using transcranial magnetic stimulation impaired the correct selection, and subsequent initiation, of approach-avoidance actions (Volman et al., 2011, 2016). Although I can only speculate from behavioural data, top-down areas involved in higher-order control appear to be involved in the selection of approach and avoidance. Top-down and bottom-up areas may therefore interact to bias the selection of actions in emotional contexts, in support of the *ACH*.

Action selection in emotional contexts: is the level of threat important?

Action selection of approach-avoidance actions is now thought of as flexible, goal-directed and contextually driven process (Beatty et al., 2016; Lang & Bradley, 2013; Laham et al., 2015; Ly et al., 2014; Phaf et al., 2014). Some open questions do arise. Work has suggested that stimuli should be categorised according to their level of threat (Fanselow, 1994; Pessoa, 2009). The “predatory imminence continuum” model, for instance, suggests that according to the level and type of threat of a negative stimulus, action selection will transition from passive immobility to active fight-or-flight responses (Fanselow, 1994). More recent work suggested a spectrum in which positive and neutral stimuli are considered low-threat, and high-arousing negative stimuli are considered high-threat (Pessoa et al., 2009). Thus, taking into consideration the extremes of a threat spectrum (i.e. only positive and negative) may be insufficient to understand action selection in emotional contexts. If we were to categorise emotional valence according to this spectrum, and approach-avoidance tendencies were to be guided by the level of threat, both positive and neutral stimuli may lead to the faster selection of approach compared to negative stimuli. Moreover, contextualising stimuli according to their level of threat may also address the range of defensive responses associated to negative stimuli, whereby both approach and avoidance can be triggered depending on the negative content. To my knowledge, the influence of the level of threat on the selection of approach-avoidance tendencies remains undetermined. It would be interesting to see if task instructions which refer to positive and neutral stimuli as "low-threat" and negative as "high-threat" might influence selection. If neutral stimuli do not impact approach-avoidance, then it would confirm that approach-avoidance tendencies are valence related and not classified according to the level of threat.

7.2. Emotional valence impacts different stages of motor processing

The "how" phase of movement generation is divided into two processes: action selection and movement planning. Movement planning is the process that establishes the parameters that define how a movement is executed and a goal is achieved (Desmurget et al., 1999; Marteniuk, 1987; Paulignan et al., 1997; Wong et al., 2015). However, in the face of ever-changing environments, these parameters may sometimes need to be updated in real time throughout execution to accommodate new goals and opportunities and ensure successful behaviour (Desmurget et al., 1999; Goodale et al., 1986). Thus, we have two interrelated yet individual motor processes (i.e. motor planning and action execution) that may be biased by approach-avoidance tendencies in order to ensure appropriate behaviour.

In the previous section I demonstrated that that the selection and initiation of actions is influenced by the reference-frame and by approach-avoidance response tendencies. Some models postulate that selection, movement planning and the re-planning of actions during execution are separate processes that work in parallel and rely on the same sensory information from the environment (Cisek, 2007; Cisek & Kalaska, 2010). This parallel processing is important because it essentially suggests that while these processes have different underlying mechanisms, information that biases one process may also bias other processes. For instance, we may be faster at selecting, planning *and* executing approach actions to positive stimuli compared to negative stimuli. Some recent evidence has supported this idea by demonstrating that the speed of executing approach-avoidance actions is influenced by the valence of the stimulus, showing effects on motor planning (Esteves et al. 2016). To this end, the influence of approach-avoidance tendencies on motor planning and the updating of motor plans was investigated in two chapters. Chapter Four examined biases on motor planning by investigating vigour, that is, the effort expended once an action has been initiated in order to achieve a desirable outcome (Niv et al., 2007). Chapter Six examined if emotional changes in the environment influenced the updating of motor plans while executing actions. In addition, biases of approach-avoidance tendencies were also investigated on the ability to suppress actions that are no longer appropriate or advantageous (Aron et al. 2007; Verbruggen & Logan, 2008). Just like planning and execution, it was postulated that approach-avoidance tendencies would have an influence on response inhibition. Chapter Five examined this.

	Chapter Four	**Chapter Five**	**Chapter Six**	
	Max Force	**Speed of Inhibition**	**Area under curve**	**Precision**
Negative	76.3 ± 4.4	319 ± 40 ms	37382 ± 1993 mm^2	1260 ± 101 mm^2
Positive	74.7 ± 4.4	431 ± 43 ms	36630 ± 1878 mm^2	1279 ± 94 mm^2
Neutral	--	416 ± 42 ms	--	1303 ± 93 mm^2

Table 7.2. Effects of emotional valence on motor processes after action selection. Approach-avoidance tendencies did not influence motor planning or action execution. In Chapter Four, participants made more effort (i.e. pressed harder) when presented with negative relative to positive stimuli. In Chapter Five, participants were faster to inhibit their responses (i.e. faster SSRTs) when presented with negative relative to positive and neutral stimuli. In Chapter Six, reaching trajectories and precision were affected by valence. Trajectory deviations (i.e. area under the curve) were significantly larger when presented with negative relative to positive stimuli. Precision (i.e. endpoint area) was significantly better for negative relative to positive and neutral stimuli. Emotional valence therefore appears to influence performance once a decision to approach or avoid has been made.

All three chapters show an effect of emotional valence on different motor processes **(Table 7.2)**. In contrast, there were no effects of approach-avoidance tendencies. Chapter Four demonstrated that vigour was greater and less variable in negative relative to positive contexts, suggesting that motor planning prior to movement initiation is biased by negative valence. Similarly, Chapter Six established an effect of valence on the late phase of reaching, affecting the accuracy and precision of movement. For instance, Experiment 1 showed that negative distractors caused larger late movement deviations relative to positive and neutral stimuli, and that emotional distractors increased the accuracy and precision of reaching relative to neutral ones. Experiment 2 showed that visuomotor corrections were faster when targets were paired with positive and negative pictures, and that accuracy was better when presented with positive and neutral relative to negative stimuli. In Chapter Five stopping processes were influenced by negative stimuli but not by positive or neutral stimuli. Overall, these results show that emotional valence impacts different stages of motor processing and suggest that mechanisms underlying emotional processing and motor processing are not independent from each other. To the best of my knowledge, this is the first demonstration of the impact of emotional valence on different underlying mechanisms of motor processing, confirming a link between emotions and action.

The results are clear: while emotional valence itself influenced the execution and suppression of actions, their associated approach-avoidance tendencies did not. This dissociation is important for two reasons. Firstly, the current work appears to have divorced the effects of approach-avoidance tendencies on different motor processes, with approach-avoidance tendencies influencing action selection but not motor planning, action execution or response inhibition. This answers the main goal of this thesis: approach-avoidance tendencies do not influence all motor processing. To my knowledge, this dissociation has not been demonstrated previously. This thesis therefore provides novel insight into the mechanisms whereby emotional tendencies are linked to action. Secondly, this work shows novel evidence of separable effects of valence and valence-related tendencies. The former influences motor planning, action execution and response inhibition whereas the latter only influences action selection. This suggests that valence and approach-avoidance tendencies do not share the same underlying mechanisms. While this was not a goal of the thesis, the experiments were designed in such a way that it allowed dissociating valence from emotional tendencies. To my knowledge this is the first demonstration of separable effects of valence and response tendencies on different motor stages within the same experiments.

The lack of any influence of approach-avoidance tendencies on other motor processes other than selection is at odds with the *ACH* (Cisek, 2007; Cisek & Kalaska, 2010) and evaluative-coding frameworks (Eder & Klauer, 2009; Lavender & Hommel, 2007). The ACH postulates that, despite being separate processes with different underlying mechanisms, there is parallel processing between action selection, planning and execution during behaviour. Furthermore, biases arising from one process should, in principle, influence processes working in parallel. Similarly, evaluative-coding frameworks suggest that selection, planning and execution of actions should be facilitated through stimuli they share features with (Eder, Müsseler, & Hommel, 2011). Thus, it was expected that any biases on selection should also influence the planning and execution of actions. In accordance with the model of movement generation (**Figure 1.1**; Wong et al. 2015), my results suggest that approach-avoidance tendencies influence the early formation and generation of goals that will subsequently only bias the selection of actions. Any ensuing motor stage may not be biased by the generation of these motor goals because presumably the bias will have already occurred. For instance, in the current experiments, goals were formed as a function of context, and this goal informed which action should be selected. The commitment to specific actions was therefore made prior to the involvement of other motor processes, such as planning. The current work is supportive of previous work that had dissociated effects of approach-avoidance tendencies on action selection and execution (Coombes et al., 2007; Stins et al., 2011).

This possibility may also explain the dissociation between approach-avoidance tendencies and valence. Approach-avoidance tendencies are goal-directed (Lang & Bradley, 2013; Lavender & Hommel, 2007) and only influence action selection, whereas valence itself is not goal-directed and instead has a generic effect on actions (Lang et al. 1997). Thus once an action has been committed during the selection phase, valence may be capable of generically influencing subsequent motor processes irrespective of whether an approach or avoidance was chosen. What this evidence suggests is that emotional stimuli do influence a variety of motor processes, but this influence is manifested in different ways, with emotional approach-avoidance tendencies influencing selection, and emotional valence taking over thereafter. There therefore appears to be an “emotion continuum” whereby response tendencies and emotional valence work together to inform motor processes during emotional behaviour, akin to the “threat continuum” postulated by Fanselow (1994). Why should this be the case? Biasing the selection of goals and actions is the first and most crucial step in movement generation and therefore it is highly advantageous to be selective during this phase. It is here that “what to do” is resolved. However, following selection, processes relative to “how to do it” can be unselective because the action itself has already been chosen. Any planning or implementation of movement parameters occurs relative to the selected action and not to initial biases on goal formation.

The main contribution of this thesis is therefore to demonstrate that predisposed tendencies do not influence all motor stages, and that valence and approach-avoidance tendencies have dissociable effects on motor processing. Some open questions do remain. Firstly, given this distinction between approach-avoidance tendencies and valence on motor processing, it is necessary to further investigate the point at which this "switch" in influence between approach-avoidance tendencies and valence occurs. This would give further insight into the different mechanisms whereby emotions and actions are linked. Secondly, it may be possible that the lack of effects in subsequent motor stages may be related to instructions being exclusive to selection. For example, in Chapter Four participants were not instructed to press as hard as possible to approach or avoid an emotional stimulus, therefore it was expected that approach-avoidance tendencies would incidentally affect force production. However, given the role of goals in approach-avoidance behaviour, it would be interesting to see if an effect of such tendencies on vigour would arise if individuals are explicitly told to press as hard as possible. This would set a goal *during* action execution. Similarly, in Chapter Six, explicitly instructing participants to approach or avoid emotional target jumps may reveal underlying effects of automatic tendencies on the speed of visuomotor corrections. Thus, giving participants explicit goals *during* movement may reveal influences of such tendencies on action execution.

7.3. **Forming action goals: an automatic process?**

The formation of goals is crucial for informing processes that select actions. In the introduction I stated that the "what" phase is concerned with how a motor goal is created, whereby stimulus identification and evaluation are necessary to determine the value of a stimulus (e.g. good or bad) and what needs to be done to the stimulus (e.g. approach or avoid). The deployment of attentional resources plays a fundamental role in this process by selecting the object of interest and excluding the surrounding environment, thereby increasing the availability of resources necessary for action (Wong et al. 2015). Evidence suggests that emotional stimuli may facilitate this process by prioritising the processing of emotional relative to non-emotional information (Ohman et al., 2001; Vuilleumier et al., 2001).

This thesis presents evidence in favour of the prioritisation of emotional information (Bradley et al., 1997; Ohman et al., 2001; Pratto & John, 1991; Vuilleumier, 2005; Yiend, 2010) and of increased perceptual processing of emotional stimuli (Pessoa et al., 2005, 2002; Pessoa & Ungerleider, 2004; Vuilleumier, Armony, Driver, & Dolan, 2003) relative to neutral stimuli. Chapter Five, for example, demonstrated that positive and negative stimuli slowed down response initiation compared to neutral stimuli. Similarly, in Chapter Six, emotional stimuli but not neutral pictures influenced the speed of visuomotor corrections, as well as the accuracy and precision of reaching movements. Thus, it is clear that emotional stimuli had an influence on the availability of attentional resources necessary for goal formation, which subsequently influenced motor processes. While this result is not novel, it corroborates previous work, further indicating the extent of the intricate relationship between emotion and action processes.

Furthermore, evidence suggests that the explicit evaluation of the emotional stimulus is essential for the formation of approach-avoidance goals (Eder & Klauer, 2009; Eder & Rothermund, 2008). In contrast, others suggest that the automaticity of approach-avoidance is implicit, without the necessary conscious evaluation of the emotional stimulus (Chen & Bargh, 1999; Duckworth et al., 2002; Krieglmeyer et al. 2010). The implicit or explicit nature of approach-avoidance biases on different motor stages was investigated as an additional goal of this thesis.

The evidence presented confirms that there are no implicit effects of approach-avoidance tendencies on any stages of motor processing and that explicit evaluation seemed crucial for specifying the goal to approach and avoid. Chapter Three demonstrated that explicit task instructions override implicit approach-avoidance tendencies: task-irrelevant subliminal and supraliminal emotional primes did not implicitly elicit approach-avoidance tendencies. Instead, task instructions related to approach and avoidance goals dictated which actions were initiated by the prime and the target. This was also demonstrated in Chapter Two, which determined that the evaluation of the content of a negative stimulus was critical for eliciting approach or avoidance. Furthermore, experiment two in Chapter Five showed that when task instructions were not relevant to emotional stimuli, approach-avoidance preparatory processes were not influenced. Similarly, in both experiments in Chapter Six task-irrelevant emotional distractors failed to implicitly elicit approach-avoidance tendencies.

Taken together, this evidence shows that for approach and avoidance to be elicited, there first needs to be the conscious evaluation of the emotional stimulus, followed by the explicit intention to approach or avoid. Despite previous work suggesting that action selection is only influenced by response tendencies when there is an explicit goal (Eder & Klauer, 2009), it had not yet been demonstrated that this may also apply to action execution. The current work demonstrates this to be the case. While these results may not be novel per se, they add to the existing literature and are supportive of common-coding accounts (Eder & Hommel, 2013; Eder & Klauer, 2009; Eder & Rothermund, 2008) which assume that for approach-avoidance tendencies to be elicited, stimulus evaluation must first occur. The few studies which have not required conscious evaluation, or have applied implicit measures, have not revealed approach-avoidance effects (Rotteveel and Phaf, 2004; Vandenbosch & De Houwer, 2011). This is supported by a recent meta-analysis which revealed that in studies in which emotional valence was task-irrelevant, there were no approach-avoidance effects (Phaf et al., 2014).

If explicit instructions and conscious evaluation of the emotional stimulus are necessary, what does this mean for automaticity? Approach-avoidance tendencies are assumed to occur automatically and unintentionally, without the need for explicit goals (Chen & Bargh, 1999; Duckworth et al., 2002). However, it is becoming more evident that approach-avoidance behaviour is likely driven by both bottom-up processes involved in processing an emotional stimulus (LeDoux, 1996), and top-down processes that generate goals following context evaluation (Lavender & Hommel, 2007). Here, this interaction is evident in the fact that in all chapters that instructed participants to approach and avoid specific pictures and in which the goal was explicit (Chapters Two, Three and Four), approach was still faster for positive and avoidance for negative. The mere fact that even when participants have intentional control over their actions, certain actions are faster than others points to approach-avoidance behaviour being goal-directed (i.e. relies on explicit task instructions) but also predisposed (i.e. automatic). That is, in goal-directed situations if such tendencies were not predisposed, we would expect there to be no difference in initiating approach towards positive and negative stimuli because presumably participants can control motor initiation. However, this is clearly not the case and supports previous studies (Roelofs et al. 2009, Volman et al. 2011, 2016) which have revealed that despite action instructions, some actions are harder to overcome than others and that eliciting actions opposite to predisposed tendencies requires higher-order areas such as the anterior PFC and OFC that exert top-down control to override automatic tendencies, often requiring more attentional capacity to do so (Gawronski et al., 2005).

The work presented in this thesis therefore adds to existing knowledge by providing novel evidence that approach-avoidance tendencies only influence motor processing when goals are explicit and emotional stimuli are consciously evaluated, and that this is applicable to action preparation and possibly execution. This work has also contributed further to our understanding of automaticity by demonstrating that even in goal-directed situations, approach-avoidance tendencies prevail, contrasting previous suggestions that automatic processes are exclusively fast, goal-independent and unconscious (Moors & De Houwer, 2006). Instead, approach-avoidance tendencies are predisposed, conscious and goal-dependent, possibly guided by interactions between bottom-up and top-down processes.

From the perspective of theories on automaticity, the automatic nature of approach-avoidance tendencies is still very much debatable. This is because purely automatic behaviour is considered to be unconscious and goal-independent (Moors & De Houwer, 2006), yet the majority of approach-avoidance work claiming automaticity allows for conscious and goal-dependent behaviour. Future work addressing the automaticity of approach-avoidance actions must design experiments in which both conscious/unconscious evaluation and goal-dependent/independent factors are taken into consideration. Only work incorporating all factors will allow us to determine the nature of automatic approach-avoidance tendencies. For instance, although Chapter Three compared the conscious/unconscious element, it did not evaluate situations in which approach-avoidance is goal dependent and independent. Participants may, for example, be given explicit approach-avoidance instructions relative to positive and negative stimuli (goal-dependent) or be simply instructed to move relative to an emotional stimulus in the direction indicated by an arrow (goal-independent).

In addition, while the evidence suggests that any influence of approach-avoidance tendencies on action execution must arise from explicit approach-avoidance goals, there is no evidence that actually shows this to be the case. As such, it is necessary to implement a task in which participants are provided with approach-avoidance goals *while* they are performing a task. An adaptation of the task used in experiment two of Chapter Six might be a possible avenue to explore this.

7.4. Human actions are affected by the activation of a primitive defensive circuitry

Much evidence in the emotion literature has shown that negative (or threatening) content is more influential than positive information (Anderson et al., 2003; Fox, Russo, & Dutton, 2002; Sagliano, D'Olimpio, Scafati, & Trojano, 2016; Schmidt, Belopolsky, & Theeuwes, 2015). For instance, negative stimuli have been shown to have a stronger involuntary interference on ongoing tasks relative to positive stimuli, and to more readily recruit attention (Hartikainen et al. 2000; Pessoa et al. 2002; Pratto & John, 1991). Similarly, biases on behaviour appear to be stronger when presented with negative or threat-related emotions (Lang et al., 2000). Furthermore, studies on the processing and detection of emotional stimuli postulate a so-called "threat advantage" whereby the processing of negative stimuli with threatening content is prioritised over other stimuli (Ohman et al., 2001; Ohman, Lundqvist, & Esteves, 2001). Importantly, from an anatomical perspective, the areas responsible for the processing of threat and negative emotions, such as the amygdala, have been more straightforward to identify (LeDoux, 2000; Phelps, Lempert, & Sokol-Hessner, 2014; Rolls, 1999) than those associated with positive emotions (Rolls, 1999). Given the more prominent effect of negative relative to positive stimuli on behaviour, it is not surprising that there are more models that explain how defensive behaviour occurs (e.g. Fanselow, 1994; Lang et al., 1997; LeDoux, 2012) relative to behaviour in pleasant or positive contexts (Lang et al., 1997). These "defensive" models suggest that negative or threatening stimuli lead to heightened vigilance that orients attention to the stimulus resulting first in immobility and subsequently in active defensive action (Fanselow, 1994), selected from a repertoire of possible actions such as withdrawal or attack based on their level of threat (Lang & Bradley, 2013).

This thesis is supportive of the above work by showing that negative stimuli had a greater influence in a variety of motor processes compared to positive stimuli. In Chapters

Two and Three, there was no difference between the selection of approach and avoidance actions in negative contexts, a result that was suggested to stem from the existence of a “threat continuum” (Bradley et al., 2001; Fanselow, 1994) that activates a variety of defensive actions such as, for example, fight-or-flight depending on the context. Furthermore, Chapter Five showed that response inhibition is faster for negative pictures possibly as a result of freezing mechanisms (Facchinetti et al., 2006; Löw, Weymar, & Hamm, 2015; Roelofs, Hagenaars, & Stins, 2010; Stins et al., 2011). This demonstrates that negative stimuli not only elicit fight-or-flight mechanisms but also freezing, supporting the idea of a repertoire of defensive actions that are context sensitive (Lang & Bradley, 2013). Negative stimuli therefore impact motor processes depending on the contextual requirement (i.e. to escape or defend).

Chapter Four also demonstrated that only negative pictures lead to greater and less variable vigour, whereas Chapter Six showed that reaching accuracy is disrupted in negative contexts only. Both chapters therefore show an influence of negative or threatening content on action execution. These data support work suggesting faster prioritisation of negative information by the attentional system relative to less threatening content, in addition to highlighting the attention-grabbing properties of negative pictures, adding to a wealth of existing literature (Mogg, Philippot, & Bradley, 2004; Notebaert, Crombez, Van Damme, De Houwer, & Theeuwes, 2010; Ohman et al., 2001; Pratto & John, 1991).

Negative stimuli therefore appear to influence various stages of motor processing including action preparation, response suppression and action execution. This provides further evidence for the existence of a fast defensive circuit that prioritises threatening information and rapidly influences the motor system in order to carry out appropriate and beneficial actions that avoid costs (LeDoux, 1996). Moreover, this thesis offers support for “defensive” models, such as the defence-cascade model (Lang et al. 1990) and the “predatory imminence continuum” (Fanselow, 1994), by showing that a wide variety of responses are triggered by negative stimuli. Although, admittedly, the results provided here are not novel, taken together they confirm an effect of negative stimuli on various motor processes. This demonstrates an intricate relationship between negative stimuli and the motor system and further suggests that these stimuli are more relevant to survival.

Given their greater impact on motor processes and behaviour, perhaps it is more appropriate to investigate the link between emotions and actions using negative stimuli only, taking into account the fact that such stimuli can elicit both approach and avoidance depending on the context. It would be interesting to narrow down on the specificity of negative stimuli and their associated actions, namely investigate which negative stimuli automatically trigger avoidance, which automatically trigger approach and which result in freezing. Some work has already addressed this by suggesting that angry faces potentiate approach (Carver & Harmon-Jones, 2009), and fearful faces potentiate avoidance (Hammer & Marsh, 2015; Marsh et al., 2005). However, Chapter Two, along with others (Coombes et al., 2007; Marsh et al., 2005), suggests that the context is important in determining whether fearful stimuli trigger avoidance or approach. Similarly, work on vigour has shown differential effects of a variety of negative stimuli (Coombes et al., 2007), with greater vigour when presented with pictures of mutilation compared to pictures of attack. The existing evidence provides support to the theory that negative stimuli potentiate different actions. It remains unknown how different negative stimuli influence different motor processes. Understanding this would give further insight into the predisposition of emotional reactions.

7.5. Possible clinical applications?

This thesis demonstrated that approach-avoidance tendencies influence selection processes. From a clinical perspective, understanding the impact that such tendencies have on action selection in normal individuals will serve as a comparison against clinical populations who, for example, display atypical social behaviour. Specifically, if response tendencies influence the selection of actions, it is possible that training to learn such tendencies may help those with atypical social behaviour. One example of such a population are children with autistic spectrum disorders (ASD) who suffer from emotional impairments and behave abnormally in response to emotional social cues. Such children lack the understanding of emotional expressions and emotional contexts, and show a lack of motivation to engage with others (DSM-V, American Psychiatric Association, 2013; Chevallier, Kohls, Troiani, Brodkin, & Schultz, 2012; Klin, Jones, Schultz, Volkmar, & Cohen, 2002). From a social and motivational perspective, ASD populations may not consider positive or aversive situations in the same light as normal individuals (Chevallier et al., 2012), failing to generate goals to maximise action outcomes. Thus, they may not have the approach-avoidance tendencies that normal individuals have. Can these tendencies be learned such that it improves social behaviour in children with ASD?

According to common-coding accounts, representations of perceptual consequences are generated through experience and stored in memory, becoming retrieval cues that will be used in subsequent similar situations and thereby leading to the selection of the most appropriate action (Eder & Rothermund, 2009; Hommel et al., 2001; Lavender & Hommel, 2007). This is similar to the somatic marker hypothesis (Damasio, 1994), whereby affective experiences are stored together with produced actions, becoming markers that are triggered in certain situations. Indeed, it is through actions that many of us create associations in our brains. For example, spelling out a telephone number might sometimes be more difficult than to actually type it on the phone. Motor memory therefore is sufficiently powerful to influence the automaticity of our actions. Thus, it is possible that training individuals to approach or avoid certain stimuli might influence action selection. Previous work has successfully trained normal individuals to be faster to approach or avoid certain stimuli, even when they were unaware of the intention to do so (Woud et al., 2008; Woud, Maas, Becker, & Rinck, 2013). Training ASD children on approach-avoidance tasks in which they directly observe the consequences of their actions may help them create automatic tendencies and interact more appropriately in the real world. Recent evidence suggests that children with ASD display increased approach towards cartoons of positive stimuli but fail to assign this positive coding to real stimuli (Silva, Da Fonseca, Esteves, & Deruelle, 2015). This suggests that these tendencies may be present but only manifest in abstract scenarios. Training may help create these motivational associations to real stimuli. To the best of my knowledge, no other studies have implemented an emotional approach-avoidance task on individuals with ASD. This avenue shows potential for promising results.

The same logic applies to clinical populations with emotional phobias, such as fear of spiders, or with mood disorders such as those with anxiety or depression. Subjects with phobias and anxiety have a tendency to avoid the stimulus that causes them fear (Roth &

Cohen, 1986), whereas individuals with depression display decreased tendencies to approach and increased avoidance (Hopko, Lejuez, Ruggiero, & Eifert, 2003; Jacobson, Martell, & Dimidjian, 2001). For example, previous work has found that individuals with a fear of spiders are faster to avoid than to approach such stimuli (Rinck & Becker, 2007), and individuals with social anxiety can be trained to display greater social approach behaviours (Taylor & Amir, 2012). Training should presumably lead to the automatic selection of certain actions, and therefore training participants to approach or avoid certain emotional stimuli may help individuals overcome certain phobias or depressive tendencies. Training has been successfully applied to alcoholic individuals who have a tendency to approach alcohol, with studies demonstrating that it is possible to retrain automatic approach-avoidance tendencies in such individuals (Wiers, Eberl, Rinck, Becker, & Lindenmeyer, 2011; Wiers, Rinck, Kordts, Houben, & Strack, 2010). In sum, clinical work should capitalise on the goal-directed nature of approach-avoidance behaviour to treat individuals who display atypical social behaviour.

References

Albert, J., López-Martín, S., & Carretié, L. (2010). Emotional context modulates response inhibition: Neural and behavioral data. *NeuroImage*, *49*(1), 914–921.

Amaral, D. (1992). Anatomical organization of the primate amygdaloid complex. In J. P. Aggleton (Ed.), *The amygdala: neurobiological aspects of emotion, memory and mental dysfunction.* (pp. 1–66). New York: Wiley-Liss.

Ambron, E., & Foroni, F. (2015). The Attraction of Emotions: Irrelevant Emotional Information Modulates Motor Actions. *Psychonomic Bulletin & Review*, *22*(4), 1117.

Ambron, E., Rumiati, R. I., & Foroni, F. (2016). Do emotions or gender drive our actions? A study of motor distractibility. *Cognitive Neuroscience*, *7*(1–4), 160–169.

American Psychiatric Association. (2013). *Diagnostic and Statistical Manual of Mental Disorders* (Fifth Edition). American Psychiatric Association. Retrieved from

Anderson, A. K., Christoff, K., Panitz, D., De Rosa, E., & Gabrieli, J. D. E. (2003). Neural correlates of the automatic processing of threat facial signals. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience*, *23*(13), 5627–5633.

Anderson, A. K., & Phelps, E. A. (2001). Lesions of the human amygdala impair enhanced perception of emotionally salient events. *Nature*, *411*(6835), 305–309.

Aron, A. R. (2007). The Neural Basis of Inhibition in Cognitive Control. *The Neuroscientist*, *13*(3), 214–228.

Aron, A. R. (2011). From reactive to proactive and selective control: developing a richer model for stopping inappropriate responses. *Biological Psychiatry*, *69*(12), e55-68.

Aron, A. R., Durston, S., Eagle, D. M., Logan, G. D., Stinear, C. M., & Stuphorn, V. (2007). Converging Evidence for a Fronto-Basal-Ganglia Network for Inhibitory Control of Action and Cognition. *The Journal of Neuroscience*, *27*(44), 11860–11864.

Aron, A. R., & Poldrack, R. A. (2006). Cortical and Subcortical Contributions to Stop Signal Response Inhibition: Role of the Subthalamic Nucleus. *The Journal of Neuroscience*, *26*(9), 2424–2433.

Aron, A. R., Robbins, T. W., & Poldrack, R. A. (2014). Inhibition and the right inferior frontal cortex: one decade on. *Trends in Cognitive Sciences*, *18*(4), 177–185.

Aron, A. R., & Verbruggen, F. (2008). Stop the presses: dissociating a selective from a global mechanism for stopping. *Psychological Science*, *19*(11), 1146–1153.

Badry, R., Mima, T., Aso, T., Nakatsuka, M., Abe, M., Fathi, D., Fukuyama, H. (2009). Suppression of human cortico-motoneuronal excitability during the Stop-signal task. *Clinical Neurophysiology: Official Journal of the International Federation of Clinical Neurophysiology*, *120*(9), 1717–1723.

Bamford, S., & Ward, R. (2008). Predispositions to approach and avoid are contextually sensitive and goal dependent. *Emotion*, *8*(2), 174–183.

Bargh, J. A. (1989). Conditional automaticity: Varieties of automatic influence in social perception and cognition. In J. A. Bargh & J. S. Uleman (Eds.), *Unintended thought* (pp. 3–51). New York: Guildford Press.

Bargh, J. A. (1992). The ecology of automaticity: toward establishing the conditions needed to produce automatic processing effects. *The American Journal of Psychology*, *105*(2), 181–199.

Bargh, J. A., Chaiken, S., Raymond, P., & Hymes, C. (1996). The Automatic Evaluation Effect: Unconditional Automatic Attitude Activation with a Pronunciation Task. *Journal of Experimental Social Psychology*, *32*(1), 104–128.

Bargh, J. A., & Morsella, E. (2008). The Unconscious Mind. *Perspectives on Psychological Science : A Journal of the Association for Psychological Science*, *3*(1), 73–79.

Bartholow, B. D., Riordan, M. A., Saults, J. S., & Lust, S. A. (2009). Psychophysiological evidence of response conflict and strategic control of responses in affective priming. *Journal of Experimental Social Psychology*, *45*(4), 655–666.

Basso, M. A., & Wurtz, R. H. (1998). Modulation of neuronal activity in superior colliculus by changes in target probability. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience*, *18*(18), 7519–7534.

Beatty, G. F., Cranley, N. M., Carnaby, G., & Janelle, C. M. (2016). Emotions predictably modify response times in the initiation of human motor actions: A meta-analytic review. *Emotion*, *16*(2), 237–251.

Beaudry, O., Roy-Charland, A., Perron, M., Cormier, I., & Tapp, R. (2014). Featural processing in recognition of emotional facial expressions. *Cognition & Emotion*, *28*(3), 416–432.

Beck, J. M., Ma, W. J., Kiani, R., Hanks, T., Churchland, A. K., Roitman, J., Pouget, A. (2008). Probabilistic population codes for Bayesian decision making. *Neuron*, *60*(6), 1142–1152.

Bogacz, R., Brown, E., Moehlis, J., Holmes, P., & Cohen, J. D. (2006). The physics of optimal decision making: a formal analysis of models of performance in two-alternative forced-choice tasks. *Psychological Review*, *113*(4), 700–765.

Bouman, D., Stins, J. F., & Beek, P. J. (2015). Arousal and exposure duration affect forward step initiation. *Emotion Science*, 1667. https://doi.org/10.3389/fpsyg.2015.01667

Bradley, B. P., Mogg, K., Millar, N., Bonham-Carter, C., Fergusson, E., Jenkins, J., & Parr, M. (1997). Attentional Biases for Emotional Faces. *Cognition & Emotion*, *11*(1), 25–42.

Bradley, M., Codispoti, M., Cuthbert, B. N., & Lang, P. J. (2001). Emotion and motivation I: defensive and appetitive reactions in picture processing. *Emotion*, *1*(3), 276–298.

Bradley, M. M., & Lang, P. J. (2007). The International Affective Picture System (IAPS) in the study of emotion and attention. In J. A. Coan & J. J. B. Allen (Eds.), *Handbook of emotion elicitation and assessment* (pp. 29–46). New York, NY, US: Oxford University Press.

Buetti, S., Juan, E., Rinck, M., & Kerzel, D. (2012). Affective states leak into movement execution: Automatic avoidance of threatening stimuli in fear of spider is visible in reach trajectories. *Cognition & Emotion*.

Bunzeck, N., Guitart-Masip, M., Dolan, R. J., & Düzel, E. (2011). Contextual novelty modulates the neural dynamics of reward anticipation. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience*, *31*(36), 12816–12822.

Cacioppo, J. T., Priester, J. R., & Berntson, G. G. (1993). Rudimentary determinants of attitudes. II: Arm flexion and extension have differential effects on attitudes. *Journal of Personality and Social Psychology*, *65*, 5–17.

Calvo, M. G., & Nummenmaa, L. (2011). Time course of discrimination between emotional facial expressions: The role of visual saliency. *Vision Research*, *51*(15), 1751–1759. https://doi.org/10.1016/j.visres.2011.06.001

Cardinal, R. N., Parkinson, J. A., Hall, J., & Everitt, B. J. (2002). Emotion and motivation: the role of the amygdala, ventral striatum, and prefrontal cortex. *Neuroscience & Biobehavioral Reviews*, *26*(3), 321–352.

Carretié, L. (2014). Exogenous (automatic) attention to emotional stimuli: a review. *Cognitive, Affective & Behavioral Neuroscience*, *14*(4), 1228–1258.

Carver, C. S., & Harmon-Jones, E. (2009). Anger is an approach-related affect: evidence and implications. *Psychological Bulletin*, *135*(2), 183–204.

Carver, C. S., & White, T. L. (1994). Behavioral inhibition, behavioral activation, and affective responses to impending reward and punishment: The BIS/BAS Scales. *Journal of Personality and Social Psychology*, *67*(2), 319–333.

Chen, M., & Bargh, J. A. (1999). Consequences of Automatic Evaluation: Immediate Behavioral Predispositions to Approach or Avoid the Stimulus. *Personality and Social Psychology Bulletin*, *25*(1), 215–224.

Chevallier, C., Kohls, G., Troiani, V., Brodkin, E. S., & Schultz, R. T. (2012). The social motivation theory of autism. *Trends in Cognitive Sciences*, *16*(4), 231–239.

Chiu, P. H., Holmes, A. J., & Pizzagalli, D. A. (2008). Dissociable recruitment of rostral anterior cingulate and inferior frontal cortex in emotional response inhibition. *NeuroImage*, *42*(2), 988–997.

Chiu, Y.-C., Cools, R., & Aron, A. R. (2014). Opposing Effects of Appetitive and Aversive Cues on Go/No-go Behavior and Motor Excitability. *Journal of Cognitive Neuroscience*, *26*(8), 1851–1860.

Cho, Y. T., Ernst, M., & Fudge, J. L. (2013). Cortico–Amygdala–Striatal Circuits Are Organized as Hierarchical Subsystems through the Primate Amygdala. *The Journal of Neuroscience*, *33*(35), 14017–14030.

Cisek, P. (2007). Cortical mechanisms of action selection: the affordance competition hypothesis. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *362*(1485), 1585–1599.

Cisek, P., & Kalaska, J. F. (2002). Simultaneous encoding of multiple potential reach directions in dorsal premotor cortex. *Journal of Neurophysiology*, *87*(2), 1149–1154.

Cisek, P., & Kalaska, J. F. (2005). Neural correlates of reaching decisions in dorsal premotor cortex: specification of multiple direction choices and final selection of action. *Neuron*, *45*(5), 801–814.

Cisek, P., & Kalaska, J. F. (2010). Neural Mechanisms for Interacting with a World Full of Action Choices. *Annual Review of Neuroscience*, *33*(1), 269–298.

Coombes, S. A., Cauraugh, J. H., & Janelle, C. M. (2006). Emotion and movement: Activation of defensive circuitry alters the magnitude of a sustained muscle contraction. *Neuroscience Letters*, *396*(3), 192–196.

Coombes, S. A., Cauraugh, J. H., & Janelle, C. M. (2007). Dissociating motivational direction and affective valence: specific emotions alter central motor processes. *Psychological Science*, *18*(11), 938–942.

Coombes, S. A., Cauraugh, J. H., & Janelle, C. M. (2007). Emotional state and initiating cue alter central and peripheral motor processes. *Emotion (Washington, D.C.)*, *7*(2), 275–284.

Coombes, S. A., Corcos, D. M., Pavuluri, M. N., & Vaillancourt, D. E. (2012). Maintaining Force Control Despite Changes in Emotional Context Engages Dorsomedial Prefrontal and Premotor Cortex. *Cerebral Cortex*, *22*(3), 616–627.

Coombes, S. A., Gamble, K. M., Cauraugh, J. H., & Janelle, C. M. (2008). Emotional states alter force control during a feedback occluded motor task. *Emotion (Washington, D.C.)*, *8*(1), 104–113.

Coombes, S. A., Higgins, T., Gamble, K. M., Cauraugh, J. H., & Janelle, C. M. (2009). Attentional control theory: anxiety, emotion, and motor planning. *Journal of Anxiety Disorders*, *23*(8), 1072–9.

Cornelia Herbert, S. S. (2011). Response Inhibition and Memory Retrieval of Emotional Target Words: Evidence from an Emotional Stop-Signal Task. *Journal of Behavioral and Brain Sciences*, *1*(3).

Cos, I., Bélanger, N., & Cisek, P. (2011). The influence of predicted arm biomechanics on decision making. *Journal of Neurophysiology*, *105*(6), 3022–3033.

Cos, I., Duque, J., & Cisek, P. (2014). Rapid prediction of biomechanical costs during action decisions. *Journal of Neurophysiology*, *112*(6), 1256–1266.

Coxon, J. P., Stinear, C. M., & Byblow, W. D. (2007). Selective inhibition of movement. *Journal of Neurophysiology*, *97*(3), 2480–2489.

Crammond, D. J., & Kalaska, J. F. (2000). Prior Information in Motor and Premotor Cortex: Activity During the Delay Period and Effect on Pre-Movement Activity. *Journal of Neurophysiology*, *84*(2), 986–1005.

Custers, R., & Aarts, H. (2010). The Unconscious Will: How the Pursuit of Goals Operates Outside of Conscious Awareness. *Science*, *329*(5987), 47–50.

Damasio, A. (1994). *Descartes' Error: Emotion, Reason, and the Human Brain*. New York, NY: G. P. Putnam's Sons.

Darwin, C. (1872). *The expression of the emotions in man and animals.* London: John Murray.

daSilva, E. B., Crager, K., Geisler, D., Newbern, P., Orem, B., & Puce, A. (2016). Something to sink your teeth into: The presence of teeth augments ERPs to mouth expressions. *NeuroImage*, *127*, 227–241.

Day, B. L., & Brown, P. (2001). Evidence for subcortical involvement in the visual control of human reaching. *Brain*, *124*(9), 1832–1840.

Day, B. L., & Lyon, I. N. (2000b). Voluntary modification of automatic arm movements evoked by motion of a visual target. *Experimental Brain Research*, *130*(2), 159–68.

Day, R.-F., Shyi, G. C.-W., & Wang, J.-C. (2006). The effect of Flash banners on multiattribute decision making: Distractor or source of arousal? *Psychology and Marketing*, *23*(5), 369–382.

De Jong, R., Coles, M. G., Logan, G. D., & Gratton, G. (1990). In search of the point of no return: the control of response processes. *Journal of Experimental Psychology. Human Perception and Performance*, *16*(1), 164–182.

Dehaene, S., Naccache, L., Le Clec'H, G., Koechlin, E., Mueller, M., Dehaene-Lambertz, G., … Le Bihan, D. (1998). Imaging unconscious semantic priming. *Nature*, *395*(6702), 597–600.

Desmurget, M., Epstein, C. M., Turner, R. S., Prablanc, C., Alexander, G. E., & Grafton, S. T. (1999). Role of the posterior parietal cortex in updating reaching movements to a visual target. *Nature Neuroscience*, *2*(6), 563–567.

Desmurget, M., & Grafton, S. (2000). Forward modeling allows feedback control for fast reaching movements. *Trends in Cognitive Sciences*, *4*(11), 423–431.

Desmurget, M., Prablanc, C., Jordan, M., & Jeannerod, M. (1999). Are Reaching Movements Planned to be Straight and Invariant in the Extrinsic Space? Kinematic Comparison Between Compliant and Unconstrained Motions. *The Quarterly Journal of Experimental Psychology Section A*, *52*(4), 981–1020.

Duckworth, K. L., Bargh, J. A., Garcia, M., & Chaiken, S. (2002). The automatic evaluation of novel stimuli. *Psychological Science*, *13*(6), 513–519.

Eder, A. B., & Hommel, B. (2013). Anticipatory Control of Approach and Avoidance: An Ideomotor Approach. *Emotion Review*, *5*(3), 275–279.

Eder, A. B., & Klauer, K. C. (2009). A common-coding account of the bidirectional evaluation-behavior link. *Journal of Experimental Psychology: General*, *138*(2), 218–235.

Eder, A. B., Leuthold, H., Rothermund, K., & Schweinberger, S. R. (2012). Automatic response activation in sequential affective priming: an ERP study. *Social Cognitive and Affective Neuroscience*, *7*(4), 436–445.

Eder, A. B., Müsseler, J., & Hommel, B. (2011). The structure of affective action representations: temporal binding of affective response codes. *Psychological Research*.

Eder, A. B., & Rothermund, K. (2008). When do motor behaviors (mis)match affective stimuli? An evaluative coding view of approach and avoidance reactions. *Journal of Experimental Psychology: General*, *137*(2), 262–281.

Eder, A. B., & Rothermund, K. (2013). Emotional action: an ideomotor model. In *Handbook of Psychology of Emotions: Recent Theoretical Perspectives and Novel Empirical Findings* (Vol. 1, pp. 11–38). Hauppauge, NY: Nova Science Publishers.

Eder, A. B., Rothermund, K., & Hommel, B. (2016). Commentary: Contrasting motivational orientation and evaluative coding accounts: on the need to differentiate the effectors of approach/avoidance responses. *Cognition*, 163.

Eimer, M. (2000). Effects of face inversion on the structural encoding and recognition of faces. Evidence from event-related brain potentials. *Brain Research. Cognitive Brain Research*, *10*(1–2), 145–158.

Eimer, M., & Schlaghecken, F. (1998). Effects of masked stimuli on motor activation: behavioral and electrophysiological evidence. *Journal of Experimental Psychology. Human Perception and Performance*, *24*(6), 1737–1747.

Elliot, A. J. (2006). The Hierarchical Model of Approach-Avoidance Motivation. *Motivation and Emotion*, *30*, 111–116.

Elliot, A. J., & Thrash, T. M. (2010). Approach and Avoidance Temperament as Basic Dimensions of Personality. *Journal of Personality*, *78*(3), 865–906.

Elliott, R., Dolan, R. J., & Frith, C. D. (2000). Dissociable functions in the medial and lateral orbitofrontal cortex: evidence from human neuroimaging studies. *Cerebral Cortex (New York, N.Y.: 1991)*, *10*(3), 308–317.

Erthal, F. S., de Oliveira, L., Mocaiber, I., Pereira, M. G., Machado-Pinheiro, W., Volchan, E., & Pessoa, L. (2005). Load-dependent modulation of affective picture processing. *Cognitive, Affective & Behavioral Neuroscience*, *5*(4), 388–395.

Esteves, P. O., Oliveira, L. a. S., Nogueira-Campos, A. A., Saunier, G., Pozzo, T., Oliveira, J. M., Vargas, C. D. (2016). Motor planning of goal-directed action is tuned by the emotional valence of the stimulus: a kinematic study. *Scientific Reports*, *6*, 28780.

Etkin, A., Egner, T., Peraza, D. M., Kandel, E. R., & Hirsch, J. (2006). Resolving emotional conflict: a role for the rostral anterior cingulate cortex in modulating activity in the amygdala. *Neuron*, *51*(6), 871–882.

Everitt, B. J., & Robbins, T. W. (1992). Amygdala-ventral striatal interactions and reward-related processes. In *The amygdala: Neurobiological aspects of emotion, memory, and mental dysfunction* (pp. 401–429). New York, NY, US: Wiley-Liss.

Facchinetti, L. D., Imbiriba, L. A., Azevedo, T. M., Vargas, C. D., & Volchan, E. (2006). Postural modulation induced by pictures depicting prosocial or dangerous contexts. *Neuroscience Letters*, *410*(1), 52–56.

Fanselow, M. S. (1994). Neural organization of the defensive behavior system responsible for fear. *Psychonomic Bulletin & Review*, *1*(4), 429–438.

Ferri, F., Stoianov, I. P., Gianelli, C., D'Amico, L., Borghi, A. M., & Gallese, V. (2010). When Action Meets Emotions: How Facial Displays of Emotion Influence Goal-Related Behavior. *PLoS ONE*, *5*(10).

Fox, E., Russo, R., & Dutton, K. (2002). Attentional bias for threat: Evidence for delayed disengagement from emotional faces. *Cognition & Emotion*, *16*(3), 355–379.

Frijda, N. H. (1986). *The emotions*. London: Cambridge University Press.

Gallistel, C. R. (1980). *The Organization of Action: A New Synthesis*. Psychology Press.

Garvert, M. M., Friston, K. J., Dolan, R. J., & Garrido, M. I. (2014). Subcortical amygdala pathways enable rapid face processing. *NeuroImage*, *102*, *Part 2*, 309–316.

Gaveau, V., Pisella, L., Priot, A.-E., Fukui, T., Rossetti, Y., Pélisson, D., & Prablanc, C. (2014). Automatic online control of motor adjustments in reaching and grasping. *Neuropsychologia*, *55*, 25–40.

Gawronski, B., Deutsch, R., & Strack, F. (2005). Approach/Avoidance-Related Motor Actions and the Processing of Affective Stimuli: Incongruency Effects in Automatic Attention Allocation. *Social Cognition*, *23*(2), 182–203.

Ghez, C., & Krakauer, J. (2000). The Organization of Movement. In *Principles of Neural Science* (IV).

Gibson, J. J. (1977). The Theory of Affordances. In *Perceiving, acting, and knowing: Toward an ecological psychology* (pp. 67–82). Hillsdale, NJ: Erlbaum.

Goeleven, E., Raedt, R. D., Leyman, L., & Verschuere, B. (2008). The Karolinska Directed Emotional Faces: A validation study. *Cognition and Emotion*, *22*(6), 1094–1118.

Goldstein, M., Brendel, G., Tuescher, O., Pan, H., Epstein, J., Beutel, M., … Silbersweig, D. (2007). Neural substrates of the interaction of emotional stimulus processing and motor inhibitory control: an emotional linguistic go/no-go fMRI study. *NeuroImage*, *36*(3), 1026–1040.

Goodale, M. A., Pelisson, D., & Prablanc, C. (1986). Large adjustments in visually guided reaching do not depend on vision of the hand or perception of target displacement. *Nature*, *320*(6064), 748–750.

Greenwald, A. G., Draine, S. C., & Abrams, R. L. (1996). Three Cognitive Markers of Unconscious Semantic Activation. *Science*, *273*, 1699–1702.

Guitart-Masip, M., Beierholm, U. R., Dolan, R., Duzel, E., & Dayan, P. (2011). Vigor in the Face of Fluctuating Rates of Reward: An Experimental Examination. *Journal of Cognitive Neuroscience*, *23*(12), 3933–3938.

Guitart-Masip, M., Duzel, E., Dolan, R., & Dayan, P. (2014). Action versus valence in decision making. *Trends in Cognitive Sciences*, *0*(0).

Guitart-Masip, M., Huys, Q. J. M., Fuentemilla, L., Dayan, P., Duzel, E., & Dolan, R. J. (2012). Go and no-go learning in reward and punishment: Interactions between affect and effect. *NeuroImage*, *62*(1), 154–166.

Hammer, J. L., & Marsh, A. A. (2015). Why do fearful facial expressions elicit behavioral approach? Evidence from a combined approach-avoidance implicit association test. *Emotion*, *15*(2), 223–231.

Haith, A. M., Pakpoor, J., & Krakauer, J. W. (2016). Independence of Movement Preparation and Movement Initiation. *The Journal of Neuroscience*, *36*(10), 3007–3015.

Hanks, T. D., Kopec, C. D., Brunton, B. W., Duan, C. A., Erlich, J. C., & Brody, C. D. (2015). Distinct relationships of parietal and prefrontal cortices to evidence accumulation. *Nature*, *520*(7546), 220–223.

Hartikainen, K. M., Ogawa, K. H., & Knight, R. T. (2000). Transient interference of right hemispheric function due to automatic emotional processing. *Neuropsychologia*, *38*(12), 1576–1580.

Hartikainen, K. M., Siiskonen, A. R., & Ogawa, K. H. (2012). Threat interferes with response inhibition. *NeuroReport*, *23*(7), 447–450.

Henneman, E. (1974). Organization of the motor system - a preview. In: *Medical Physiology*. Vol 1. 13th Edn., pp.603-607. Ed. V. B. Mountcastle. C. V. Mosby Co., St. Louis.

Henson, R. N., Mouchlianitis, E., Matthews, W. J., & Kouider, S. (2008). Electrophysiological correlates of masked face priming. *NeuroImage*, *40*(2), 884–895.

Hermans, D., Spruyt, A., De Houwer, J., & Eelen, P. (2003). Affective priming with subliminally presented pictures. *Canadian Journal of Experimental Psychology = Revue Canadienne De Psychologie Expérimentale*, *57*(2), 97–114.

Hogan, N. (1985a). Impedance Control: An Approach to Manipulation: Part II—Implementation. *Journal of Dynamic Systems, Measurement, and Control*, *107*(1), 8–16.

Hogan, N. (1985b). Impedance Control: An Approach to Manipulation: Part I—Theory. *Journal of Dynamic Systems, Measurement, and Control*, *107*(1), 1–7.

Hommel, B. (1997). Toward an Action-Concept Model of Stimulus-Response Compatibility. In B. Hommel & W. Prinz (Eds.), *Theoretical issues in stimulus-response compatibility* (pp. 281–320). US: Elsevier Science/JAI Press.

Hommel, B. (1998). Automatic stimulus-response translation in dual-task performance. *Journal of Experimental Psychology. Human Perception and Performance*, *24*(5), 1368–1384.

Hommel, B., Müsseler, J., Aschersleben, G., & Prinz, W. (2001). The Theory of Event Coding (TEC): a framework for perception and action planning. *The Behavioral and Brain Sciences*, *24*(5), 849-878-937.

Hopko, D. R., Lejuez, C. W., Ruggiero, K. J., & Eifert, G. H. (2003). Contemporary behavioral activation treatments for depression: procedures, principles, and progress. *Clinical Psychology Review*, *23*(5), 699–717.

Horstmann, G., & Bauland, A. (2006). Search asymmetries with real faces: testing the anger-superiority effect. *Emotion (Washington, D.C.)*, *6*(2), 193–207.

Horstmann, G., Lipp, O. V., & Becker, S. I. (2012). Of toothy grins and angry snarls—Open mouth displays contribute to efficiency gains in search for emotional faces. *Journal of Vision*, *12*(5).

Houlihan, M., Campbell, K., & Stelmack, R. M. (1994). Reaction time and movement time as measures of stimulus evaluation and response processes. *Intelligence*, *18*(3), 289–307.

Howard, L. A., & Tipper, S. P. (1997). Hand deviations away from visual cues: Indirect evidence for inhibition. *Experimental Brain Research*, *113*(1), 144–152.

Hsu, S.-M., Hetrick, W., & Pessoa, L. (2008). Depth of facial expression processing depends on stimulus visibility: Behavioral and electrophysiological evidence of priming effects. *Cognitive, Affective, & Behavioral Neuroscience*, *8*(3), 282–292.

Hudson, T. E., Maloney, L. T., & Landy, M. S. (2008). Optimal Compensation for Temporal Uncertainty in Movement Planning. *PLOS Comput Biol*, *4*(7), e1000130.

Jacobson, N. S., Martell, C. R., & Dimidjian, S. (2001). Behavioral Activation Treatment for Depression: Returning to Contextual Roots. *Clinical Psychology: Science and Practice*, *8*(3), 255–270.

Jahanshahi, M., Obeso, I., Rothwell, J. C., & Obeso, J. A. (2015). A fronto-striato-subthalamic-pallidal network for goal-directed and habitual inhibition. *Nature Reviews Neuroscience*, *16*(12), 719–732.

James, W. (1884). What is an Emotion? *Mind*, (9), 188–205.

Jeannerod, M. (1988). *The neural and behavioural organization of goal-directed movements* (Vol. xii). New York, NY, US: Clarendon Press/Oxford University Press.

Jensen, A. R. (1987). Individual differences in the Hick paradigm. In *Speed of information processing and intelligence*. Norwood, NJ: Ablex.

John, O. P., Donahue, E. M., & Kentle, R. L. (1991). The big five inventory - versions 4a and 54.

Kalaska, J., & Crammond, D. (1992). Cerebral cortical mechanisms of reaching movements. *Science*, *255*(5051), 1517–1523.

Kalaska, J. F., Scott, S. H., Cisek, P., & Sergio, L. E. (1997). Cortical control of reaching movements. *Current Opinion in Neurobiology*, *7*(6), 849–859.

Kiesel, A., Kunde, W., & Hoffmann, J. (2007). Mechanisms of subliminal response priming, *3*(1–2), 307–315.

Kim, M. J., Loucks, R. A., Neta, M., Davis, F. C., Oler, J. A., Mazzulla, E. C., & Whalen, P. J. (2010). Behind the mask: the influence of mask-type on amygdala response to fearful faces. *Social Cognitive and Affective Neuroscience*, *5*(4), 363–368.

Klauer, K. C. (1997). Affective Priming. *European Review of Social Psychology*, *8*, 67–103.

Klein-Flügge, M. C., Kennerley, S. W., Saraiva, A. C., Penny, W. D., & Bestmann, S. (2015). Behavioral Modeling of Human Choices Reveals Dissociable Effects of Physical Effort and Temporal Delay on Reward Devaluation. *PLOS Comput Biol*, *11*(3), e1004116.

Klin, A., Jones, W., Schultz, R., Volkmar, F., & Cohen, D. (2002). Visual fixation patterns during viewing of naturalistic social situations as predictors of social competence in individuals with autism. *Archives of General Psychiatry*, *59*(9), 809–816.

Koch, S., Holland, R. W., Hengstler, M., & van Knippenberg, A. (2009). Body locomotion as regulatory process: stepping backward enhances cognitive control. *Psychological Science*, *20*(5), 549–50.

Krieglmeyer, R., & Deutsch, R. (2010). Comparing measures of approach–avoidance behaviour: The manikin task vs. two versions of the joystick task. *Cognition & Emotion*, *24*(5), 810.

Krieglmeyer, R., Deutsch, R., Houwer, J. D., & Raedt, R. D. (2010). Being Moved: Valence Activates Approach-Avoidance Behavior Independently of Evaluation and Approach-Avoidance Intentions. *Psychological Science*, *21*(4), 607–613.

Krieglmeyer, R., Houwer, J. D., & Deutsch, R. (2013). On the Nature of Automatically Triggered Approach–Avoidance Behavior. *Emotion Review*, *5*(3), 280–284.

Kühn, S., Keizer, A., Rombouts, S. A. R. B., & Hommel, B. (2011). The functional and neural mechanism of action preparation: roles of EBA and FFA in voluntary action control. *Journal of Cognitive Neuroscience*, *23*(1), 214–220.

Kunde, W. (2004). Response priming by supraliminal and subliminal action effects. *Psychological Research*, *68*(2), 91–96.

Kunde, W., Kiesel, A., & Hoffmann, J. (2003). Conscious control over the content of unconscious cognition. *Cognition*, *88*(2), 223–242.

Laham, S. M., Kashima, Y., Dix, J., & Wheeler, M. (2015). A meta-analysis of the facilitation of arm flexion and extension movements as a function of stimulus valence. *Cognition and Emotion*, *29*(6), 1069–1090.

Lähteenmäki, M., Hyönä, J., Koivisto, M., & Nummenmaa, L. (2015). Affective processing requires awareness. *Journal of Experimental Psychology. General*, *144*(2), 339–365.

Lang, P. J. (1995). The emotion probe. Studies of motivation and attention. *The American Psychologist*, *50*(5), 372–385.

Lang, P. J., & Bradley, M. M. (2010). Emotion and the motivational brain. *Biological Psychology*, *84*(3), 437–450.

Lang, P. J., & Bradley, M. M. (2013). Appetitive and Defensive Motivation: Goal-Directed or Goal-Determined? *Emotion Review*, *5*(3), 230–234.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1990). Emotion, attention, and the startle reflex. *Psychological Review*, *97*(3), 377–395.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1997). Motivated attention: Affect, activation and action. In *Attention and Orienting: Sensory and Motivational Processes* (pp. 97–135). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (2008). *International affective picture system (IAPS): Affective ratings of pictures and instruction manual. Technical Report A-8.* University of Florida, Gainesville, FL.

Lang, P. J., Davis, M., & Ohman, A. (2000). Fear and anxiety: animal models and human cognitive psychophysiology. *Journal of Affective Disorders*, *61*(3), 137–159.

Langner, O., Dotsch, R., Bijlstra, G., Wigboldus, D. H. J., Hawk, S. T., & van Knippenberg, A. (2010). Presentation and validation of the Radboud Faces Database. *Cognition & Emotion*, *24*(8), 1377–1388.

Lavender, T., & Hommel, B. (2007). Affect and action: Towards an event-coding account. *Cognition & Emotion*, *21*(6), 1270. =

LeDoux, J. (2012). Rethinking the Emotional Brain. *Neuron*, *73*(4), 653–676.

LeDoux, J. E. (1995). Emotion: Clues from the Brain. *Annual Review of Psychology*, *46*(1), 209–235.

LeDoux, J. E. (1996). *The emotional brain: the mysterious underpinnings of emotional life*. New York: Simon and Schuster.

LeDoux, J. E. (2000). Emotion circuits in the brain. *Annual Review of Neuroscience*, *23*, 155–184.

Lee, S., Kang, J., Lee, E., Namkoong, K., & An, S. (2011). Differential priming effect for subliminal fear and disgust facial expressions. *Attention, Perception, & Psychophysics*, *73*(2), 473–481.

Leuthold, H. (2003). Programming of expected and unexpected movements: effects on the onset of the lateralized readiness potential. *Acta Psychologica*, *114*(1), 83–100.

Li, W., Zinbarg, R. E., Boehm, S. G., & Paller, K. A. (2008). Neural and behavioral evidence for affective priming from unconsciously perceived emotional facial expressions and the influence of trait anxiety. *J. Cognitive Neuroscience*, *20*(1), 95–107.

Lichtenstein-Vidne, L., Henik, A., & Safadi, Z. (2012). Task relevance modulates processing of distracting emotional stimuli. *Cognition & Emotion*, *26*(1), 42–52.

Liddell, B. J., Williams, L. M., Rathjen, J., Shevrin, H., & Gordon, E. (2004). A Temporal Dissociation of Subliminal versus Supraliminal Fear Perception: An Event-related Potential Study. *Journal of Cognitive Neuroscience*, *16*(3), 479–486.

Liefooghe, B., Houwer, J. D., & Wenke, D. (2013). Instruction-based response activation depends on task preparation. *Psychonomic Bulletin & Review*, *20*(3), 481–487.

Liefooghe, B., Wenke, D., & De Houwer, J. (2012). Instruction-based task-rule congruency effects. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *38*(5), 1325–1335.

Lipp, O. V., Price, S. M., & Tellegen, C. L. (2009). No effect of inversion on attentional and affective processing of facial expressions. *Emotion*, *9*(2), 248–259.

Logan, G. D. (1994). On the ability to inhibit thought and action: A users' guide to the stop signal paradigm. In D. Dagenbach & T. H. Carr (Eds.), *Inhibitory processes in attention, memory, and language* (pp. 189–239). San Diego, CA, US: Academic Press.

Logan, G. D., & Cowan, W. B. (1984). On the ability to inhibit thought and action: A theory of an act of control. *Psychological Review*, *91*(3), 295–327.

Löw, A., Weymar, M., & Hamm, A. O. (2015). When Threat Is Near, Get Out of Here Dynamics of Defensive Behavior During Freezing and Active Avoidance. *Psychological Science*.

Lundqvist, D., Flykt, A., & Öhman, A. (1998). Karolinska Directed Emotional Faces (KDEF), CD ROM from Department of Clinical Neuroscience, Psychology section. *Karolinska Institutet*.

Ly, V., Huys, Q. J. M., Stins, J. F., Roelofs, K., & Cools, R. (2014). Individual differences in bodily freezing predict emotional biases in decision making. *Frontiers in Behavioral Neuroscience*, *8*, 237.

Majid, D. S. A., Cai, W., George, J. S., Verbruggen, F., & Aron, A. R. (2012). Transcranial Magnetic Stimulation Reveals Dissociable Mechanisms for Global Versus Selective Corticomotor Suppression Underlying the Stopping of Action. *Cerebral Cortex (New York, NY)*, *22*(2), 363–371.

Marcos, E., Cos, I., Girard, B., & Verschure, P. F. M. J. (2015). Motor Cost Influences Perceptual Decisions. *PLOS ONE*, *10*(12), e0144841.

Markman, A. B., & Brendl, C. M. (2005). Constraining theories of embodied cognition. *Psychological Science*, *16*(1), 6–10.

Marsh, A. A., Ambady, N., & Kleck, R. E. (2005). The Effects of Fear and Anger Facial Expressions on Approach- and Avoidance-Related Behaviors. *Emotion*, *5*(1), 119–124.

Marteniuk, R. G., MacKenzie, C. L., Jeannerod, M., Athenes, S., & Dugas, C. (1987). Constraints on human arm movement trajectories. *Canadian Journal of Psychology*, *41*(3), 365–378.

Matzke, D., Dolan, C. V., Logan, G. D., Brown, S. D., & Wagenmakers, E.-J. (2013). Bayesian parametric estimation of stop-signal reaction time distributions. *Journal of Experimental Psychology. General*, *142*(4), 1047–1073.

Matzke, D., Love, J., Wiecki, T. V., Brown, S. D., Logan, G. D., & Wagenmakers, E.-J. (2013). Release the BEESTS: Bayesian Estimation of Ex-Gaussian STop-Signal reaction time distributions. *Frontiers in Psychology*, *4*.

McDougle, S. D., Boggess, M. J., Crossley, M. J., Parvin, D., Ivry, R. B., & Taylor, J. A. (2016). Credit assignment in movement-dependent reinforcement learning. *Proceedings of the National Academy of Sciences*, *113*(24), 6797–6802.

McSorley, E., Haggard, P., & Walker, R. (2006). Time course of oculomotor inhibition revealed by saccade trajectory modulation. *Journal of Neurophysiology*, *96*(3), 1420–4.

Meegan, D. V., & Tipper, S. P. (1998). Reaching into cluttered visual environments: spatial and temporal influences of distracting objects. *The Quarterly Journal of Experimental Psychology. A, Human Experimental Psychology*, *51*(2), 225–249.

Méndez-Bértolo, C., Moratti, S., Toledano, R., Lopez-Sosa, F., Martínez-Alvarez, R., Mah, Y. H., Strange, B. A. (2016). A fast pathway for fear in human amygdala. *Nature Neuroscience*.

Messier, J., & Kalaska, J. F. (1999). Comparison of variability of initial kinematics and endpoints of reaching movements. *Experimental Brain Research*, *125*(2), 139–152.

Messier, J., & Kalaska, J. F. (1999). Comparison of variability of initial kinematics and endpoints of reaching movements. *Experimental Brain Research*, *125*(2), 139–52.

Messier, J., & Kalaska, J. F. (2000). Covariation of primate dorsal premotor cell activity with direction and amplitude during a memorized-delay reaching task. *Journal of Neurophysiology*, *84*(1), 152–165.

Middleton, F. A., & Strick, P. L. (2000). Basal ganglia and cerebellar loops: motor and cognitive circuits. *Brain Research. Brain Research Reviews*, *31*(2–3), 236–250.

Mink, J. W. (1996). The basal ganglia: focused selection and inhibition of competing motor programs. *Progress in Neurobiology*, *50*(4), 381–425.

Mobbs, D., Marchant, J. L., Hassabis, D., Seymour, B., Tan, G., Gray, M., … Frith, C. D. (2009). From Threat to Fear: The Neural Organization of Defensive Fear Systems in Humans. *The Journal of Neuroscience*, *29*(39), 12236–12243.

Mogg, K., Philippot, P., & Bradley, B. P. (2004). Selective Attention to Angry Faces in Clinical Social Phobia. *Journal of Abnormal Psychology*, *113*(1), 160–165.

Moors, A., & De Houwer, J. (2006). Automaticity: a theoretical and conceptual analysis. *Psychological Bulletin*, *132*(2), 297–326.

Moors, A., & De Houwer, J. (2010). Implicit Measures: Similarities and Differences. In *Handbook of implicit social cognition: Measurement, theory, and applications*. New York, NY: Guildford Press.

Morris, J. S., Friston, K. J., Büchel, C., Frith, C. D., Young, A. W., Calder, A. J., & Dolan, R. J. (1998). A neuromodulatory role for the human amygdala in processing emotional facial expressions. *Brain: A Journal of Neurology*, *121 (Pt 1)*, 47–57.

Morris, J. S., Öhman, A., & Dolan, R. J. (1999). A subcortical pathway to the right amygdala mediating ‘unseen’ fear. *Proceedings of the National Academy of Sciences*, *96*(4), 1680–1685.

Most, S. B., Smith, S. D., Cooter, A. B., Levy, B. N., & Zald, D. H. (2007). The naked truth: Positive, arousing distractors impair rapid target perception. *Cognition & Emotion*, *21*(5), 964–981.

Naugle, K. M., Coombes, S. A., Cauraugh, J. H., & Janelle, C. M. (2012). Influence of Emotion on the Control of Low-Level Force Production. *Research Quarterly for Exercise and Sport*, *83*(2), 353–358.

Naugle, K. M., Hass, C. J., Joyner, J., Coombes, S. A., & Janelle, C. M. (2011). Emotional state affects the initiation of forward gait. *Emotion*, *11*(2), 267–277.

Neumann, R., Förster, J., & Strack, F. (2003). Motor compatibility: The bidirectional link between behavior and evaluation. In J. Musch & K. C. Klauer (Eds.), *The psychology of evaluation: Affective processes in cognition and emotion* (pp. 371–391). Mahwah, NJ, US: Lawrence Erlbaum Associates Publishers.

Nijhof, E.-J. (2003). On-line trajectory modifications of planar, goal-directed arm movements. *Human Movement Science*, *22*(1), 13–36.

Niv, Y., Daw, N. D., & Dayan, P. (2005). How fast to work: Response vigor, motivation and tonic dopamine. In *ResearchGate* (Vol. 18).

Niv, Y., Daw, N. D., Joel, D., & Dayan, P. (2007). Tonic dopamine: opportunity costs and the control of response vigor. *Psychopharmacology*, *191*(3), 507–520.

Notebaert, L., Crombez, G., Van Damme, S., De Houwer, J., & Theeuwes, J. (2010). Looking out for danger: An attentional bias towards spatially predictable threatening stimuli. *Behaviour Research and Therapy*, *48*(11), 1150–1154.

Ohman, A., Flykt, A., & Esteves, F. (2001). Emotion drives attention: detecting the snake in the grass. *Journal of Experimental Psychology. General*, *130*(3), 466–478.

Ohman, A., Lundqvist, D., & Esteves, F. (2001). The face in the crowd revisited: a threat advantage with schematic stimuli. *Journal of Personality and Social Psychology*, *80*(3), 381–396.

Ohman, A., & Soares, J. J. (1998). Emotional conditioning to masked stimuli: expectancies for aversive outcomes following nonrecognized fear-relevant stimuli. *Journal of Experimental Psychology. General*, *127*(1), 69–82.

Okon-Singer, H., Tzelgov, J., & Henik, A. (2007). Distinguishing between automaticity and attention in the processing of emotionally significant stimuli. *Emotion (Washington, D.C.)*, *7*(1), 147–157.

Oliveira, L. A. S. de, Imbiriba, L. A., Russo, M. M., Nogueira-Campos, A. A., Rodrigues, E. de C., Pereira, M. G., … Vargas, C. D. (2012). Preparing to Grasp Emotionally Laden Stimuli. *PLOS ONE*, *7*(9), e45235.

Oliveira, F. T. P., Diedrichsen, J., Verstynen, T., Duque, J., & Ivry, R. B. (2010). Transcranial magnetic stimulation of posterior parietal cortex affects decisions of hand choice. *Proceedings of the National Academy of Sciences*, *107*(41), 17751–17756.

Olofsson, J. K., Nordin, S., Sequeira, H., & Polich, J. (2008). Affective picture processing: An integrative review of ERP findings. *Biological Psychology*, *77*(3), 247–265.

Oya, H., Kawasaki, H., Howard, M. A., & Adolphs, R. (2002). Electrophysiological Responses in the Human Amygdala Discriminate Emotion Categories of Complex Visual Stimuli. *The Journal of Neuroscience*, *22*(21), 9502–9512.

Ozono, H., Watabe, M., & Yoshikawa, S. (2012). Effects of facial expression and gaze direction on approach–avoidance behaviour. *Cognition & Emotion*, *26*(5), 943–949.

Padoa-Schioppa, C., & Assad, J. A. (2008). The representation of economic value in the orbitofrontal cortex is invariant for changes of menu. *Nature Neuroscience*, *11*(1), 95–102.

Paulignan, Y., Frak, V. G., Toni, I., & Jeannerod, M. (1997). Influence of object position and size on human prehension movements. *Experimental Brain Research*, *114*(2), 226–234.

Paulignan, Y., MacKenzie, C., Marteniuk, R., & Jeannerod, M. (1991). Selective perturbation of visual input during prehension movements. 1. The effects of changing object position. *Experimental Brain Research*, *83*(3), 502–512.

Pawliczek, C. M., Derntl, B., Kellermann, T., Kohn, N., Gur, R. C., & Habel, U. (2013). Inhibitory control and trait aggression: neural and behavioral insights using the emotional stop signal task. *NeuroImage*, *79*, 264–274.

Pereira, M. G., de Oliveira, L., Erthal, F. S., Joffily, M., Mocaiber, I. F., Volchan, E., & Pessoa, L. (2010). Emotion affects action: Midcingulate cortex as a pivotal node of interaction between negative emotion and motor signals. *Cognitive, Affective & Behavioral Neuroscience*, *10*(1), 94–106.

Pereira, M. G., Volchan, E., de Souza, G. G. L., de Oliveira, L., Campagnoli, R., Pinheiro, W. M., & Pessoa, L. (2006). Sustained and transient modulation of performance induced by emotional picture viewing. *Emotion (Washington, D.C.)*, *6*(4), 622–634.

Pessoa, L. (2005). To what extent are emotional visual stimuli processed without attention and awareness? *Current Opinion in Neurobiology*, *15*(2), 188–196.

Pessoa, L. (2009). How do emotion and motivation direct executive control? *Trends in Cognitive Sciences*, *13*(4), 160–166.

Pessoa, L., & Adolphs, R. (2010). Emotion processing and the amygdala: from a ‘low road’ to ‘many roads’ of evaluating biological significance. *Nature Reviews Neuroscience*, *11*(11), 773–783.

Pessoa, L., Japee, S., & Ungerleider, L. G. (2005). Visual awareness and the detection of fearful faces. *Emotion (Washington, D.C.)*, *5*(2), 243–247.

Pessoa, L., Kastner, S., & Ungerleider, L. G. (2002). Attentional control of the processing of neutral and emotional stimuli. *Cognitive Brain Research*, *15*(1), 31–45.

Pessoa, L., McKenna, M., Gutierrez, E., & Ungerleider, L. G. (2002). Neural processing of emotional faces requires attention. *Proceedings of the National Academy of Sciences*, *99*(17), 11458–11463.

Pessoa, L., Padmala, S., Kenzer, A., & Bauer, A. (2012). Interactions between cognition and emotion during response inhibition. *Emotion (Washington, D.C.)*, *12*(1), 192–197.

Pessoa, L., & Ungerleider, L. G. (2004). Neuroimaging studies of attention and the processing of emotion-laden stimuli. *Progress in Brain Research*, *144*, 171–182.

Phaf, R. H., Mohr, S. E., Rotteveel, M., & Wicherts, J. M. (2014). Approach, avoidance, and affect: a meta-analysis of approach-avoidance tendencies in manual reaction time tasks. *Frontiers in Psychology*, *5*.

Phelps, E. A., Lempert, K. M., & Sokol-Hessner, P. (2014). Emotion and Decision Making: Multiple Modulatory Neural Circuits. *Annual Review of Neuroscience*, *37*(1), 263–287.

Pisella, L., Gréa, H., Tilikete, C., Vighetto, A., Desmurget, M., Rode, G., … Rossetti, Y. (2000). An ‘automatic pilot’ for the hand in human posterior parietal cortex: toward reinterpreting optic ataxia. *Nature Neuroscience*, *3*(7), 729–736.

Pizzagalli, D., Regard, M., & Lehmann, D. (1999). Rapid emotional face processing in the human right and left brain hemispheres: an ERP study. *Neuroreport*, *10*(13), 2691–2698.

Prablanc, C., & Martin, O. (1992). Automatic control during hand reaching at undetected two-dimensional target displacements. *Journal of Neurophysiology*, *67*(2), 455–469.

Pratt, J., & Abrams, R. A. (1994). Action-centered inhibition: Effects of distractors on movement planning and execution. *Human Movement Science*, *13*(2), 245–254.

Pratto, F., & John, O. P. (1991). Automatic vigilance: the attention-grabbing power of negative social information. *Journal of Personality and Social Psychology*, *61*(3), 380–391.

Prinz, W. (1987). Ideomotor action. In F. Heuer & A. F. Sanders (Eds.), *Perspectives on perception and action* (pp. 47–76). Hillsdale, NJ: Erlbaum.

Prinz, W. (1990). A Common Coding Approach to Perception and Action. In O. Neumann & W. Prinz (Eds.), *Relationships Between Perception and Action* (pp. 167–201). Springer Berlin Heidelberg.

Proctor, R. W., & Zhang, Y. (2010). ‘Mother nature doesn’t have a bullet with your name on it’: Coding with reference to one’s name or object location? *Journal of Experimental Social Psychology*, *46*(2), 336–343.

Pylyshyn, Z. W. (1986). *Computation and Cognition: Toward a Foundation for Cognitive Science*. Cambridge, Mass.: A Bradford Book.

Radke, S., Volman, I., Mehta, P., Son, V. van, Enter, D., Sanfey, A., Roelofs, K. (2015). Testosterone biases the amygdala toward social threat approach. *Science Advances*, *1*(5), e1400074.

Ratcliff, R., & McKoon, G. (2008). The Diffusion Decision Model: Theory and Data for Two-Choice Decision Tasks. *Neural Computation*, *20*(4), 873–922.

Redgrave, P., Prescott, T. J., & Gurney, K. (1999). The basal ganglia: a vertebrate solution to the selection problem? *Neuroscience*, *89*(4), 1009–1023.

Rieth, C. A., & Huber, D. E. (2010). Priming and habituation for faces: Individual differences and inversion effects. *Journal of Experimental Psychology: Human Perception and Performance*, *36*(3), 596–618.

Rinck, M., & Becker, E. S. (2007). Approach and avoidance in fear of spiders. *Journal of Behavior Therapy and Experimental Psychiatry*, *38*(2), 105–120.

Roelofs, K., Hagenaars, M. A., & Stins, J. (2010). Facing Freeze Social Threat Induces Bodily Freeze in Humans. *Psychological Science*.

Roelofs, K., Minelli, A., Mars, R. B., van Peer, J., & Toni, I. (2009). On the neural control of social emotional behavior. *Social Cognitive and Affective Neuroscience*, *4*(1), 50–58.

Rolls, E. T. (1999). *The brain and emotion*. Oxford University Press.

Roseman, I. J. (2008). Motivations and Emotivations: Approach, Avoidance, and Other Tendencies in Motivated and Emotional Behavior. In A. J. Elliott (Ed.), *Handbook of Approach and Avoidance Motivation* (pp. 343–366). New York: Routledge.

Roth, S., & Cohen, L. J. (1986). Approach, avoidance, and coping with stress. *American Psychologist*, *41*(7), 813–819.

Rotteveel, M., Gierholz, A., Koch, G., Van Aalst, C., Pinto, Y., Matzke, D., … Wagenmakers, E.-J. (2015). On the automatic link between affect and tendencies to approach and avoid: Chen and Bargh (1999) revisited. *Cognition*, *6*, 335.

Rotteveel, M., & Phaf, R. H. (2004). Automatic affective evaluation does not automatically predispose for arm flexion and extension. *Emotion (Washington, D.C.)*, *4*(2), 156–172.

Rotteveel, M., Spinhoven, P., Tollenaar, M. S., Roelofs, K., & Van Peer, J. M. (2010). Affect-congruent approach and withdrawal movements of happy and angry faces facilitate affective categorisation. *Cognition & Emotion*, *24*(5), 863–875.

Rushworth, M. F. S., Behrens, T. E. J., Rudebeck, P. H., & Walton, M. E. (2007). Contrasting roles for cingulate and orbitofrontal cortex in decisions and social behaviour. *Trends in Cognitive Sciences*, *11*(4), 168–176.

Sabes, P. N. (2000). The planning and control of reaching movements. *Current Opinion in Neurobiology*, *10*(6), 740–746.

Sagliano, L., D’Olimpio, F., Scafati, I. T., & Trojano, L. (2016). Eye movements reveal mechanisms underlying attentional biases towards threat. *Cognition and Emotion*, *30*(7), 1344–1351.

Sainburg, R. L., & Kalakanis, D. (2000). Differences in Control of Limb Dynamics During Dominant and Nondominant Arm Reaching. *Journal of Neurophysiology*, *83*(5), 2661–2675.

Saraiva, A. C., Schüür, F., & Bestmann, S. (2013). Emotional valence and contextual affordances flexibly shape approach-avoidance movements. *Frontiers in Emotion Science*, *4*, 933.

Scharlau, I. (2002). Leading, but not trailing, primes influence temporal order perception: further evidence for an attentional account of perceptual latency priming. *Perception & Psychophysics*, *64*(8), 1346–1360.

Scherer, K. R. (2005). What are emotions? And how can they be measured? *Social Science Information*, *44*(4), 695–729.

Schimmack, U. (2005). Attentional Interference Effects of Emotional Pictures: Threat, Negativity, or Arousal? *Emotion*, *5*(1), 55–66.

Schmidt, F., Haberkamp, A., & Schmidt, T. (2011). Dos and don'ts in response priming research. *Advances in Cognitive Psychology*, *7*, 120–131.

Schmidt, L., Cléry-Melin, M.-L., Lafargue, G., Valabrègue, R., Fossati, P., Dubois, B., & Pessiglione, M. (2009). Get Aroused and Be Stronger: Emotional Facilitation of Physical Effort in the Human Brain. *The Journal of Neuroscience*, *29*(30), 9450–9457.

Schmidt, L. J., Belopolsky, A. V., & Theeuwes, J. (2012). The presence of threat affects saccade trajectories. *Visual Cognition*, *20*(3), 284–299.

Schmidt, L. J., Belopolsky, A. V., & Theeuwes, J. (2015). Potential threat attracts attention and interferes with voluntary saccades. *Emotion*, *15*(3), 329–338.

Schoenbaum, G., Roesch, M. R., Stalnaker, T. A., & Takahashi, Y. K. (2009). A new perspective on the role of the orbitofrontal cortex in adaptive behaviour. *Nature Reviews Neuroscience*, *10*(12), 885–892.

Schulz, K. P., Clerkin, S. M., Halperin, J. M., Newcorn, J. H., Tang, C. Y., & Fan, J. (2009). Dissociable Neural Effects of Stimulus Valence and Preceding Context during the Inhibition of Responses to Emotional Faces. *Human Brain Mapping*, *30*(9), 2821–2833.

Schupp, H. T., Flaisch, T., Stockburger, J., & Junghöfer, M. (2006). Emotion and attention: event-related brain potential studies. In G. E. S. Anders (Ed.), *Progress in Brain Research* (Vol. Volume 156, pp. 31–51). Elsevier.

Schupp, H. T., Junghöfer, M., Weike, A. I., & Hamm, A. O. (2004). The selective processing of briefly presented affective pictures: An ERP analysis. *Psychophysiology*, *41*(3), 441–449.

Seibt, B., Neumann, R., Nussinson, R., & Strack, F. (2008). Movement direction or change in distance? Self- and object-related approach-avoidance motions. *Journal of Experimental Social Psychology*, *44*(3), 713–720.

Seidel, E. M., Habel, U., Kirschner, M., Gur, R. C., & Derntl, B. (2010a). The impact of facial emotional expressions on behavioral tendencies in females and males. *Journal of Experimental Psychology. Human Perception and Performance*, *36*(2), 500–507.

Senderecka, M. (2016). Threatening visual stimuli influence response inhibition and error monitoring: An event-related potential study. *Biological Psychology*, *113*, 24–36.

Shadmehr, R., & Krakauer, J. W. (2008). A computational neuroanatomy for motor control. *Experimental Brain Research*, *185*(3), 359–381.

Shadmehr, R., & Mussa-Ivaldi, F. A. (1994). Adaptive representation of dynamics during learning of a motor task. *Journal of Neuroscience*, *14*(5), 3208–3224.

Shafritz, K. M., Collins, S. H., & Blumberg, H. P. (2006). The interaction of emotional and cognitive neural systems in emotionally guided response inhibition. *NeuroImage*, *31*(1), 468–475.

Silva, C., Da Fonseca, D., Esteves, F., & Deruelle, C. (2015). Motivational approach and avoidance in autism spectrum disorder: A comparison between real photographs and cartoons. *Research in Autism Spectrum Disorders*, *17*, 13–24.

Spruyt, A., Hermans, D., Houwer, J. D., Vandromme, H., & Eelen, P. (2007). On the nature of the affective priming effect: Effects of stimulus onset asynchrony and congruency proportion in naming and evaluative categorization. *Memory & Cognition*, *35*, 95–106.

Stins, J. F., & Beek, P. J. (2011). Organization of voluntary stepping in response to emotion-inducing pictures. *Gait & Posture*, *34*(2), 164–168.

Stins, J. F., Roelofs, K., Villan, J., Kooijman, K., Hagenaars, M. A., & Beek, P. J. (2011). Walk to me when I smile, step back when I'm angry: emotional faces modulate whole-body approach–avoidance behaviors. *Experimental Brain Research*, *212*(4), 603–611.

Stins, J. F., Roerdink, M., & Beek, P. J. (2011). To freeze or not to freeze? Affective and cognitive perturbations have markedly different effects on postural control. *Human Movement Science*, *30*(2), 190–202.

Stins, J. F., van Gelder, L. M. A., Oudenhoven, L. M., & Beek, P. J. (2015). Biomechanical organization of gait initiation depends on the timing of affective processing. *Gait & Posture*, *41*(1), 159–163.

Stock, A., & Stock, C. (2004). A short history of ideo-motor action. *Psychological Research*, *68*(2–3), 176–188.

Strack, F., & Deutsch, R. (2004). Reflective and Impulsive Determinants of Social Behavior. *Personality and Social Psychology Review*, *8*(3), 220–247.

Striemer, C. L., Yukovsky, J., & Goodale, M. A. (2010). Can intention override the 'automatic pilot'? *Experimental Brain Research*, *202*(3), 623–632.

Sweeny, T. D., Grabowecky, M., Suzuki, S., & Paller, K. A. (2009). Long-Lasting Effects of Subliminal Affective Priming from Facial Expressions. *Consciousness and Cognition*, *18*(4), 929–938.

Tamietto, M., & de Gelder, B. (2010). Neural bases of the non-conscious perception of emotional signals. *Nature Reviews. Neuroscience*, *11*(10), 697–709.

Taylor, C. T., & Amir, N. (2012). Modifying automatic approach action tendencies in individuals with elevated social anxiety symptoms. *Behaviour Research and Therapy*, *50*(9), 529–536.

Temel, Y., Blokland, A., Steinbusch, H. W. M., & Visser-Vandewalle, V. (2005). The functional role of the subthalamic nucleus in cognitive and limbic circuits. *Progress in Neurobiology*, *76*(6), 393–413.

Tipper, S. P. (2001). Does negative priming reflect inhibitory mechanisms? A review and integration of conflicting views. *The Quarterly Journal of Experimental Psychology. A, Human Experimental Psychology*, *54*(2), 321–343.

Tipper, S. P., Howard, L. A., & Houghton, G. (1998). Action-based mechanisms of attention. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *353*(1373), 1385–1393.

Tipper, S. P., Howard, L. A., & Jackson, S. R. (1997). Selective Reaching to Grasp: Evidence for Distractor Interference Effects. *Visual Cognition*, *4*(1), 1–38.

Tottenham, N., Tanaka, J. W., Leon, A. C., McCarry, T., Nurse, M., Hare, T. A., Nelson, C. (2009). The NimStim set of facial expressions: Judgments from untrained research participants. *Psychiatry Research*, *168*(3), 242–249.

van Dantzig, S., Pecher, D., & Zwaan, R. A. (2008). Approach and avoidance as action effects. *Quarterly Journal of Experimental Psychology (2006)*, *61*(9), 1298–1306.

van Dantzig, S., Zeelenberg, R., & Pecher, D. (2009). Unconstraining theories of embodied cognition. *Journal of Experimental Social Psychology*, *45*(2), 345–351.

van den Dobbelsteen, J., Brenner, E., & Smeets, J. (2001). Endpoints of arm movements to visual targets. *Experimental Brain Research*, *138*(3), 279–287.

van Peer, J. M., Roelofs, K., Rotteveel, M., van Dijk, J. G., Spinhoven, P., & Ridderinkhof, K. R. (2007). The effects of cortisol administration on approach–avoidance behavior: An event-related potential study. *Biological Psychology*, *76*(3), 135–146.

Vandenbosch, K., & De Houwer, J. (2011). Failures to induce implicit evaluations by means of approach–avoid training. *Cognition & Emotion*, *25*(7), 1311–1330.

Verbruggen, F., Chambers, C. D., & Logan, G. D. (2013). Fictitious Inhibitory Differences How Skewness and Slowing Distort the Estimation of Stopping Latencies. *Psychological Science*, *24*(3), 352–362.

Verbruggen, F., & De Houwer, J. (2007). Do emotional stimuli interfere with response inhibition? Evidence from the stop signal paradigm. *Cognition & Emotion*, *21*(2), 391–403.

Verbruggen, F., & Logan, G. D. (2008). Response inhibition in the stop-signal paradigm. *Trends in Cognitive Sciences*, *12*(11), 418–424.

Verbruggen, F., & Logan, G. D. (2009). Models of response inhibition in the stop-signal and stop-change paradigms. *Neuroscience & Biobehavioral Reviews*, *33*(5), 647–661.

Volman, I., Borries, A. K. L. von, Bulten, B. H., Verkes, R. J., Toni, I., & Roelofs, K. (2016). Testosterone Modulates Altered Prefrontal Control of Emotional Actions in Psychopathic Offenders. *Eneuro*, *3*(1), ENEURO.0107-15.2016.

Volman, I., Roelofs, K., Koch, S., Verhagen, L., & Toni, I. (2011). Anterior Prefrontal Cortex Inhibition Impairs Control over Social Emotional Actions. *Current Biology*, *21*(20), 1766–1770.

Vorberg, D., Mattler, U., Heinecke, A., Schmidt, T., & Schwarzbach, J. (2003). Different time courses for visual perception and action priming. *Proceedings of the National Academy of Sciences*, *100*(10), 6275–6280.

Vrtička, P., Sander, D., & Vuilleumier, P. (2011). Effects of emotion regulation strategy on brain responses to the valence and social content of visual scenes. *Neuropsychologia*, *49*(5), 1067–1082.

Vuilleumier, P. (2005). How brains beware: neural mechanisms of emotional attention. *Trends in Cognitive Sciences*, *9*(12), 585–594.

Vuilleumier, P., Armony, J. L., Driver, J., & Dolan, R. J. (2001). Effects of Attention and Emotion on Face Processing in the Human Brain: An Event-Related fMRI Study. *Neuron*, *30*(3), 829–841.

Vuilleumier, P., Armony, J. L., Driver, J., & Dolan, R. J. (2003). Distinct spatial frequency sensitivities for processing faces and emotional expressions. *Nature Neuroscience*, *6*(6), 624–631.

Vuilleumier, P., Richardson, M. P., Armony, J. L., Driver, J., & Dolan, R. J. (2004). Distant influences of amygdala lesion on visual cortical activation during emotional face processing. *Nature Neuroscience*, *7*(11), 1271–1278.

Waszak, F., Pfister, R., & Kiesel, A. (2013). Top-down versus bottom-up: when instructions overcome automatic retrieval. *Psychological Research*, *77*(5), 611–617.

Welford, A. T. (1980). Choice reaction time: Basic concepts. In A. T. Welford (Ed.), *Reaction Times* (pp. 73–128). New York: Academic Press.

Welsh, T. N. (2011). The relationship between attentional capture and deviations in movement trajectories in a selective reaching task. *Acta Psychologica*, *137*(3), 300–308.

Welsh, T. N., & Elliott, D. (2004). Movement trajectories in the presence of a distracting stimulus: Evidence for a response activation model of selective reaching. *The Quarterly Journal of Experimental Psychology Section A*, *57*(6), 1031–1057.

Welsh, T. N., Elliott, D., & Weeks, D. J. (1999). Hand deviations toward distractors Evidence for response competition. *Experimental Brain Research*, *127*(2), 207–212.

Wentura, D., Rothermund, K., & Bak, P. (2000). Automatic vigilance: the attention-grabbing power of approach- and avoidance-related social information. *Journal of Personality and Social Psychology*, *78*(6), 1024–1037.

West, G. L., Anderson, A. K., Bedwell, J. S., & Pratt, J. (2010). Red diffuse light suppresses the accelerated perception of fear. *Psychological Science*, *21*(7), 992–9.

Whalen, P. J., Rauch, S. L., Etcoff, N. L., McInerney, S. C., Lee, M. B., & Jenike, M. A. (1998). Masked presentations of emotional facial expressions modulate amygdala activity without explicit knowledge. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience*, *18*(1), 411–418.

Wickens, T. D. (2001). *Elementary Signal Detection Theory*. Oxford University Press.

Wiers, R. W., Eberl, C., Rinck, M., Becker, E. S., & Lindenmeyer, J. (2011). Retraining Automatic Action Tendencies Changes Alcoholic Patients' Approach Bias for Alcohol and Improves Treatment Outcome. *Psychological Science*, *22*(4), 490–497.

Wiers, R. W., Rinck, M., Kordts, R., Houben, K., & Strack, F. (2010). Retraining automatic action-tendencies to approach alcohol in hazardous drinkers. *Addiction*, *105*(2), 279–287.

Wilkowski, B. M., & Meier, B. P. (2010). Bring it on: Angry facial expressions potentiate approach-motivated motor behavior. *Journal of Personality and Social Psychology*, *98*(2), 201–210.

Williams, M. A., McGlone, F., Abbott, D. F., & Mattingley, J. B. (2005). Differential amygdala responses to happy and fearful facial expressions depend on selective attention. *NeuroImage*, *24*(2), 417–425.

Winecoff, A., Clithero, J. A., Carter, R. M., Bergman, S. R., Wang, L., & Huettel, S. A. (2013). Ventromedial Prefrontal Cortex Encodes Emotional Value. *The Journal of Neuroscience*, *33*(27), 11032–11039.

Wolpe, J., & Lang, P. J. (1964). A fear survey schedule for use in behaviour therapy. *Behaviour Research and Therapy*, *2*(1), 27–30.

Wolpert, D. M., & Miall, R. C. (1996). Forward Models for Physiological Motor Control. *Neural Networks: The Official Journal of the International Neural Network Society*, *9*(8), 1265–1279.

Wong, A. L., Haith, A. M., & Krakauer, J. W. (2015). Motor Planning. *The Neuroscientist: A Review Journal Bringing Neurobiology, Neurology and Psychiatry*, *21*(4), 385–398.

Wong, A. L., Lindquist, M. A., Haith, A. M., & Krakauer, J. W. (2015). Explicit knowledge enhances motor vigor and performance: motivation versus practice in sequence tasks. *Journal of Neurophysiology*, *114*(1), 219–232.

Woud, M. L., Becker, E. S., & Rinck, M. (2008). Implicit evaluation bias induced by approach and avoidance. *Cognition & Emotion*, *22*, 1187–1197.

Woud, M. L., Maas, J., Becker, E. S., & Rinck, M. (2013). Make the manikin move: Symbolic approach–avoidance responses affect implicit and explicit face evaluations. *Journal of Cognitive Psychology*, *25*(6), 738–744.

Xu, M., Li, Z., Ding, C., Zhang, J., Fan, L., Diao, L., & Yang, D. (2015). The Divergent Effects of Fear and Disgust on Inhibitory Control: An ERP Study. *PLOS ONE*, *10*(6), e0128932.

Yiend, J. (2010). The effects of emotion on attention: A review of attentional processing of emotional information. *Cognition and Emotion*, *24*(1), 3–47.

Young, M. P., Scannell, J. W., Burns, G. A., & Blakemore, C. (1994). Analysis of connectivity: neural systems in the cerebral cortex. *Reviews in the Neurosciences*, *5*(3), 227–250.

Zhang, H., Morvan, C., & Maloney, L. T. (2010). Gambling in the Visual Periphery: A Conjoint-Measurement Analysis of Human Ability to Judge Visual Uncertainty. *PLOS Comput Biol*, *6*(12), e1001023.

Zhu, J., & Thagard, P. (2002). Emotion and Action. *Philosophical Psychology*, *15*(1), 19–36.