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Attention and choice: A review on eye movements in decision making

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ABSTRACT

This paper reviews studies on eye movements in decision making, and compares their observations to theoretical predictions concerning the role of attention in decision making. Four decision theories are examined: rational models, bounded rationality, evidence accumulation, and parallel constraint satisfaction models. Although most theories were confirmed with regard to certain predictions, none of the theories adequately accounted for the role of attention during decision making. Several observations emerged concerning the drivers and down-stream effects of attention on choice, suggesting that attention processes plays an active role in constructing decisions. So far, decision theories have largely ignored the constructive role of attention by assuming that it is entirely determined by heuristics, or that it consists of stochastic information sampling. The empirical observations reveal that these assumptions are implausible, and that more accurate assumptions could have been made based on prior attention and eye movement research. Future decision making research would benefit from greater integration with attention research.

1. Introduction

Until recently, most theories on decision making have been remarkably silent regarding the role of attention during decision making. This is not to say that no assumptions were made with regard to attention, but rather that attention has been of no real interest to decision research. Perhaps as a consequence of this disinterest, two of the major and competing lines of thought, rationality and bounded rationality, make the same assumptions about attention. Both models assume that the role of attention is to serve the decision maker by passively acquiring the information needed to make a decision. In both models, attention is determined by the information needs of the decision maker and, with regard to this point, the models only differ in what they deem to be necessary and sufficient information.

However, recent developments in decision research have questioned what could be described as the assumption of passive information acquisition. One of these developments stems from extensions of rational models that aim to predict, rather than explain, decisions (Hensher, 2010). This line of research centered on choice modeling has begun to incorporate process measures, such as objective fixation measures and self-reported nonattendance, i.e. ignoring choice information. In general, they determine that process measures improve predictive validity (Hensher, 2010; Scarpa, Zanoli, Bruschi, & Naspetti, 2013). These models typically make few conjectures about attention processes per se; however, by relaxing assumptions on passive information acquisition, they implicitly acknowledge that attention has down-stream effects on choice.

Another development, known as drift diffusion models, has sprung out of neuroscience, and distinguishes itself by making a strong assertion about down-stream effects of attention. According to this theory, decisions are based on accumulated evidence which is sampled during fixations (Krajbich, Armel, & Rangel, 2010). Both the drift diffusion models and the relaxed rational models question the assumption of passive attention, by showing that modeling down-stream effects of attention can improve predictive validity. In other words, while earlier decision theories, such as strong rational models (March, 1978) and bounded rationality models (Simon, 1955), assumed that attention passively serves the decision process later models have shown that attention plays an active role in constructing the decision (Krajbich et al., 2010; Shimojo, Simion, Shimojo, & Scheier, 2003).

Unfortunately, neither the former nor later decision theories can claim to make accurate assumptions about attention processes; in any case not when their assumptions are compared with what is known from research on attention and eye movements.

In this paper, we aim to critically evaluate a selection of relevant decision theories against prior research on attention and eye movements, and to assess the body of literature on eye movements during decision making. The first section reviews findings on attention and eye movements from research in various areas, such as scene viewing, problem solving, natural tasks, visual search, and expertise. Based on these findings, a

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theoretical framework is derived to understand visual attention during decision making. Three major questions are examined: What happens during a fixation (Section 2.1), what determines where we fixate (Sections 2.2 and 2.3), and lastly, how does attention and working memory interact (Section 2.4)? Section 3 summarizes four decision theories (strong and relaxed rational models, bounded rationality models, evidence accumulation models, and parallel constraint satisfaction models), and derives explicit predictions about attention during decision making from each theory. The primary part of the review (Section 4) contains observations based on studies of eye movements during decision making. Section 5 then evaluates the predictions of each decision theory according to the findings. The paper concludes with an outlook for future theory development in decision making research.

2. Visual attention and eye movements

The following sections examine findings on attention and eye movements from a variety of tasks similar or related to behavioral decision tasks. The primary questions concern the cognitive processes before and during fixations, as well as the integration between attention and working memory. Each section outlines theoretical expectations about eye movements during decision making, thereby establishing a theoretical framework for interpreting the empirical findings on eye movements in decision making. Furthermore, the framework serves to organize the results in Section 4.

2.1. Visual attention and perception

Attention is normally defined as selectivity in perception (for a review on attention theories see Bundesen, Habekost, & Kyllingsbæk, 2005). Although early theories of attention emphasized the selection and filtering of perceptual input, it has become clear that attention also influences perception to a great extent, for instance by enhancing contrast sensitivity and spatial resolution (for a review see Carrasco, 2011). One of the obvious ways in which attention influences perception is by directing overt visual attention to a specific stimulus. Overt visual attention brings the stimulus into the fovea, which has a higher density of sensory neurons and, thereby, enhanced visual processing. Although it is possible to covertly attend to objects outside the fovea, overt attention is most likely the default state. Many studies have demonstrated a strong coupling between eye movements and visual attention (Deubel & Schneider, 1996; Hoffman & Subramaniam, 1995; Kowler, Anderson, Dosher, & Blaser, 1995). These studies show that decoupling normally only occurs prior to a saccade, when attention moves to a new location that is subsequently fixated (Rayner, McConkie, & Ehrlich, 1978; Shepherd, Findlay, & Hockey, 1986). This means that most of the time perception is enhanced by attention simply through the increase in sensory processing of stimuli.

Attention also modulates perception at later stages in visual processing, particularly in brain area V1 (Brefczynski & DeYoe, 1999; Gandhi, Heeger, & Boynton, 1999; Kastner, Pinsk, De Weerd, Desimone, & Ungerleider, 1999). Similarly, single-cell recordings show that attending to a specific location increases firing rates for neurons that encode that particular response field (Ito & Gilbert, 1999; McAdams & Maunsell, 2000; Motter, 1993; Reynolds, Pasternak, & Desimone, 2000). This modulation is specifically noteworthy when considering behavioral evidence showing that attention demands lead to quite specific processing of stimuli (Droll, Hayhoe, Triesch, & Sullivan, 2005; Triesch, Ballard, Hayhoe, & Sullivan, 2003). In other words, attention not only affects perceptual thresholds, but can also determine what is being perceived at both the object and feature level.

With regard to decision making, if a stimulus receives no fixations and is outside the perceptual span of the nearest fixation, then it seems plausible that it cannot be identified and is, therefore, unavailable to the decision maker. However, this is only relevant in situations wherein the decision maker is unfamiliar with the visual scene. In familiar visual scenes, the decision maker could potentially retrieve a stimulus location from memory, and subsequently choose to attend or ignore the stimulus even before it is perceived.

Since visual attention enhances perception, fixating a stimulus should result in an enhanced perceptual representation, when compared to non-fixated stimuli. Furthermore, visual attention limits and controls perception. When a decision maker fixates a stimulus, this is likely to enhance the perception of the object category, its visual features, or the object location (although not all information is necessarily perceived). In other words, attention is likely to cause two forms of down-stream effects on decision making: a) limiting the decision to fixated stimuli, and b) enhancing the influence of fixated information.

2.2. Bottom up control of visual attention

Top down and bottom up control of attention, occasionally referred to as endogenous and exogenous attention, are commonly defined as goal-driven, versus stimulus-driven, attention (for reviews see Corbetta & Shulman, 2002; Theeuwes, 2010). In relation to bottom up processes, much of the debate has centered on the role of visual saliency. Visual saliency has not only led to an interesting debate on the nature of attention, but also to computational models of gaze patterns (for reviews see Frintrop, Rome, & Christensen, 2010; Judd, Durand, & Torralba, 2012; Rothenstein & Tsotsos, 2008). Computational saliency models assume that a visual scene is encoded in parallel at the first glance, and that a topographic saliency map is computed, which guides attention selection. Depending on the implementation, visual saliency can consist of different aspects of visual conspicuity, such as contrast, color, edge orientation, and movement. Visual saliency has been shown to predict attention capture (Foulsham & Underwood, 2008; Itti & Koch, 2000; Parkhurst, Law, & Niebur, 2002; Rutishauser & Koch, 2007), and to affect encoding to visual short term memory (Nordfang, Dyrholm, & Bundesen, 2013).

The effect of saliency on attention capture and encoding to visual short term memory is generally smaller than that of top down control (see Section 2.3). Therefore, it has been proposed that saliency plays little or no role in human gaze allocation outside the laboratory (Tatler, Hayhoe, Land, & Ballard, 2011). However, an alternative view is that visual saliency does play a role, albeit not in situations where task demands on attention are strong. Several factors have been identified that override attention capture by visual saliency, such as semantic or contextual cues about a visual scene, feature based attention, object representations, task demands, and rewards for task performance (Kowler, 2011).

Although most saliency models operate at a pixel level, and therefore ignore object representations, it has been argued that so-called 'proto-objects' might pertain to a mid-level system between bottom up and top down control (Rensink, 2000; Wischnewski, Belardinelli, Schneider, & Steil, 2010). Proto-objects could potentially explain other bottom up phenomena, such as attention capture by surface size increments (Wedel & Pieters, 2008). Surface size is most likely a critical attribute of proto-objects (Wischnewski et al., 2010), and an increase in the surface size of an object could make it more distinguishable from other objects; this has been shown to affect object recognition (Franconeri, Bemis, & Alvarez, 2009; vanMarle & Scholl, 2003).

Although bottom up control has mostly been demonstrated independent of top down processes, the two processes have been shown to interact. Such an interaction occurs, for instance, when searching for a person with a red shirt attention is increased to all red objects in the environment. The interaction between bottom up and top down control has been shown to amplify attention capture (Folk, Remington, & Johnston, 1992) and encoding to visual short term memory (Nordfang et al., 2013). The interaction effect between top down and bottom up processes has not yet received much attention; however, it seems plausible that a large part of our attentional control consists of mixed top down/bottom up processes (Corbetta & Shulman, 2002; Wischnewski et al., 2010).

With regard to decision making, it is expected that attention to some extent will be driven by low-level salient features, thus decision makers will fixate on salient stimuli with a higher likelihood, regardless of its importance to the decision. Attention might also be driven by mid-level proto-objects, denoting that decision makers are more likely to attend to stimuli that resemble large and discrete objects. Furthermore, a high number of discrete objects may clutter the visual scene (Rosenholtz, Li, & Nakano, 2007), which would prolong search time. The effect of saliency on attention capture should also interact with task demands, in that decision makers are more likely to attend to salient stimuli that share features with goal-related objects.

2.3. Top down control of attention

As mentioned above, top down control is usually defined as goal-driven attention. Top down control of attention was first described in the seminal work by Yarbus (1967), in which participants were instructed to inspect a photograph with different goals in mind. Yarbus showed that eye movements differed by the viewing task, and that participants gazed at the part of the visual scene that was most informative to their task. The idea that stimulus or task relevance is contingent on task demands is crucial to understanding top down control. Task relevance has been identified as the primary driver of attention in, for instance, natural tasks (Hayhoe, 2000; Hayhoe, Shrivastava, Mruczek, & Pelz, 2003; Land, Mennie, & Rusted, 1999), and has been implemented in computational models of visual attention (Navalpakkam & Itti, 2005; Sprague, Ballard, & Robinson, 2007). With regard to decision tasks, it is therefore expected that decision makers will attend preferentially to stimuli with higher task relevance, and perhaps ignore stimuli with little or no task relevance. However, the critical question is, how do decision makers know what stimuli are task relevant?

One possibility is that decision makers learn through practice to distinguish relevant from irrelevant stimuli (Haider & Frensch, 1999); a process which could be driven by feedback about the reward value of attending to particular stimuli (Hayhoe & Rothkopf, 2011; Tatler et al., 2011). In an eye movement study based in natural environments, Jovancevic-Misic and Hayhoe (2009) showed that participants learn to attend to important events in the environment, and that the probability of fixating, and the duration of single fixations, increases while the time taken to first fixate on the stimulus decreases for important events as participants become more experienced with the task. Another perspective on learning is through expertise effects on attention. Studies on expertise effects on comprehension of visualizations, show that experts have shorter fixation durations, more fixations to relevant areas, fewer fixations to irrelevant areas, longer saccades, and shorter time to first fixate relevant areas, when compared with novices (for a review see Gegenfurtner, Lehtinen, & Säljö, 2011). Similarly, expertise in reading is associated with longer saccades, shorter fixation durations, and fewer repeated fixations (Ashby, Rayner, & Clifton, 2005; Rayner, 1998).

The high degree of similarity between the findings of Jovancevic-Misic and Hayhoe (2009), and the findings on expertise effects, implies a common pattern with regard to how learning affects attention. These effects should continue to occur in decision making, both between-subjects as expertise effects and within-subjects as learning effects, in, for instance, repeated exposures to decision tasks. Learning effects should increase decision efficiency through more fixations to task-relevant stimuli, fewer fixations to task-irrelevant stimuli, and faster stimulus processing.

2.4. Attention and working memory

One of the theories which have had significant influence on eye tracking based decision research is the eye-mind assumption. The eye-mind assumption suggests a strong causal relationship between working memory and attention: “The eye-mind assumption posits that there is no appreciable lag between what is being fixated and what is being processed” (Just & Carpenter, 1980, p. 331). This assumption has been exemplified by showing that increasing task difficulty (i.e., working memory load) leads to a linear increase in either the number of fixations (Just & Carpenter, 1976), or in fixation durations (Gould, 1973).

Although the eye-mind assumption is generally validated, recent studies on problem solving have shown that the relationship between attention and working memory cannot be simply described as a linear function. These studies show that participants often rely on the use of fixations as an external memory space, thereby reducing demands on working memory (Droll & Hayhoe, 2007; Hayhoe, Bensinger, & Ballard, 1998; Karn & Hayhoe, 2000). In doing so, participants employ a just-in-time strategy that entails fixating relevant information only when necessary. It has been argued that the just-in-time strategy is an essential operating characteristic of the visual system, because it minimizes working memory load through exploiting the availability of external information (Ballard, Hayhoe, Pook, & Rao, 1997; O'Regan, 1992). Furthermore, when the processing demands of the just-in-time strategy increase, participants tend to rely more on working memory (Ballard, Hayhoe, & Pelz, 1995). This increase has been manipulated through increasing the physical distance between stimuli, thereby leading to greater head movements to re-fixate stimuli. Conversely, increasing demands on working memory, through for example increased memory load, leads to greater reliance on just-in-time fixations (Droll & Hayhoe, 2007) and decreasing working memory demands reduces the number of just-in-time fixations (Aivar, Hayhoe, Chizk, & Mruczek, 2005).

These studies not only suggest that the just-in-time fixation strategy is an essential operating characteristic of the visual system (Ballard et al., 1997; O'Regan, 1992), but also that another operating characteristic might exist, which strives to minimize processing demands in general. This mechanism could be responsible for trade-offs between fixations and working memory, depending on whether it is more efficient to retrieve information from the environment or from memory.

Another important aspect of the relationship between attention and working memory relates to the information that is extracted and encoded during fixations. Using experimental paradigms from change blindness, it has been shown that participants only encode a limited amount of object features during fixations. The particular feature, which is encoded during a given fixation, depends on the current goal of the participant. For instance, information can be encoded concerning object color in one fixation and object shape in the next. Several researchers have demonstrated the selectiveness of working memory encoding (Droll & Hayhoe, 2007; Droll et al., 2005; Hayhoe et al., 1998; Karn & Hayhoe, 2000; Triesch et al., 2003). Their work suggests that visual objects are not encoded as complete or naturalistic representations, and that the visual binding in working memory is highly selective. Furthermore, this denotes that object representations are not necessarily updated during fixations, as previously assumed (Kahneman, Treisman, & Gibbs, 1992).

The findings on attention and working memory have several possible repercussions with regard to decision making. Firstly, fixations can lower the demands on working memory by serving as an external memory space. Through encoding the stimulus location, decision makers are able to strategically re-fixate the stimulus the moment its features are needed in the decision task. For example, knowing the location of price tags on the shelf may allow consumers to ignore the price until it is needed in the decision (e.g., when comparing a favorite brand to a competitor). The alternative, and inconvenient option, would be to fixate and encode all information concerning one alternative, proceed to the next alternative, and, lastly, compare the alternatives based on the memorized information.

Larger working memory demands increase just-in-time fixations. Cognitively demanding decision tasks (e.g., those that involve attribute dependencies, such as the probabilities and pay-offs in risky gambles) may, therefore, trigger more strategic re-fixations to lower working memory demands. Conversely, increasing attention demands should diminish the use of just-in-time fixations and increase the use of working memory. This could mean that visually complex or fragmented decision tasks, which hinder visual grouping by spacing the stimuli apart, are likely to increase the use of working memory.

Finally, encoding from attention to working memory is highly selective and depends on the current task demands. Thus, decision makers can encode any number of features to working memory during fixations; however, the features that are encoded are likely to be relevant to the decision task.

2.5. Summary of attention and eye movements

The overview on attention and eye movements has several important implications for understanding attention during decision making. By assuming that attention processes in decision making are similar to the tasks reviewed above, we should expect the following: 1) eye movements during decision making are controlled both by top down and bottom up processes, 2) learning significantly influences the speed and accuracy of fixations, 3) decision makers trade-off between fixations and working memory, and 4) fixated information influences decision making more than non-fixated information.

3. Decision theories

The following section reviews four decision theories with regard to their assumptions and predictions concerning attention during decision making. The theories were chosen based on their relevance to the topic, and the extent to which they make testable predictions about attention. Thus far, only a few studies have attempted to compare these theories and their ability to account for eye movements in decision making (for decision making under risk see: Fiedler & Glöckner, 2012; Glöckner & Herbold, 2011). Therefore, large scale benchmarking against existing findings should be of substantial benefit to future theory development.

3.1. Rational models

The rational or neoclassical model of decision making makes few, if any, process predictions about human decision making. This is not to say that the rational model makes no assumptions about information use — the most prominent being that humans make decisions based on full and relevant information (March, 1978; Simon, 1955). From this process prediction, it can be assumed that decision makers must unavoidably attend to all relevant information in their decision environment, and that information integration must not be influenced by external or internal factors. Despite its controversial status in psychology, the rational model has persisted as one of the fundamental models in economics and marketing, where its primary application lies in predicting consumer choices. Thereby, these disciplines take a rather pragmatic approach by focusing fundamentally on the predictive validity of the model as the major criterion.

One of the most common applications of the rational model is found in structural modeling (for an introduction see Hensher, Rose, & Greene, 2005), which typically ignores the decision process by focusing on the information–choice relationship. The structural modeling of decision making is usually based on a variation of weighted additive utility models in which process measures are captured in the residual. Recently, new forms of structural models have been developed. These introduce either attribute nonattendance, thereby relaxing the assumption of full information integration (Hensher et al., 2005; Scarpa et al., 2013) and allowing a mix of different decision rules (Hensher, 2010; Hess, Rose, & Polak, 2010) and choice uncertainty (Balcombe & Fraser, 2011; Lundhede, Olsen, Jacobsen, & Thorsen, 2009), or directly introduce process measures, such as fixation frequency (Meißner, Musalem, & Huber, 2012) and attention selection (Balcombe, Fraser, & McSorley, 2011). The motivation for these new developments stems principally from the objective to improve predictive validity, rather than to test theories regarding the nature of the decision process.

Irrespective of the assumptions concerning information uptake, rational models also make an important assumption about the relationship between preference and choice; rational models assume that people have stable preferences, and that these preferences are revealed through their decisions (McFadden, 2001). The assumption regarding stability of preferences has been challenged both from within structural modeling (Desarbo, Lehmann, & Hollman, 2004), and judgment and decision making research (e.g. Kahneman, 2003). Despite these theoretical challenges, it can be argued that the assumption of preference stability is exactly what makes structural modeling useful as a prediction tool to policy makers and marketers.

In summary, two assumptions are derived from rational models:

(1.1) Information acquisition is complete and no information is ignored. All information is fixated. (Strong rational model)
(1.2) Information acquisition is incomplete, and attributes are discounted in the structural model based on the level of attendance. (Relaxed rational model).

3.2. Bounded rationality models

The notion of bounded rationality was proposed by Herbert Simon (1957) and distinguishes itself from the rational model by introducing cognitive capacity limitations. The capacity limitation suggests that the assumption concerning the use of full and relevant information cannot be true when decision makers face choice environments that exceed their processing capacity. Rather than complete information use, bounded rationality proposes that decision makers construct the decision problem by prioritizing the information to which to attend. This prioritization is accomplished by selecting a decision strategy or heuristic that serves as a shortcut to decision making (for reviews see Gigerenzer & Gaissmaier, 2011; Payne, Bettman, & Johnson, 1992).

Herbert Simon was the first to propose the use of decision strategies, and described the ‘satisficing’ heuristic as the tendency to select the first available option that meets an acceptable threshold (Simon, 1957). Subsequently, several other heuristics have been proposed, such as the lexicographic, elimination by aspect, and take the best rules (Fishburn, 1974; Goldstein & Gigerenzer, 1999; Tversky, 1972). More recently, the priority heuristic (Brandstätter, Gigerenzer, & Hertwig, 2006) and the recognition heuristic (Goldstein & Gigerenzer, 2002) have also been proposed. Using simulations, heuristics have been shown to outperform rational models based on complete information acquisition, however this is only true for certain decision tasks performed mainly under time pressure (Gigerenzer & Goldstein, 1996; Payne, Bettman, & Johnson, 1988).

By introducing different heuristics, bounded rationality provided an answer to how it is possible to optimize decisions when cognitive capacity is limited. However, this raised another question: How do decision makers select between available heuristics? Several views have been defended, the most prominent being the meta-cognitive cost/benefit theory, which states that decision makers select a heuristic based on a trade-off between effort and accuracy (Beach & Mitchell, 1978). Other views of strategy selection have been proposed based on, for instance, learning (Rieskamp, 2008) or context (Fazio, 1990; Petty & Cacioppo, 1986). While the theories differ with regard to the particular selection rule, they all assume that decision makers have a mental representation of the choice problem, and that a heuristic is chosen based on a meta-cognitive strategy selection rule.

Another common characteristic of strategy selection models is that information acquisition is considered to implement the decision rule. For instance, if decisions are made according to a lexicographic heuristic, then the decision maker must first attend to the most important attribute across all alternatives and only if no alternative stands out will he proceed to the next most important attribute (Fishburn, 1974). Following this logic, very specific predictions have been made regarding the distribution of attention according to each heuristic (Riedl, Brandstätter, & Roithmayr, 2008) which furthermore implies that one can infer the underlying heuristic based on the distribution of attention. This inference is typically accomplished by measuring 'elementary information processes', such as information acquisition, time spent per unit of information, variances in proportions of time spent on each alternative, the distribution of alternative versus attribute-based transitions, and so on (Payne et al., 1988).

The assumptions of bounded rationality models, with regard to attention, are as follows:

(2.1) The particular heuristic employed by the decision maker determines visual attention.
(2.2) Each heuristic results in a particular distribution of attention.
(2.3) The underlying heuristic can be inferred from the distribution of attention.

3.3. Evidence accumulation models

Although several theories have been described under the term 'evidence accumulation model' (see for instance Busemeyer & Townsend, 1993; Ratcliff & Smith, 2004), this paper considers the attentional drift diffusion model (aDDM), as outlined by Krajbich et al. (2010). Earlier versions of the drift diffusion model (Ratcliff & Smith, 2004) were concerned with perceptual discrimination; the aDDM extended this modus operandi to decision making (see Rangel, 2009 for an overview of both models). The aDDM assumes that decision makers accumulate evidence in favor of an alternative when fixating it, and that the speed of accumulation is a function of the value of the alternative relative to other alternatives in the choice set, which is called the bias rate. The decision is made when the accumulated evidence reaches a threshold for one of the alternatives.

The aDDM was generalized to consumer purchase decisions that involved two attributes, product and price, for which the consumer must decide to accept or reject the product (Krajbich, Lu, Camerer, & Rangel, 2012). The interesting prediction from this generalization is that the product and the price compete to influence the decision, and that fixating more on the price will lead to a rejection of the product, whereas fixating more on the product will lead to acceptance. In addition to the underlying assumptions contained in the model specification regarding attention and choice processes, several other predictions follow from the model about the relationship between visual attention and decision making:

(3.1) The fixation process is stochastic, and fixations are assigned to the alternatives in an alternating pattern.
(3.2) Fixation patterns should not change over the course of the decision process because the fixation process is stochastic.
(3.3) The last fixation should be shorter than the mean fixation duration because the fixation is interrupted when the threshold is reached.
(3.4) Fixation durations follow a fixed distribution given by the difference between the best and the worst alternatives in the choice set.
(3.5) The last fixation is to the chosen alternative.
(3.6) A choice bias exists in favor of the alternatives fixated first and last because these alternatives have accumulated more evidence.
(3.7) The accumulated evidence determines choices.
(3.8) Any process that exogenously interferes with the accumulation of evidence toward an alternative will bias the decision in favor of that alternative.
(3.9) The information sampling needed to reach a decision increases as options become more similar.

Importantly, the high number of predictions and their specificity means that proving the aDDM correct will inevitably be more difficult, when compared with more vaguely specified models.

It is worth noting that through testing the aDDM, other evidence accumulation models, such as the Decision Field Theory (Busemeyer & Townsend, 1993), are simultaneously being evaluated. Like other evidence accumulation models, Decision Field Theory (DFT) assumes that information is sampled sequentially and stochastically, and that the decision maker gradually builds up evidence in favor of an alternative until a decision threshold is reached. DFT therefore shares predictions (3.2), (3.7), and (3.9). Unlike the aDDM which assumes an even distribution of attention, the DFT assumes that attention is distributed similar to the attention weights in a deterministic weighted additive model (Busemeyer & Johnson, 2004), i.e. important alternatives will on average receive more attention, relative to less important alternatives. To evaluate the DFT, it is necessary to analyze predictions (3.2), (3.7), (3.9), and a final prediction about a stochastic distribution of attention, with a mean value equal to the importance of each alternative.

3.4. Parallel constraint satisfaction models

According to the parallel constraint satisfaction (PCS) model, decisions are constructed in a process that maximizes the coherence of the representation of the choice problem. The choice is made when the decision maker reaches a threshold of sufficient internal coherence. The PCS model has been implemented in neural networks that simulate the coherence maximization process (Glöckner & Betsch, 2008; Glöckner & Herbold, 2011; Kunda & Thagard, 1996; Read, Vanman, & Miller, 1997; Rumelhart & McClelland, 1986).

In the framework of Glöckner and Betsch (2008), the PCS model has a dual process component where the primary network, the neural network representing the automatic decision processes, is activated first, and only in situations where the network fails to reach the threshold is the secondary network activated. The secondary network consists of deliberate constructions, i.e. explicit information search strategies. Glöckner and Betsch (2008) also propose that the initial activation level in the primary network is partially determined by salient features in the environment, along with internal accessibility of information. Herein, the influence of bottom up processes on decision making is acknowledged, and because salient alternatives have a higher initial activation level they are, ceteris paribus, more likely of being chosen.

Furthermore, the PCS model makes two assumptions about the distribution of attention when decisions are based on the primary network. The first assumption is that information acquisition consists mainly of information screening (Glöckner & Herbold, 2011), leading to the prediction that fixation durations should remain constant throughout the decision process consisting mainly of short fixations (<250 ms). The second assumption is that attention is preferentially guided toward information with a higher activation level (Fiedler & Glöckner, 2012), therefore increasing the likelihood of decision makers fixating the chosen alternative towards the end of the decision process.

The following tenets can be derived about visual attention:

(4.1) Information acquisition consists mainly of screening of information which is reflected in an even distribution of single fixation durations.
(4.2) The feature currently highlighted in the decision process, such as the favored alternative or most important attribute, receives attention.
(4.3) The information sampling needed to reach a decision increases as alternatives become more similar, which reflects the difficulty of maximizing coherence.
(4.4) Salient alternatives will initially attract more attention and are, ceteris paribus, more likely of being chosen.

4. Results on eye movements in decision making

4.1. Methods

The review includes peer-reviewed studies on discrete choice and decision making using eye tracking methodology. Papers relating to perceptual decision making, in which participants categorize or discriminate between visual stimuli, as well as studies on problem solving, were excluded. The databases Web of Science and PsychINFO were searched using the terms: eye track* OR eye move* OR eye fix* AND decision making OR choice. The identified papers were published between 1975 (first published study) and 2012. Additional searching was conducted using the reference lists of the identified papers and through personal contact with the authors. Seventy five papers measuring eye movements during decision making were identified. Ten papers were excluded due to the following reasons: a) no peer-review or unpublished manuscript, b) did not concern discrete choice, or c) no independent variables of relevance to the review. A total of sixty five papers were included in the review. The extracted results were classified as belonging to bottom up processes, top down processes, attention and working memory, or down-stream effects of attention on choice. An overview of the results is shown in Table 1.

4.2. Stimulus-driven attention

Although few of the reviewed decision theories make conjectures with regard to bottom up processes, the reviewed eye tracking studies clearly demonstrate that stimulus-driven attention plays an important role in decision making. Four major factors were identified: saliency, surface size, visual clutter, and position. With regard to the classification of position as stimulus-driven attention, it is worth noting that attention to central or top locations could stem from visual routines, such as learned reading patterns. This partly qualifies position effects as goal-driven attention.

All four factors influence attention during decision making either by increasing or decreasing fixation likelihood to the stimulus. The role of stimulus-driven attention in decision making clearly demonstrates that, although visual attention serves the decision process, it also operates as a separate process with its own modus operandi.

4.2.1. Saliency

The effect of saliency on attention capture in decision making has been demonstrated in several different domains. Milosavljevic, Navalpakkam, Koch, and Rangel (2012) showed that visually salient alternatives in a shelf-like setup capture attention more readily than less salient alternatives, whereas Bialkova and van Trijp (2011) and Orquin, Scholderer, and Jeppesen (2012) showed that salient attributes, such as product labels, attract more attention than low saliency attributes. Navalpakkam, Kumar, Li, and Sivakumar (2012) demonstrated a similar effect for salient website elements, and Lohse (1997) found that visually salient color ads in yellow page listings receive more attention than less salient ads without color. Four of the studies revealed down-stream effects of saliency on decision making, i.e. salient alternatives or attributes are more likely to attract attention and affect the decision in favor of the attended alternative or attribute (Lohse, 1997; Milosavljevic et al., 2012; Navalpakkam et al., 2012; Orquin et al., 2012). Milosavljevic et al. (2012) found that utility differences and working memory load moderated the down-stream effect of saliency on choice.

4.2.2. Surface size

Lohse (1997) showed that larger ads attract more attention than smaller ads, and that the effect of surface size increments follows a log-shaped distribution. Chandon, Hutchinson, Bradlow, and Young (2009) demonstrated the effect of surface size by showing that brands with more shelf facings attract more attention and have an increased choice likelihood. Chandon and colleagues also found that surface size increments only led to marginal increases in attention after a certain point. A similar effect of surface size was found at the attribute level, in that product features, which occupy a larger percentage of the total product, were more likely to be fixated and to influence the decision (Orquin et al., 2012).

4.2.3. Visual clutter

In a study on consumer choice concerning breakfast cereals, Visschers, Hess, and Siegrist (2010) showed that participants pay less attention to nutrition labels in more cluttered products. This finding suggests that clutter creates a competition for attention between an increased number of visual objects, which results in less attention to individual attributes. Similarly, increases in the number of information elements also create competition for attention by directly increasing the set size. This effect is described in Section 4.4.3 on information complexity.

4.2.4. Position

Sütterlin, Brunner, and Opwis (2008) demonstrated position effects on attention by showing that items at the top of a list receive more attention than those at the bottom. This list position effect has been replicated in other decision tasks (Chandon et al., 2009; Chen & Pu, 2010; Huang & Kuo, 2011; Navalpakkam et al., 2012; Shi, Wedel, & Pieters, in press) and is a consequence of the fact that decision makers generally prefer to read from top to bottom or from left to right. The attributes or alternatives that are located near the end of the list either vertically or horizontally receive less attention.

Chandon et al. (2009) showed that brands located at the center of a shelf receive more attention and are more likely to be chosen than brands located near the bottom. This finding of a central position effect has been replicated for other types of choice sets as well (Chen & Pu, 2010; Glaholt, Wu, & Reingold, 2010; Huang & Kuo, 2011; Krajbich & Rangel, 2011; Lohse, 1997; Navalpakkam et al., 2012; Reutskaja, Nagel, Camerer, & Rangel, 2011; Shi et al., in press). It has been argued that the central position effect may be an artifact that stems from participants' tendency to gaze at the center of the screen (Tatler et al., 2011). However, Atalay, Bodur, and Rasolofoarison (2012) rejected this interpretation by showing that alternatives in the middle of a choice set receive more attention, regardless of whether the choice set is located in the center of the screen or on the left or right side. Atalay et al. (2012) also showed that the centrally positioned brand is more likely to be fixated at stimulus onset and 5 s before the choice, and more likely of being chosen.

An interesting question regarding the central position effect is whether the effect may stem from the fact that the center of the choice set is the optimal viewing position (OVP) for gaging the entire choice set. Reading research has shown that the OVP is located in the center of a word, and fixations to this location minimize recognition time (Rayner, 2009). This could denote that it is advantageous for decision makers to fixate on the center of a choice set, to encode scene gist or the layout of the information.

4.3. Goal-oriented attention

As predicted by several decision theories, goal-oriented attention plays a significant role in decision making. Five major factors were observed: task instructions, utility effects, heuristics, attention phases, and learning effects. The effect of task instructions stems from direct experimental manipulations (which is also true for the effect of heuristics in most cases), and results in increased attention to goal-relevant stimuli. Utility effects refer to the observation that participants overwhelmingly attend to important or high utility information. The only way in which utility effects differ from the effect of task instructions and heuristics, is that utility effects are attributable to individual differences, whereas task instructions and heuristics are caused by experimental manipulations.

Observations on attention phases indicate that specific task demands often change during the decision task. Thus, a decision maker can begin the decision task with one top down goal, such as scanning alternatives, and later proceed to another goal, such as comparing alternatives based on relevant attributes.

Furthermore, findings on learning effects show that practicing a decision task increases top down control (e.g., the utility effect). Learning also increases processing efficiency, thereby diminishing the total number of fixations.

4.3.1. Task instructions

Several researchers have demonstrated task-specific effects on attention by manipulating task instructions (Glaholt et al., 2010; Glöckner, Fiedler, Hochman, Ayal, & Hilbig, 2012; Huang & Kuo, 2011; Kim, Seligman, & Kable, 2012; Rosen & Rosenkoetter, 1976; Toubia, de Jong, Stieger, & Füller, 2012). All studies replicate the original finding of Yarbus (1967): Observing the same stimulus with different goals leads to different scanpaths based on the goal-relevance of the stimuli.

Other studies have manipulated task demands using motivational or goal states. Pieters and Warlop (1999) and Selart, Kuvaas, Boe, and Takemura (2006), demonstrated motivation effects by showing that task motivation (i.e., the motivation to provide an accurate response) results in longer fixation durations, greater number of fixated attributes, additional time spent searching for information, and increased within-attribute transitions. Other studies have manipulated goal-specific motivation, such as health motivation, which has resulted in attention capture by goal-relevant health related information (Bialkova & van Trijp, 2011; van Herpen & Trijp, 2011; Visschers et al., 2010). The effect of goal-specific motivation is therefore similar to the effect of task instructions.

4.3.2. Utility effect

The utility effect refers to the observation that participants tend to gaze at information with a greater utility or importance to their decision. The utility effect is the most robust observation on eye movements in decision making, and has been demonstrated across many different tasks. Several findings have emerged.

First of all, participants have more fixations to the alternative they choose (Bee, Prendinger, Nakasone, André, & Ishizuka, 2006; Glaholt & Reingold, 2012; Glaholt, Wu, & Reingold, 2009; Glöckner & Herbold, 2011; Glöckner et al., 2012; Kim et al., 2012; Meißner et al., 2012; Nittono & Wada, 2009; Pieters & Warlop, 1999; Russo & Leclerc, 1994; Russo & Rosen, 1975; Schotter, Gerety, & Rayner, 2012; Wedell & Senter, 1997), longer first fixation duration (Glaholt & Reingold, 2012), and longer first dwell duration (Glaholt & Reingold, 2009b, 2011; Schotter, Berry, McKenzie, & Rayner, 2010; Schotter et al., 2012); dwell duration is defined as the sum of fixations made to a stimulus before the decision maker fixates another area. The higher number of fixations applied to chosen alternatives is due both to a greater number of dwells (Glaholt & Reingold, 2009b, 2011, 2012; Glaholt et al., 2010; Schotter et al., 2010, 2012), and to more fixations within each dwell (Glaholt & Reingold, 2011, 2012).

Furthermore, decision makers are marginally more likely to fixate the chosen alternative first (Glaholt & Reingold, 2011; Schotter et al., 2010), and very likely to have their last fixation towards the chosen alternative before the decision is made (Krajbich & Rangel, 2011; Krajbich et al., 2010, 2012).

Several studies have demonstrated that the likelihood of fixating the chosen alternative increases until the decision is made (Atalay et al., 2012; Fiedler & Glöckner, 2012; Glaholt & Reingold, 2009a, 2009b, 2011; Glaholt et al., 2009; Meißner et al., 2012; Shi et al., in press; Shimojo et al., 2003; Simion & Shimojo, 2006, 2007). This observation is commonly referred to as the 'gaze cascade'. The phenomenon was first described by Shimojo et al. (2003), who proposed that the gaze cascade effect was driven by a positive feedback loop between preferential looking (Birch, Shimojo, & Held, 1985) and a mere exposure effect (Zajonc, 1968). The authors furthermore proposed, that the allocation of gaze to the chosen alternative serves as a somatic marker (Bechara & Damasio, 2005) driving the cascade, and that the case cascade is exclusive to preference-based decision making. The gaze cascade model by Shimojo and colleagues has later been rejected by studies showing that gaze allocation is not a necessary condition for preference formation (Bird, Lauwereyns, & Crawford, 2012; Nittono & Wada, 2009), and studies demonstrating a gaze cascade in decision making that is not preference-based (Glaholt & Reingold, 2009a, 2009b, 2011). As an alternative to the gaze likelihood analysis employed by Shimojo et al. (2003), Glaholt and Reingold developed an analysis based on dwell sequences. The dwell sequence analysis demonstrated two choice-related gaze biases: That dwell frequency for the chosen alternative increases at the end of the trial, and that dwell durations are in general longer for the chosen alternative throughout the trial (Glaholt & Reingold, 2009a, 2009b, 2011). The authors have proposed that the dwell duration reflects differential encoding of task relevant stimuli, whereas the dwell frequency reflects comparison processes (Glaholt & Reingold, 2011).

Attributes with a greater importance to the decision maker also receive more fixations (Glöckner & Herbold, 2011; Glöckner et al., 2012; Hristova & Grinberg, 2008; Kim et al., 2012; Meißner & Decker, 2010; Reisen, Hoffrage, & Mast, 2008; Su, Rao, Li, Wang, & Li, 2012; Van Raaij, 1977; Wedell & Senter, 1997), and alternatives with a higher mean expected value receive more fixations and longer fixation durations (Fiedler & Glöckner, 2012). Framing effects, such as expressing probabilities in either positive or negative terms, have also been shown to affect the number of fixations and the distribution of fixations (Kuo, Hsu, & Day, 2009) consistent with a higher weighting of losses over gains.

In certain decision tasks, the attention–attribute importance relationship follows a u-shaped curve, with more fixations to high and low importance attribute levels (Meißner et al., 2012; Mueller Loose & Orquin, 2012; Sütterlin et al., 2008). The u-shape has not been found in other tasks, such as risky gambles, which leave open the question concerning which task characteristics generate the u-shape function. The utility effect is also seen during retrieval of information from memory; as demonstrated by participants who gazed longer at empty locations where important attributes were previously presented (Renkewitz & Jahn, 2012). Task instructions (Glaholt et al., 2010; Schotter et al., 2010; Shimojo et al., 2003) and individual traits, such as indecisiveness or achievement ability (Patalano, Juhasz, & Dicke, 2010; Selart et al., 2006), have been shown to moderate the utility effect.

4.3.3. Heuristics

As predicted by bounded rationality models, different heuristics do lead to distinct patterns of attention. Several researchers have demonstrated the effect of heuristics on attention by directly manipulating the use of heuristics (Day, 2010; Day, Lin, Huang, & Chuang, 2009; Day, Shyi, & Wang, 2006; Renkewitz & Jahn, 2012). These manipulations were generally accomplished by training participants in the use of heuristics and familiarizing them with the choice stimuli (Renkewitz & Jahn, 2012). In a similar vein, Huang and Kuo (2011) primed accurate versus emotional decision making, and observed longer decision times, larger shares of fixated information, and a more even distribution of fixations, across attributes in the accuracy condition. Using a similar approach, Horstmann, Ahlgrimm, and Glöckner (2009) manipulated deliberate versus intuitive decisions, and found that deliberate decision making led to more fixations, information fixated, re-fixations, and attribute-wise transitions. Patalano et al. (2010) found that decisive compared to indecisive decision makers were more consistent in their transition patterns throughout the decision task.

Although these studies reliably demonstrate that heuristics do influence attention, the evidence is less convincing with regard to the actual use of heuristics. One study confirmed that attention patterns differ across heuristics, but attention patterns were far from those predicted by heuristics (Reisen et al., 2008). Furthermore, this study relied on a self-reported use of heuristics, which may be unreliable. Some studies have attempted to model or directly test the effect of heuristics on attention (Glöckner & Herbold, 2011; Knoepfle, Tao-yi Wang, & Camerer, 2009; Reutskaja et al., 2011; Sütterlin et al., 2008; Wedell & Senter, 1997), however none of the studies have successfully demonstrated such an effect. Furthermore, Shi et al. (in press) found that decision makers frequently switch between alternative- and attribute-wise transition patterns within a single decision task, which makes defending the use of a single heuristic even more implausible.

In summary, heuristics do influence attention patterns as demonstrated by instruction-based studies, however, little or no evidence exists supporting the claim that decision makers use heuristics in the way or to the extent proposed in the literature.

4.3.4. Attention phases

A group of studies have shown that attention during decision making can be segmented into different phases. These phases have been referred to as 'overview', 'comparison', and 'checking'. In the first and last phases, no re-fixations to alternatives exist, whereas the middle phase consists primarily of pair-wise comparisons between alternatives (Russo, 1977; Russo & Leclerc, 1994). Other studies have confirmed the findings on attention phases, although with slight differences to the number of phases (Clement, 2007; Glaholt & Reingold, 2011; Reutskaja et al., 2011; Russo & Dosher, 1983; Wedell & Senter, 1997). Glöckner and Herbold (2011) showed that the first 10–20 fixations in a choice task have a larger share of short fixations (<150 ms), which suggests an initial search or scanning phase. Other studies have also found that the first and last fixations are typically shorter than the middle fixations (Krajbich & Rangel, 2011; Krajbich et al., 2010, 2012).

Many questions still linger with regard to attention phases. One problem is that none of the studies directly examined attention phases, but rather identified the phases on a more exploratory basis. Therefore, the plausibility of attention phases in decision making stems not as much from the eye tracking papers reviewed here, but from other research areas demonstrating a hierarchical and successive structure of attention tasks (Hayhoe & Rothkopf, 2011). In light of the findings and theoretical considerations, it seems plausible that decision makers parse their decisions into sequential attention tasks, such as obtaining an overview, finding relevant alternatives, comparing relevant alternatives, checking chosen alternative, and so forth (Glaholt & Reingold, 2011).

4.3.5. Learning effects

Several studies have confirmed the effects of learning on attention by showing that participants reduce the number of fixations during the course of repeated decision tasks (Bialkova & van Trijp, 2011; Fiedler & Glöckner, 2012; Knoepfle et al., 2009; Meißner & Decker, 2010; Mueller Loose & Orquin, 2012; Toubia et al., 2012). However, one study could not confirm this effect (Lohse & Johnson, 1996). During repeated choice experiments, participants also become more selective with a greater number of fixations to important attributes, such as price and brand, and have a gradual increase in alternative-wise transitions (Meißner & Decker, 2010). In addition, the utility effect strengthens during choice experiments. This can be seen from the increased correlation between attention and attribute values (Meißner et al., 2012). Patalano et al. (2010) showed that learning effects on attention depend on individual traits and that decisive (however, not indecisive) participants changed their transition patterns during the experiment.

4.4. Attention and working memory

The following section describes a group of observations that are best classified as the intersection between attention and working memory resources. Most of the observations involve both top down and bottom up processes, however assigning the observations to either of these sections would be inappropriate. Several effects have been observed: information complexity, presentation effects, decision difficulty, time pressure, distracters, consideration sets, and pair-wise comparisons. Presentation effects and information complexity alter the demands on attentional resources by determining the number of fixations, fixation durations, and saccade amplitudes needed to accomplish the decision task. Decision difficulty and time pressure increase demands on working memory resources, leading to more fixations. Many of these effects naturally affect the demands on both attention and working memory resources, whereas learning (Section 4.3.5) effectively lowers the demands on both processes. Furthermore, the prevalence of consideration sets and pair-wise comparisons reflect the inherent drive to minimize attention and working memory demands (see Section 2.4).

4.4.1. Consideration sets

Although several studies have shown that participants tend to ignore information in decision tasks (Chen & Pu, 2010; Glaholt et al., 2010; Horstmann et al., 2009; Huang & Kuo, 2011; Lohse & Johnson, 1996; Pieters & Warlop, 1999; Reutskaja et al., 2011; Toubia et al., 2012; van Herpen & Trijp, 2011; Wedell & Senter, 1997), fewer studies have directly addressed the question of how information is incorporated or ignored in the decision process. The subset of alternatives that are under consideration during decision making is usually referred to as the 'consideration set' (Howard & Sheth, 1969). The reviewed studies show that alternatives entering the consideration set are more likely to be chosen (Chandon et al., 2009; Glaholt et al., 2009; Russo & Leclerc, 1994; Shi et al., in press). Furthermore, Shi et al. (in press) found that the number of alternatives in the consideration set varies between one and four alternatives within the decision task, and that previously excluded alternatives are sometimes integrated into the consideration set later in the decision task. Glaholt et al. (2009) found a gaze bias to the consideration set.

The studies confirm the notion of the consideration set as a choice set within a choice set. Alternatives inside the consideration set are compared and considered, whereas alternatives outside the set are ignored. Despite these conclusions, many questions remain regarding how consideration sets develop, which alternatives enter the set, and which are ignored.

4.4.2. Pair-wise comparisons

A small group of studies have demonstrated the use of pair-wise comparisons in decision making by defining comparisons as X–Y–X or X–Y–X–Y sequences of transitions between alternatives (Russo, 1977; Russo & Leclerc, 1994; Russo & Rosen, 1975). Russo (1977) and Russo and Leclerc (1994) also found that participants occasionally use three-way comparisons, although to a much smaller extent than pair-wise comparisons. The preference for pair-wise comparisons over three- or four-way comparisons suggests that participants minimize working memory load by relying on re-fixations (Glaholt & Reingold, 2011). Furthermore, Russo and Rosen (1975) showed that pair-wise comparisons are primarily restricted to spatially proximate alternatives, which suggests that participants also strive to minimize attention costs by using shorter saccades. This result is in line with that of Ballard et al. (1995), who showed that increasing spatial distances between stimuli reduced the amount of transitions. Van Raaij (1977) made a similar observation showing that participants group information around the brand when brand information is available, thereby lowering the number of fixations and increasing choice accuracy. The brand most likely serves as a visual and working memory anchor, thereby reducing both attention and working memory demands, although this supposition is yet to be confirmed.

4.4.3. Information complexity

Information complexity is defined here as the amount of information presented to the decision maker in a given decision task. Many studies have manipulated information complexity either by increasing the number of attributes or alternatives. The results generally show that participants respond to information complexity with an increase in the absolute number of fixations and a reduction in the relative amount of information fixated (Horstmann et al., 2009; Lohse & Johnson, 1996; Reutskaja et al., 2011; Russo & Dosher, 1983).

Conflicting results have been reported with regard to fixation durations. Some studies have found that information complexity increases fixation durations (Horstmann et al., 2009), whereas others have found reduced fixation durations (Chen & Pu, 2010; Reutskaja et al., 2011).

Table 1
Summary of papers included in the review and their results on eye movements in decision making.

Study	Stimulus-driven attention				Goal-driven attention					Attention and working memory							Down-stream effects
	Saliency	Surface size	Visual clutter	Position	Task instructions	Utility effect	Heuristics	Attention phases	Learning effects	Consideration sets	Pair-wise comparisons	Information complexity	Presentation effects	Decision difficulty	Time pressure	Distracters	
Atalay et al. (2012)				x		x											x
Bee et al. (2006)						x											
Bialkova and van Trijp (2011)	x				x				x								
Bird et al. (2012)						x											x
Chandon et al. (2009)		x		x						x							x
Chen and Pu (2010)				x													
Clement (2007)								x									
Day (2010)							x										
Day et al. (2009)							x									x	
Day et al. (2006)							x									x	
Fiedler and Glöckner (2012)						x								x			
Glaholt and Reingold (2009a)						x											
Glaholt and Reingold (2009b)						x											
Glaholt and Reingold (2011)						x		x									x
Glaholt and Reingold (2012)						x				x							
Glaholt et al. (2009)						x				x							
Glaholt et al. (2010)				x	x	x				x							
Glöckner and Herbold (2011)						x	x	x						x			
Glöckner et al. (2012)					x	x											
Horstmann et al. (2009)							x					x					
Hristova and Grinberg (2008)						x											
Huang and Kuo (2011)				x	x		x										
Kim et al. (2012)					x	x											
Knoepfle et al. (2009)									x								
Krajbich et al. (2010)						x		x						x			
Krajbich et al. (2012)						x		x						x			x
Krajbich and Rangel (2011)				x		x		x						x			
Kuo et al. (2009)						x											

Lim et al. (2011)															x
Lohse (1997)	x	x		x											x
Lohse and Johnson (1996)									x		x				
Meißner and Decker (2010)						x			x						
Meißner et al. (2012)						x			x						
Milosavljevic et al. (2012)	x												x	x	x
Mueller Loose and Orquin (2012)						x			x			x			x
Nittono & Wada (2009)						x									x
Navalpakkam et al. (2012)	x			x											x
Orquin et al. (2012)	x	x													x
Patalano et al. (2010)						x	x		x						
Pieters and Warlop (1999)					x	x								x	
									x						
Reisen et al. (2008)						x									
Renkewitz and Jahn (2012)						x	x								
Reutskaja et al. (2011)				x				x			x				x
Richardson et al. (2009)															x
Rosen and Rosenkoetter (1976)					x		x								
Russo (1977)								x		x					
Russo and Dosher (1983)								x			x		x		
Russo and Leclerc (1994)								x		x					
Russo and Rosen (1975)						x				x					
Schotter et al. (2010)						x									
Schotter et al. (2012)						x									
Selart et al. (2006)					x										
Shi et al. (in press)				x		x	x								
Shimojo et al. (2003)						x									x
Simion and Shimojo (2006)						x									
Simion and Shimojo (2007)						x									
Smead et al. (1981)												x			
Su et al. (2012)						x									
Sütterlin et al. (2008)				x		x									
Toubia et al. (2012)					x				x						
van Herpen and Trijp (2011)					x							x		x	
Van Raaij (1977)						x						x			
Visschers et al. (2010)			x		x										
Wedell and Senter (1997)						x		x							

With regard to transition patterns, Lohse and Johnson (1996) showed that more alternatives led to more attribute-wise transitions, whereas more attributes led to more alternative-wise transitions.

4.4.4. Presentation effects

A group of studies have examined the effects of presentation formats on attention by using either naturalistic product representations or information matrices. These studies have shown that product representations reduce the number of fixations (Mueller Loose & Orquin, 2012; Smead, Wilcox, & Wilkes, 1981; Van Raaij, 1977), lead to shorter fixation durations (Huang & Kuo, 2011), and different attributes being fixated (Huang & Kuo, 2011; Mueller Loose & Orquin, 2012; Van Raaij, 1977). Presentation effects have also been demonstrated at the attribute level using verbal versus pictorial attributes. Once fixated, verbal attributes produced longer fixation durations than pictorial attributes (van Herpen & Trijp, 2011). Presentation effects, furthermore, lead to down-stream effects on choice likelihood (Mueller Loose & Orquin, 2012). Presentation effects most likely stem from differences in surface size, saliency, as well as required processing time between verbal and pictorial information. The former is more demanding in terms of attention and working memory resources, which could explain the increase in fixations and the decrease in choice accuracy.

4.4.5. Decision difficulty

Decision difficulty is defined here as the difference in utility between alternatives, in that as the difference decreases, decision difficulty increases. Decision difficulty has been shown to increase the number of fixations (Fiedler & Glöckner, 2012; Glöckner & Herbold, 2011; Krajbich & Rangel, 2011; Krajbich et al., 2010, 2012), which is most likely a consequence of the higher demand on working memory. No effect of decision difficulty was found on the share of alternative- and attribute-wise transitions (Russo & Dosher, 1983).

4.4.6. Time pressure

Three studies have demonstrated the effect of time pressure on attention. The first found shorter fixation durations, fewer fixations to textual elements, and more attribute-wise transitions under high time pressure (Pieters & Warlop, 1999). Later studies confirmed the results regarding shorter fixation durations, and found that time pressure reduces the amount of information fixated (Reutskaja et al., 2011; van Herpen & Trijp, 2011), and increases down-stream effects of visual saliency on choice (Milosavljevic et al., 2012).

4.4.7. Distracters

Two studies have shown that different distracters can affect attention during decision making. In the presence of flash advertisements, Day et al. (2006) observed fewer fixations and shorter decision times, however no differences in decision accuracy. Day et al. (2009) manipulated music tempo and observed that a faster tempo increased alternative-wise transitions and decision accuracy, however had no effect on decision time or the percentage of information searched. The results are somewhat counterintuitive because one would expect distracters to increase the difficulty of the decision task, which should increase the number of fixations. One possible interpretation is that distracters increase arousal, which might affect the decision process.

4.5. Down-stream effects of attention on decision making

One of the difficulties in classifying down-stream effects of attention on decision making is distinguishing it from utility effects (i.e., that decision makers tend to fixate more often on high utility alternatives and attributes, see Section 4.3.2). Although many of the reviewed studies may have found down-stream effects, the lack of a proper control with regard to the utility effect strongly limits the number of studies that can corroborate this.

The interest in down-stream effects of attention on choice was sparked by the findings of Shimojo and colleagues on gaze duration effects (Shimojo et al., 2003). The authors argued that gaze allocation plays a causal role in preference formation, a claim which was later implemented in the attentional Drift Diffusion Model (Krajbich et al., 2010). The aDDM model incorporates the causality assumption in an evidence accumulation model, in which more fixations to an alternative predict increasing preferences and choice likelihood for that alternative. Applications of the aDDM have shown that modeling evidence accumulation through gaze allocation can accurately predict decision times as well as choices (Krajbich & Rangel, 2011; Krajbich et al., 2010, 2012). Although the findings from the aDDM studies are compelling, the simulations do not in themselves constitute a proof of a causal effect of gaze allocation on choice. Other processes, such as the utility effect, could have generated similar observations. One interesting observation by Krajbich et al. (2012), showed that the last fixation predicts choices in choice sets with a high decision difficulty, i.e. choice sets where the distance between price and product value is small. Because of the high decision difficulty, the last fixation is less likely to be driven by the utility effect.

In a more direct manipulation of attention using a gaze contingent display, Richardson, Spivey, and Hoover (2009) showed that interrupting participants while they fixated on the yes or no option for more than 500 ms biased decisions in favor of the last fixated option. This finding matches predictions by evidence accumulation models, however it does not preclude alternative process explanations. Lim, O'Doherty, and Rangel (2011) found a fixation-dependent relative value signal in the vmPFC and ventral striatum, which further supports both evidence accumulation and utility effect interpretations.

More direct examinations of the role of gaze allocation in preference formation stem from experiments which directly manipulate gaze duration. In the second experiment by Shimojo et al. (2003), gaze allocation was shown to have a causal effect on choices. The exposure effect on choice was later replicated by studies showing that alternatives that have been pre-exposed are more likely to be chosen (Bird et al., 2012; Nittono & Wada, 2009). However, these studies did not find a causal role of gaze allocation, but rather demonstrated a mere exposure effect independent of gaze allocation. Glaholt and Reingold (2009a) did not find an effect of pre-exposure on choice; however they found that pre-exposed alternatives had shorted dwell times. The same authors later demonstrated an effect of gaze duration on choice likelihood by applying a gaze contingent paradigm thereby dynamically controlling gaze duration to the alternatives (Glaholt & Reingold, 2011). Although these studies overall reject a strong interpretation of evidence accumulation assuming a causal role of gaze allocation on choice, they generally support a soft interpretation in accordance with a mere exposure effect (Zajonc, 1968).

Another body of observations stems from studies on bottom up processes. The studies show that attention capture by salient alternatives or attributes (Lohse, 1997; Milosavljevic et al., 2012; Navalpakkam et al., 2012; Orquin et al., 2012), position (Atalay et al., 2012; Chandon et al., 2009; Navalpakkam et al., 2012; Reutskaja et al., 2011), and surface size (Chandon et al., 2009; Lohse, 1997; Orquin et al., 2012), all result in increased choice likelihood for the fixated alternative. In all of these cases, the down-stream effects are clearly distinguishable from utility effects, because the former is due to stimulus-driven attention while the latter is due to goal-driven attention. These effects could, in principle, stem from soft evidence accumulation, in the sense that salient alternatives attract more fixations leading to a stronger exposure effect. However, a simpler explanation is that stimulus-driven attention capture diminishes nonattendance so that alternatives that capture attention are more likely to enter the consideration set and hence to be chosen, whereas alternatives that fail to capture attention fall victim to nonattendance.

Overall, the observations on down-stream effects of attention on choice lead to three conclusions: First of all, a strong interpretation of evidence accumulation, in which gaze allocation has a causal effect on choice as proposed by Shimojo and colleagues and later by Krajbich and colleagues, is rejected.

In more general terms, attention does, however, have a causal effect on preference formation, in accordance with the mere exposure effect. This effect has been demonstrated within decision trials by dynamically controlling gaze duration (Glaholt & Reingold, 2011; Richardson et al., 2009), which supports a soft interpretation of evidence accumulation.

Finally, attention capture by bottom up processes was shown to affect choice likelihood, not because fixating an alternative increases preference for the fixated alternative, as suggested by evidence accumulation models, but because not fixating the alternative excludes it from the consideration set.

Down-stream effects are therefore driven by two different processes: A soft evidence accumulation process, in accordance with mere exposure effects, leading to higher choice likelihood for longer exposed alternatives, and a bottom up attention capture process gatekeeping the alternatives entering the consideration set.

5. Discussion

5.1. Summary of results

The review identified and classified findings from studies on eye movements in decision making according to a conceptual framework of eye movements in similar tasks, such as visual search, problem solving, scene viewing, and reading.

At the super-ordinate level, the findings were categorized as pertaining to stimulus-driven attention, goal-oriented attention, attention and working memory, and down-stream effects of attention.

In relation to stimulus-driven attention, several observations were made, such as attention capture by visually salient stimuli, surface size increments, visual clutter, and position. The bottom up processes furthermore led to down-stream effect on choice, in that alternatives or attributes capturing attention were more likely to be chosen. As described in Section 2.2 (bottom up control), all of these effects have already been studied in vision and attention research, and were entirely predictable based on this literature. Thus, it is not surprising that bottom up attention capture influences eye movements in decision making. However, it is surprising that only the PCS model incorporates assumptions about bottom up attention capture, whereas all other decision theories either ignore bottom up processes or refer to these as exogenous processes.

With respect to goal-oriented attention, robust observations were made regarding the effect of task instructions, utility effect, heuristics, attention phases, and learning effects. These observations all relate to top down control of attention (Section 2.3), and indicate the same underlying principle: Decision makers preferentially direct attention to goal-relevant stimuli. The utility effect is a particularly strong indicator of the influence of goal-relevance, whereas attention phases and heuristics indicate the dynamic state of goal-relevance. Furthermore, the findings on learning effects demonstrate how attention to goal-relevant stimuli increases during the course of repeated decision tasks.

With regard to attention and working memory interactions, several findings emerged including: consideration sets, information complexity, pair-wise comparisons, presentation effects, decision difficulty, time pressures, and distracters. The general theme that unites these effects is that they all involve trade-offs between attention and working memory. A plausible explanation for nonattendance, the formation of consideration sets, and effects of information complexity, is that decision makers reduce maximal accuracy to lower the demands on attention and working memory. Attending to a large number of alternatives or attributes is demanding in terms of the number of fixations and items that decision makers need to encode in order to make an accurate choice.

Pair-wise comparisons are another example of how decision makers lower working memory demands. There is no reason why decision makers should not compare all alternatives or attributes simultaneously as it is prescribed in, for instance, process accounts of the weighted additive decision rule (Riedl et al., 2008). However, such a comparison would place a high demand on working memory. Making multiple pair-wise comparisons might increase the number of fixations needed to make a choice, which means that decision makers' trade-off working memory demands for more fixations. This supposition also indicates that fixations are, in processing terms, cheaper than working memory.

Presentation effects are one way to manipulate this trade-off. In this case, the same stimuli are presented in either verbal or pictorial forms. Presentation effects resemble findings from reading studies showing that increasing word difficulty leads to longer processing times. In decision tasks, presenting information in a format that is more demanding to process, leads to more and longer fixations and decreases choice accuracy due to, among other things, nonattendance. In other words, presentation effects increase demands on attention, and conceivably on working memory as well, which leads decision makers to trade-off accuracy for lower processing demands.

Decision difficulty is similar to presentation effects in that both manipulate processing demands. Although presentation effects primarily concern the amount of focal attention needed to process information, one possible interpretation of decision difficulty is that it increases working memory demands. According to this interpretation, decision makers increase the number of fixations to trade-off working memory demands for attention.

Time pressure is another interesting manipulation that most likely leads to greater working memory demands. One possible interpretation is that time pressure limits the total number of serial cognitive operations that can be performed within the task. Thus, decision makers must perform fewer and more complex operations (e.g., within-attribute comparisons).

Additionally, the review revealed down-stream effects of attention on decision making. In comparison to the utility effect in which alternatives that are more likely to be chosen receive more attention, down-stream effects indicate that increased attendance to an alternative increases the likelihood of it being chosen. The observations suggest two underlying processes behind down-stream effects: a soft evidence accumulation process, which leads to higher choice likelihood for longer exposed alternatives, consistent with the mere exposure effect, and a bottom up attention capture process reducing the likelihood of nonattendance, i.e. that the alternative is ignored in the decision process. The observations also showed that gaze allocation does not have a direct causal effect on preference formation, contrary to the predictions by the gaze cascade hypothesis (Shimojo et al., 2003) and the attentional Drift Diffusion Model (Krajbich et al., 2010).

5.2. Evaluation of decision theories

Although the reviewed decision theories differ greatly with regard to how they understand the decision process and the role of attention, they all share one trait: Each of the decision theories defends one or more inadequate assumptions about basic properties of eye movements and attention. An overview of the underlying assumptions, predictions and their evaluations is shown in Table 2.

Strong rational models make one prediction about attention: Decision makers must attend to all available information. This prediction is easily rejected based on the robust observations on nonattendance. Relaxed rational models, on the other hand, do not make any assumptions about attention per se, but suggest that incorporating fixation frequencies and nonattendance increase predictive validity. Observations of down-stream effects of attention on choice confirm this assumption. Comparing the strong and relaxed rational models begs the question of what exactly the strong rational model can provide in terms of process understanding or predictive validity. Although the relaxed rational models make no theoretical attempts to explain nonattendance or down-stream effects, nonetheless they take a large step in the right direction. The future development of relaxed rational

Table 2
Evaluation of decision theories and their predictions. Relevant section numbers in parentheses.

Rational models		
(1.1)	Information acquisition is complete and no information is ignored. All information is fixated. (Strong rational model)	*Rejected*. Findings on nonattendance falsify this tenet. (4.4.1; 4.4.3; 4.5)
(1.2)	Information acquisition is incomplete and attributes are discounted in the structural model based on the level of attendance. (Relaxed rational model)	*Confirmed*. Nonattendance has down-stream effects on decision making. (4.5)
Bounded rationality models		
(2.1)	The particular heuristic employed by the decision maker determines visual attention.	*Rejected*. Visual attention is driven both by bottom up and top down processes. (4.2; 4.3)
(2.2)	Each heuristic results in a particular distribution of attention.	*Confirmed*. Experiments manipulating heuristics confirm this. (4.3.3)
(2.3)	The underlying heuristic can be inferred from the distribution of attention.	*Not confirmed*. Attempts to classify heuristics based on attention are largely unsuccessful. (4.3.3)
Evidence accumulation models		
(3.1)	The fixation process is stochastic, and fixations are assigned to the alternatives in an alternating pattern.	*Rejected*. Task demands flexibly control allocation of fixations, alternating or not. (4.3)
(3.2)	Fixation patterns should not change over the course of the decision process because the fixation process is stochastic.	*Rejected*. Findings on attention phases falsify this. (4.3.4)
(3.3)	The last fixation should be shorter than the mean fixation duration because the fixation is interrupted when the threshold is reached.	*Confirmed*. The theoretical interpretation, however, assumes evidence accumulation. (4.3.4)
(3.4)	Fixation durations follow a fixed distribution given by the difference between the best and the worst alternative in the choice set.	*Rejected*. Fixation durations vary according to many factors such as attention phases (4.3.4), presentation effects (4.4.4), and time pressure (4.4.6).
(3.5)	The last fixation is to the chosen alternative.	*Confirmed*. Higher likelihood of fixating the chosen alternative during entire decision task. (4.3.2)
(3.6)	A choice bias exists in favor of the alternatives fixated first and last because these alternatives have accumulated more evidence.	*Confirmed*. The theoretical interpretation assumes evidence accumulation. (4.3.2; 4.5)
(3.7)	The accumulated evidence determines choices.	*Not confirmed*. See section on down-stream effects. (4.5)
(3.8)	Any process that exogenously interferes with the accumulation of evidence toward an alternative will bias the decision in favor of that alternative.	*Confirmed*. Bottom up attention capture can, for instance, affect choices. (4.5)
(3.9)	The information sampling needed to reach a decision increases as options become more similar.	*Confirmed*. See section on decision difficulty. (4.4.5)
Parallel constraint satisfaction models		
(4.1)	Information acquisition consists mainly of screening of information which is reflected in an even distribution of single fixation durations.	*Rejected*. Fixation durations change during the decision process. See section on utility effect (4.3.2)
(4.2)	The feature currently highlighted in the decision process, such as the favored alternative or most important attribute, receives attention.	*Confirmed*. See section on preferential looking particularly the gaze cascade. (4.3.2)
(4.3)	The information sampling needed to reach a decision increases as alternatives become more similar which reflects the difficulty of maximizing coherence.	*Confirmed*. See section on decision difficulty. (4.4.5)
(4.4)	Salient alternatives will initially attract more attention and are, ceteris paribus, more likely of being chosen.	*Confirmed*. See section on bottom up effects (4.2) and section on down-stream effects (4.5)

models would benefit greatly from increased understanding of the processes behind nonattendance, and the precise circumstances under which attention leads to down-stream effects.

Bounded rationality models make three assumptions about the role of attention: that the heuristic determines attention, that each heuristic results in a distinct pattern of attention, and that heuristics can be identified from patterns of attention. A strong interpretation of the first prediction was rejected. Although heuristics affect the distribution of attention, they are not the only factor doing so. Furthermore, it is highly questionable whether decision makers actually use heuristics in the form and to the extent specified by the literature. A group of experiments studied heuristics by instructing participants in the use of certain strategies. These studies showed that different heuristics resulted in different distributions of attention, thereby confirming the second prediction. The third prediction, that heuristics can be identified based on the distribution of attention, was neither confirmed nor rejected. Heuristics can seemingly be identified when participants have been instructed in their use; however other studies remain somewhat ambiguous.

One future direction for research in bounded rationality would be to develop new and more advanced process measures that are able to substitute the more traditional metrics derived from Elementary Information Processes (Payne et al., 1988). Another direction would be to relax the definition of heuristics away from strict process descriptions. Although eye movements show no indications of heuristics in a strict sense, they do reveal several processes that map onto discrete steps in heuristic process descriptions, such as comparisons, eliminations, weighting, trade-offs, process phases etc. It is important to note that decision makers do not follow a clearly defined process path, but rather circle back and forth between different visual operations. Therefore, a more accurate account of heuristics would need to reflect the stochastic nature of these operations.

Evidence accumulation models generated the most precise, and therefore testable, predictions regarding attention in decision making. Regarding the distribution of attention, the model assumes that the fixation process is stochastic and that fixations alternate between alternatives. Although the alternation assumption is a priori true for two-alternative choice sets, in which there are no other options than to alternate between the two alternatives, the statement about a stochastic fixation process could be problematic. In general terms the statement is rejected because eye movements in decision making are driven by processes, such as top down and bottom up control. Although it may be useful to model eye movements as stochastic rather than deterministically, it should not lead to the conclusion that fixations are evenly distributed.

The prediction that fixation patterns and durations do not change during the decision task was rejected, based on observations of attention phases. The theory also predicts that the last fixation prior to the choice should be to the chosen alternative, and that the fixation should be shorter because it is interrupted when the evidence accumulation reaches a threshold. Both predictions were confirmed, however the interpretation rests on another assumption, i.e. evidence accumulation. Although a strong interpretation of evidence accumulation was rejected, a soft interpretation, in accordance with the mere exposure effect, was confirmed by the literature. However, it is questionable to what extent soft evidence accumulation affects decision making, apart from experimental setups manipulating exposure or gaze duration.

The prediction that exogenous effects on attention bias decision making was confirmed in general terms as down-stream effects caused by bottom up attention capture. Conclusively, the theory predicts that choice sets with highly similar alternatives require more fixations to reach a decision because of a slower evidence accumulation process. This prediction was confirmed, although another plausible explanation is that difficult decisions are more demanding in terms of working memory, which also increases the number of fixations. Overall, the model does not adequately describe eye movements in decision making, but fails to recognize important aspects of eye movement control, such as bottom up and top down processes, and the authors have also commented on this issue (Krajbich et al., 2012; Rangel, 2009). Future developments of the aDDM should, therefore, attempt to incorporate a more realistic understanding of eye movement processes. A better understanding of information extraction and encoding during fixations would also help to answer a pertinent question: does evidence accumulation actually occur in decision tasks without direct gaze manipulations?

Along with the evaluation of the aDDM, it was also possible to evaluate the Decision Field Theory. The two evidence accumulation models share predictions (3.2), (3.7), and (3.9), but differ with regard to their assumptions about the distribution of attention. The Decision Field Theory predicts that attention will follow a stochastic distribution, with a mean value equal to the importance of each alternative, i.e. assuming top down control. Although this prediction was not directly confirmed, the findings on the utility effect indicate that attention is distributed according to the importance of alternatives. As summarized above: prediction (3.2) about the stability of fixation patterns was rejected, prediction (3.7) about evidence accumulation was partially confirmed as soft evidence accumulation, and prediction (3.9) about increasing information sampling due to decision difficulty was confirmed. Overall, the evidence in favor of Decision Field Theory is meager, and moreover the confirmed predictions are similar to those made by parallel constraint satisfaction models.

Parallel constraint satisfaction (PCS) models make four predictions about attention during decision making: that information acquisition consists mainly of information screening reflected in an even distribution of single fixation durations, that decision makers attend to the alternatives or attributes that are currently highlighted in the decision process, that the number of fixations will increase as the alternatives become more similar, and that salient alternatives will attract more attention and are, everything else equal, more likely of being chosen. The first prediction was rejected based on evidence indicating differential processing of information due to task relevance. The second prediction was confirmed by findings demonstrating a gaze cascade effect. According to the PCS models, the gaze cascade reveals a process of convergence toward the chosen or favored alternative. As the decision maker becomes more internally coherent regarding which alternative to choose, the activation of the alternative increases, which leads to a higher fixation likelihood for that alternative. The PCS account constitutes an interesting alternative to the gaze cascade hypothesis by Shimojo et al. (2003), which has been rejected by several studies (see Section 4.3.2 on utility effect and Section 4.5 on down-stream effects).

The third prediction concerning decision difficulty was confirmed. Three competing interpretations therefore exist for the effect of decision difficulty on attention: lower evidence accumulation rates, slower convergence on favored alternatives, and that decision difficulty increases working memory demands, thereby increasing fixations.

The fourth prediction concerning bottom up attention capture and consequences for down-stream effects was also confirmed, although it remains uncertain how this will be implemented in the PCS model as no studies have examined PCS predictions on bottom up processes. Overall, PCS models make few but generally correct predictions about attention in decision making; therefore constituting itself as an interesting location for gaining a better understanding of the relation between attention and choice. Future developments of PCS models would benefit from more specific predictions regarding the role of attention in the construction of the decision problem.

5.3. Conclusions

An important conclusion of this review is that attention plays an active role in constructing decisions. Contrary to the assumption of passive information acquisition, it has been shown how attention is not only driven by information demands, but also by bottom up processes, and interactions with working memory. Furthermore, attention leads to down-stream effects on decision making. Thus, the final decision emerges, not as a simple application of preferences and heuristics to choice stimuli but, through complex interactions among stimuli, attention processes, working memory, and preferences. Therefore, it is only fair to conclude that attention plays a constructive role in decision making.

It can also be deduced, that the cognitive processes driving eye movements during decision making are not in any consequential way different from those in similar tasks. Attention processes, such as top down or bottom up attention capture or learning effects on fixations, play similar and important roles in decision making, problem solving, visual search, scene viewing, and so forth. Despite the high consistency and predictability of attention and eye movements, the evaluated decision theories only partially accounted for these processes. That being said, all of the theories, with exception of the strong rational model, made several correct predictions about the role of visual attention during decision making. This suggests that, although the decision theories supposedly aim for parsimony, their primary concern has been with a subset of decision tasks. One can easily see how each theoretical paradigm seeks to test its own hypotheses so that, for instance, expectations about top down control lead to neglecting bottom up control. Existing decision theories have come a long way in understanding several aspects concerning the role of attention in decision making; however, a better integration of these insights is needed. Future theory development in decision making should focus on integrating the findings across different decision tasks and creating a stronger integration with vision and attention research.

To summarize, any theory that aims to describe decision making, in which visual information play a central role, must reflect the following assumptions:

- Eye movements in decision making are partially driven by task demands, i.e. by describing the attention and decision processes as segregated process streams sees the former being dependent on the latter.
- Eye movements in decision making are partially driven by stimulus properties that bias information uptake in favor of visually salient stimuli.
- Eye movements do not have a causal effect on preference formation; however through properties inherent to the visual system, such as stimulus-driven attention, eye movements do lead to down-stream effects on decision making.
- Decision makers optimize eye movements to reduce the demand on working memory and, in some cases, to reduce the number of fixations and length of saccades needed to complete the decision task.
- The drivers of eye movements in decision making change dynamically within tasks, such as in attention phases, and across time, such as through learning effects.

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