SUMMARY
While not all too long ago, many were convinced that the question why people pay attention to certain things and not to others has been sufficiently addressed, those that begged to differ are gaining tailwind. Contrary to traditional theories on how attention resolves the bottleneck of how and what information we can process, studies now clearly show that attention cannot be sufficiently accounted for by dichotomizing attention, or more specifically selective attention, in top-down and bottom-up control processes.

It does not need looking at our primate ancestors to understand that our survival depends on how effective we are in obtaining rewards such as water, food or sex. We still respond to rewards in a highly adaptive manner. Behavior that is rewarded is more likely to be repeated and refined to ensure obtaining rewards in the future. In this dissertation, I demonstrate evidence that visual cognition and perception is similarly responsive to rewards but, importantly, that the influence of reward extends beyond the deployment of strategic control.

While it is true that much of reward’s impact on cognition and perception can be explained in terms of its effect on top-down control, this is far from the complete picture. With this in mind, Chapter 1 reviewed the extant literature describing the extent to which attentional processes are affected by (the expectation of) reward. I discuss a large and diverse body of research that shows a strong influence of reward on the formation of attentional control. Much of this research suggests that strategic attentional control is aided through the preparation of important cognitive processes (including perception and action) and the refinement of the task set representation when rewards are expected. Importantly, however, I discuss evidence which supports a distinctly non-strategic influence of reward on attentional control. A rapidly growing body of studies, in part stemming from my own research presented in the other chapters of this dissertation, shows a direct impact of reward on the representation of a stimulus which cannot be otherwise accounted for by known top-down or bottom-up processes. In Chapter 1, I conclude that the scientific evidence supports the notion that associating reward with a stimulus renders it more pertinent to the visual system and makes it more likely to be selected when competing with other stimuli for attentional selection.

Chapter 2 of this dissertation presents a powerful demonstration of how reward associated to a stimulus affects selection. In this experiment,
participants had to search for a letter target that was consistently presented inside colored circles. Throughout a designated training session in which participants had to learn stimulus-reward associations, successful identification of the target was rewarded whenever it appeared inside one particularly colored circle but not when it appeared in another. In a subsequent test session, consisting of a cueing experiment in which participants could no longer earn reward, we observed performance costs and benefits in response to the stimulus previously associated with reward. In other words, the stimulus previously associated with reward captured attention even though it was irrelevant for the task, was not more salient than any other stimulus and did not predict reward anymore. In line with the notion of reward learning, participants who showed facilitated performance in response to reward-signaling targets during the training session also showed larger reward capture effects during the test session.

Chapter 3 further elaborates on the idea of a prioritized attentional state of the reward-associated stimulus by investigating whether this prioritized state can only be the consequence of an instrumental stimulus-reward association or may also be the result of a Pavlovian association. In two separate experiments, participants completed an oculomotor search task in which they had to saccade as quickly as possible to the shape singleton target. Critically, the color of a physically non-salient and task-irrelevant stimulus signaled the magnitude of reward participants could earn for moving their eyes to the target. However, if they were to look at the reward-signaling stimulus at any point during a trial, reward for that trial would be omitted. In other words, selection of the reward-signaling stimulus was not only unnecessary but detrimental for reward payoff. Regardless, results showed that a stimulus signaling high reward caused more reward omissions (i.e. oculomotor capture) than a stimulus signaling low reward. This is consistent with the idea that capture can be the consequence of a Pavlovian association influencing selection independently of top-down and bottom-up processes. Importantly, particularly quicker first saccades were prone to capture which further corroborates the idea that capture occurs involuntarily and only later in time strategic top-down control can prevent capture from happening.

In a series of covert search experiments, whose design was similar to the oculomotor task of the studies of the previous chapter, Chapter 4 further expands the evidence for capture by reward-signaling stimuli whose selection is never necessary to obtain reward. In two experiments, we demonstrated
attentional capture by stimuli that merely signal reward but are otherwise task-irrelevant and physically non-salient. Moreover, by swapping the relationship between the magnitude of reward and the stimulus feature that signals it, a follow-up experiment showed a gradual build-up of capture which would indeed be predicted by a learning account. Importantly, however, in these and additional experiments we found that capture only occurred if participants were either explicitly informed about or became aware of the stimulus-reward association throughout the experiment. The findings therefore suggest that the reward-signaling stimuli must first receive attentional prioritization in order to capture attention and that this initial prioritization can be achieved by rendering the stimuli task-relevant or physically salient, or by observers gaining awareness of the stimulus-reward association. Due to initial attentional prioritization, reward learning is triggered and only then can the reward-signaling stimulus bias attentional selection independently of other top-down or bottom-up processes.

Chapter 5 tests the hypothesis that reward affects nonspatial attentional selection. Participants had to first complete a choice game in which different rewards were associated with the selection of different semantic categories of scene pictures (e.g. forest sceneries). In a subsequent test session, the previously rewarded pictures were presented as distractors in a stream of neutral pictures, all presented at the center of fixation for only a brief period of time. The results showed that participants’ ability to detect pictures of a designated target category was worse when a picture of one of the categories that were previously associated with reward was presented as a distractor in the stream. Critically, performance in target detection deteriorated as a function of the reward associated with the distractor category with larger reward resulting in worse target detection. This is consistent with the idea that reward-associations can cause nonspatial attentional capture thereby limiting the availability of attention across time even if observers no longer receive any reward. Interestingly, a virtually identical reward effect was observed in a follow-up experiment in which the distractors during the test session were new (i.e. unseen) pictures of the same categories that were associated with reward during the training session. This finding illustrates that reward generalized to the complex set of features or scene semantics of the entire category rather than being restricted to the individual features of the specific pictures associated with reward.
Chapter 6 investigated whether reward-based attentional deployment affects perception, more specifically time perception. In particular, we tested the hypothesis that reward distorts time perception by increasing perceived duration of a stimulus. To that end, participants had to judge whether a temporal oddball (i.e. a colored disk presented for varying durations) was presented shorter or longer than the standard stimuli (i.e. several black disks each presented for the same duration). Critically, the color of the oddball signaled the reward participants could earn. Results showed that larger associated rewards distorted temporal perception to a larger degree such that oddballs associated with high reward were perceived to last longer than when they were associated with low or no reward. Importantly, a follow-up experiment suggested that this effect was specific to the to-be-discriminated stimulus rather than due to differential levels of reward-induced alertness. We furthermore found that reward effects were discrete rather than proportional to objective duration which supports the idea that reward affects the initiation of the timing signal rather than the amount of temporal units processed.

Chapter 7 investigated whether threat has a similar influence on attention than reward. In this oculomotor experiment, participants had to saccade as quickly as possible to a shape singleton while the presence of a particularly colored non-salient distractor signaled whether they could receive an electric shock or whether they could be certain of not receiving a shock. The results showed that participants moved their eyes more often to the distractor when it signaled the possibility of receiving a shock compared to when it signaled that no shock would be received. Importantly, this occurred even though moving the eyes to the threat-signaling stimulus would actually increase the likelihood of receiving a shock. In other words, oculomotor capture could neither be explained in terms of top-down nor in terms of bottom-up processes but must have been due to a threatening information conveyed by the distractor. Much like oculomotor capture by reward (see Chapter 3), oculomotor capture by threat-related stimuli was particularly observed in early first saccades strengthening the idea that the bias was not under voluntary control.

Reward has a powerful influence on visual cognition and attention. It is known that reward affects attentional control by promoting cognitive or executive control. In this dissertation, I have provided evidence that the influence of reward goes beyond that. Reward has a direct impact on attentional and perceptual processing independent of strategic or stimulus-
driven attentional control. I show that reward-based selection history imbued to an otherwise task-irrelevant and physically non-salient stimulus causes attentional capture that is truly spatial in origin (Chapter 2). I show that reward also causes oculomotor capture which is particularly dominant early in the selection process and occurs as a consequence of a Pavlovian association (Chapter 3). My research further emphasizes the need for initial prioritization of the reward-associated stimulus in order to initiate learning of the association which eventually causes capture (Chapter 4). I also demonstrate that reward not only affects spatial attention but causes nonspatial capture thereby limiting the availability of attention over time (Chapter 5). In my recent studies, I have shown that the manner by which reward affects attention also reflects on perception such that reward expands perceived duration of a stimulus (Chapter 6). Finally, my findings suggest that threat affects selection in a similar way as reward such that stimuli signaling the likelihood of an electric shock cause oculomotor capture that occurs early in the selection process even if selection is equivalent to an increased likelihood of receiving a shock (Chapter 7). My research therefore shows that traditional theories on attentional control need to be revised. More specifically, it demonstrates that selection history based on reward or threat shapes current and future attentional processing and has far-reaching consequences for our perception, most notably our subjective perception of time.