Review of Psychology,
2014, Vol. 21, No. 1, 3-15 UDC 159.9

Neurocognitive bases of future oriented cognition

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In recent decades, the importance of future oriented processing across different cognitive domains and time-scales has been recognized. The underlying neural mechanisms of these processes have been explored, resulting in findings that have associated predictive processing with the functioning of different brain regions and neural systems. However, although individual incarnations of future oriented processing within cognitive domains have been meticulously investigated and described, a unified approach that would summarize and compare such processes across domains is still lacking. The present review succinctly describes future oriented cognitive processes across different psychological domains and discusses their underlying neural mechanisms. In doing so, it examines the manifestations and beneficial aspects of future orientation in perception, motor behavior, attention, and higher order cognition as well as in emotional and motivational processing. In addition, the importance of future orientation for self-referential processing is evaluated and novel insights are offered into some of the critical questions that remain to be elucidated in future research within this field.

Key words: future thinking, memory, planning, prediction, prospection

We live in the here and now, at a certain location and in a specific moment of time which provides our minds with ample stimulation that must be processed in order to survive. In addition to being determined by available external stimuli, our behavior is often driven by our current internal states, visceral needs and emotions. Thus, for purely evolutionary reasons, it is beneficial to focus on the present and remain vigilant for relevant information and events that we continuously encounter or experience. Furthermore, being mindful, committed, and present in the current moment is associated with numerous psychological benefits that include increased psychological well-being and positive emotional states (Brown & Ryan, 2003; Zimbardo & Boyd, 1999). However, despite its beneficial consequences, it is hard to be consistently mindful because our cognitive capacities are limited and the encountered information often remain insufficiently processed. People have finite working memory (Conway & Engle, 1996) and attentional (Dukas, 2004) resources, continuously fail to notice numerous changes and events surrounding them (Rensink, O'Regan, & Clark, 1997; Simons & Rensink, 2005), and easily get depleted by everyday decisions as well as acts of self-regulation (Baumeister, Bratslavsky, Muraven, & Tice, 1998). Therefore, our capacity for managing present oriented information and behaviors is highly constrained. Although this may suggest that all our cognitive resources should be maximally engaged in more efficient processing of present oriented tasks, it has been demonstrated that our minds often engage in various types of mental time travel, in thinking about the past (retrospection) and contemplating the future (prospection; Suddendorf & Corballis, 1997).

While the necessity and the benefits of memory and past oriented processing are somewhat self-explanatory, the advantages of mental time travel towards the future may not be immediately obvious. We are all aware that our daily stream of consciousness includes a certain amount of planning and preparation for the future, and that our emotional states are often oriented towards anticipated events. However, these examples of future considerations represent a very small fraction of cognitive processes and phenomena oriented towards the future. In reality, our brains and minds are constantly focused on the future (Andrews-Hanna, Reidler, Huang, & Buckner, 2010) and this provides us with numerous benefits and advantages. The present manuscript presents a review of different instantiations of future oriented cognition and describes their underlying information processing and neural mechanisms. Therein, a very broad

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Acknowledgements: This work has been supported by the European project COST ISCH Action TD0904 "Time In MEntaL activitY: theoretical, behavioral, bioimaging and clinical perspectives (TIMELY)".

conceptualization of future oriented cognition is adopted which reflects various processes that incorporate explicit or implicit considerations of the future states of the body or the environment (Bubic, von Cramon, & Schubotz, 2010). In doing so, we will not discuss the differences in the use of various terms often found within this field, such as expectations, prediction, anticipation, or others, as these have been addressed elsewhere (Bubic et al., 2010). However, it has to be emphasized that such differences are relevant as the use of different terms across diverse domains hinders the attempts of bringing various approaches together and unifying the acquired knowledge within the field. In addition, we will not present arguments for different factors that may be used for developing a more systematic taxonomy of future oriented processes, such as the type (probabilistic vs. deterministic), specificity (high vs. low), level (explicit vs. implicit), or timescale (short vs. long-term) of predictive processes. Instead, in the following sections we will review different instantiations of future oriented processes across the different domains that form the structure of the present manuscript.

VARIOUS MANIFESTATIONS OF FUTURE ORIENTED COGNITION

Future oriented cognition refers to a wide range of processes encountered within different mental domains. On the one hand, these include very basic predictive processes encountered within the sensory and motor domains (Bar, 2007; Butz, Sigaud, & Gérard, 2003; LaBerge, 1995), as well as more elaborate explicit mental constructions of possible personal future scenarios (episodic future thinking) investigated within the mental time travel domain (Suddendorf & Corballis, 1997). Regardless of the characteristics of specific future oriented processes, they are all associated with a number of benefits, such as an increase in accuracy and speed of information processing, structuring of more coherent environmental representations, more efficient use of cognitive resources, and improved information seeking (Butz & Pezzulo, 2008; Kveraga, Ghuman, & Bar, 2007; LaBerge, 1995; Llinás, 2002). Given these benefits, it is not surprising that the relevance of predictive processes within the perceptual, attentional, and motor domains was already recognized in the 19th century (James, 1890; LaBerge, 1995). In addition, the relevance of expectations for learning, motivation, and behavior in general was also recognized during the early decades of psychological research (Bandura, 1977; Rosenthal & Jacobson, 1968; Tolman, 1948).

Recent decades have seen a revival of interest in predictive processing within all the aforementioned domains. Specifically, when studying future oriented cognition in these areas, researchers employ a wide range of paradigms from the domains such as visual recognition, sequential processing, motor control, mental state reasoning, declarative memory, and social cognition, to name a few. Typically, this does not imply that researchers always develop specific paradigms for investigating individuals' expectations, but instead utilize numerous approaches already developed within the field for studying the relevance of future orientation therein. In addition, in recent years researchers have begun to explore individual differences in personal tendencies related to the explicit consideration of future outcomes and consequences during decision making. Furthermore, a novel direction of research was established within the field of mental time travel that studies prospection, an ability to simulate the expected personal future, albeit in a shortened and more abstract manner when compared with real events (Gilbert & Wilson, 2007). These studies have indicated an intricate and inseparable relationship between future oriented cognition, memory, and imagination (Mullally & Maguire, 2013; Schacter, Addis, & Buckner, 2007). Furthermore, the relevance of future oriented processing for spontaneous, default mode processing has been established (Buckner, 2007).

In the next sections, we discuss these different cognitive future oriented processes as well as their underlying neural mechanisms in more detail. We present arguments to showcase the relevance of future orientation across different domains. First, we discuss the mechanisms underlying prediction in the sensory-motor and attentional, as well as higher cognitive domains. Next, the relevance of considering the future for motivation and goal-directed behavior will be described. Finally, we will present findings that demonstrate the importance of predictive processes in prospection, social, and self-referential processing, while discussing their similarities to other, seemingly unrelated phenomena such as creativity and imagination. Within each domain we first present behavioral findings and the insights that have been gained with respect to the neural underpinnings of the phenomena of interest (for an overview, please refer to Table 1 and Figure 1). Finally, we describe the advantages of future oriented cognition and discuss the benefits of considering what lies ahead for our judgment, decision making, and psychological well-being.

PREDICTION IN SENSORY-MOTOR AND ATTENTIONAL DOMAINS

Studying prediction in sensory-motor and attentional domains has a very long tradition, as the early psychological experiments conducted in 19th and 20th century by Wundt, Lange, and James demonstrated how perceptual expectations may shorten recognition time and guide actions (LaBerge, 1995). In addition, anticipatory processing within the motor system was addressed in the 19th century within the so-called ideomotor principle (James, 1890), as well as by von Helmholtz who speculated about the relevance of expected action outcomes for subsequent perception (Bays & Wolpert, 2008). Subsequently, these ideas were further advanced in the 1950s by von Holst, Mittelstaedt, and Sperry who experimentally demonstrated the role of motor-to-sensory feedback in controlling behavior (Wolpert & Flanagan, 2001). Ever since then, the role of anticipation has been explored within the motor system and different sensory domains, revealing the existence of numerous instantiations of such processing that take place on different temporal scales and are based on different types of information.

For example, in a classical motion perception task that requires a judgment of time to collision, we make predictions about the future motion of involved objects even when we are not explicitly required to do so (Lin, Franconeri, & Enns, 2008; Tresilian, 1999). In addition, examples of predictive processing in vision include the representational momentum (Kerzel, 2005) and the flash-lag effect (Nijhawan, 1997), although some more complex explanations of these phenomena have been suggested (Eagleman & Sejnowski, 2000; Whitney & Murakami, 1998). Furthermore, there is evidence that visual search involves a certain degree of predictive processing, and that identifying expected events within the visual display is faster and more accurate when compared to unexpected events (Enns & Lleras, 2008). When considering the types of contexts that trigger predictive processing within sensory systems, it has been determined that expectations may be formulated in situations where a stimulus is presented in isolation (Bar, 2007) or a contextually rich environment (Bar, 2004). In these cases, perceptual expectations are grounded in long-term memory that allows us to connect the available input with previous experiences. For example, a global shape of an object can trigger the recollection of previously encountered similar stimuli and facilitate its recognition even before the more detailed, identity revealing information become available (Bar, 2003, 2007).

In addition, formulating visual expectations may be based on context frames, namely structures that provide visuospatial and abstract contextual associations and, consequently, facilitate object perception (Bar, 2004; Fenske, Aminoff, Gronau, & Bar, 2006). In this context, it is important to note that facilitated object and pattern recognition have also been demonstrated in situations where expertise results in strengthened associative processing among features or objects (Cheung & Bar, 2012), suggesting a close relation between prediction and expertise. Specifically, experts typically have more elaborative knowledge structures that enable predictions about stimulus input and automatically direct attention towards the most important stimulus and object features, thus enabling more efficient pattern recognition (Bilalić, Langner, Erb, & Grodd, 2010; Bilalić, Turella, Campitelli, Erb, & Grodd, 2012; Cheung & Bar, 2012).

While the predictive process in the aforementioned cases is initialized only after stimulus presentation, in other situations expectations may be formulated prior to the appearance of the stimulus itself when triggered by task instructions (Carlsson, Petrovic, Skare, Petersson, & Ingvar, 2000; Simmons, Matthews, Stein, & Paulus, 2004) or by the stimuli preceding the critical event (Schubotz & von Cramon, 2001). Specifically, predictability of the incoming stimuli may be afforded by regular relations of different complexity between events (Näätänen, Tervaniemi, Sussman, Paavilainen, & Winkler, 2001; Opitz & Friederici, 2007; Sutton, Braren, Zubin, & John, 1965), as demonstrated by numerous studies within the perceptual domain (Remillard, 2003; Schubotz, 2007; Schubotz & von Cramon, 2001, 2002). For example, it has been show that learning triggered by short-term exposure to non-random patterns leads to predictive processing within subsequent pattern repetitions. Interestingly, such predictive strategies may be employed even when random input is presented, thus reflecting the brain's attempts to extract an orderly pattern (Schubotz, 2007; Schubotz & von Cramon, 2002). The relevance of prediction for efficient processing of sequentially ordered stimuli is even more evident in the motor domain (Clegg, DiGirolamo, & Keele, 1998; Keele, Ivry, Mayr, Hazeltine, & Heuer, 2003). In addition, within this domain it has often been argued that prediction constitutes a necessary prerequisite for action because all behavior is contingent on formulating response-related anticipations (Kunde, Elsner, & Kiesel, 2007). Numerous studies have indeed shown that action representations include their anticipated effects as well as the underlying intentions (Kerzel, 2005; Schütz-Bosbach & Prinz, 2007). In addition, prediction has been associated with other forms of motor imagery, action understanding (Jeannerod, 2001; Kilner, Friston, & Frith, 2007) as well as motor control (Wolpert & Flanagan, 2001). Similar to the perceptual domain, a relevance of expertise for predictive processes in action understanding has also been established (Balser et al., 2014).

With regard to the neural implementation of prediction, the motor system has thus far received a lot of attention. Based on the results showing the involvement of the motor system not only in motor behavior, but also in perceptual sequencing, it has been suggested that prediction in the motor domain and some forms of perceptual expectations may reflect common underlying neural mechanisms (Schubotz, 2007). In this account, predictive sequencing across domains is afforded by the so-called internal models that mimic the dynamics of relevant body or environmental states, thus providing bases for anticipatory processing. The motor system would represent an ideal candidate for formulating such models and simulating the expected events, regardless of their domain of origin (Jeannerod, 2001; Wolpert & Flanagan, 2001). In addition, orbitofrontal and medial prefrontal cortices have been related to other forms of perceptual anticipatory processing. Specifically, it has been argued that the recognition of visual objects presented in isolation is aided by the process of rapid transmission of crude object information to the orbitofrontal cortex. Here, predictions are formulated and sent back to the visual cortices in order to facilitate the processing of other object features (Bar, 2003, 2007). In a comparable fashion, it has been suggested that context-based expectations are formulated within the medial prefrontal cortex, and then communicated to the connecting parahippocampal and retrosplenial cortices (Bar, 2004; Bar & Aminoff, 2003). In addition, the relevance of insula engagement was established with respect to expectations regarding painful sensory stimuli (Ploghaus et al., 1999). Finally, while Gómez, Vaquero, and Marrufo (2004) suggested that the frontomedial cortex may be critical for initiating perception and action preparation by recruiting specific sensory (and motor) cortices needed for subsequent processing, Brunia (1999) argued for the relevance of the prefrontal cortex in organizing anticipatory behavior in general.

However, when discussing the neural correlates of predictive processing it is important to highlight that these encompass more brain regions than those formulating specific predictions. As such expectations need to be communicated to all the relevant brain systems, further processing is potentially implemented though changes in connectivity across brain regions (O'Reilly, Mesulam, & Nobre, 2008) or long-range phase synchronization (Gross et al., 2006). Once communicated, expectations modulate the activity within the sensory cortices that later process the anticipated events. For example, prediction is associated with changes of neuronal threshold in sensory cortices (Gómez et al., 2004) as well as the suppression of specific brain rhythms (Bastiaansen & Brunia, 2001), and the appearance of particular event-related anticipatory components, such as stimulus preceding negativity, contingent negative variation, or the readiness potential (Brunia, 1999; Praamstra, Kourtis, Kwok, & Oostenveld, 2006), as measured using electroencephalography (EEG).

Interestingly, it has been suggested that anticipatory and actual somatosensory stimulation engage the same somatosensory network (Carlsson et al., 2000), indicating that expectations indeed preactivate and facilitate the relevant sensory cortex that will later process that particular stimulus (LaBerge, 1995). Finally, it is important to note that numerous effects related to anticipatory processing greatly resemble the classical effects of attention that also include facilitated processing of attended, similar to expected, stimuli (Corbetta & Shulman, 2002; Hopfinger, Buonocore, & Mangun, 2000). However, although expectations and attention often coincide and may interact within different contexts, it is important not to confuse the two processes as they also differ in numerous ways. For instance, while expectations are associated with an attenuation of neural responses, attentional effects are typically characterized by enhanced processing of relevant stimuli (Summerfield & Egner, 2009).

Summarizing the available findings, it is important to emphasize the relevance of future orientation in both motor and sensory domains. As mentioned earlier, predictive processes have been established as crucial for action understanding and execution, leading to suggestions that the motor system should be viewed as central for simulating expected events across different domains (Jeannerod, 2001; Schubotz, 2007; Wolpert & Flanagan, 2001). With respect to the sensory domain, it has been suggested that perception in general may be conceptualized as constituting three cycles: activate (feedforward sweep that carries information from the peripheral organs), predict (feedback sweep that carries information from higher to lower regions in the sensory hierarchy), and confirm (stable state of resonance that is realized after matching predictions with the incoming information; Enns & Lleras, 2008). Such an account incorporates prediction as an inherent part of perceptual processing, and is in line with other accounts that have posited predictive processing as a fundamental mechanism underlying our perception, cognition, and behavior in general (Friston & Stephan, 2007; Pezzulo, 2008).

THE RELEVANCE OF FUTURE ORIENTATION FOR HIGHER COGNITION, MOTIVATION AND GOAL-DIRECTED BEHAVIOR

The importance of future oriented processes for higher cognition was first recognized within the domain of learning, when Edward Tolman (1932) suggested that learning is contingent on non-behaviorist processes such as expectations and beliefs. He introduced the idea of purpose into learning and behavior in general, and paved a way for modern theories of motivation. Specifically, although motivational and emotional processes may seem to represent psychological domains grounded in the present, the regulation of our behavior is strongly contingent on how we represent our future. Hence, it has long been recognized that self-regulatory processing depends on our self-efficacy beliefs which are based on previous experiences and current appraisal, as well as our considerations of future options (Bandura, 1977; Bandura, Barbaranelli, Caprara, & Pastorelli, 2001). Such views were further expanded, and the relevance of future expectations for motivation was widely explored among various expectancy-based theories (Atkinson, 1964; Wigfield & Eccles, 2000) as well as theories that have related such predictions with individuals' feelings of control (Rotter, 1966; Weiner, 1985). These accounts emphasize that our predicted success in a task determines whether or not we will be motivated to engage in a certain behavior, while our expectations depend on how much we feel in control of our failures and successes. Therefore, our current and previous experiences shape the perceived quality and likelihood of potential outcomes which, together with the value placed on each of them, determine our motivation for action (Hall & Fong, 2007).

Furthermore, one of the core components of motivated and goal-directed behavior includes the formulation of goals (Covington, 2000; Nicholls, 1984; Schunk, 1990) and implementation intentions (Gollwitzer, 1999). Once formulated, goals are easier to accomplish if we make an explicit plan and formulate an organized method for action in advance (Friedman & Scholnick, 1997). This includes a very complex set of operations that unite various cognitive, emotional, and motivational processes brought together in order to accomplish something envisioned for the future (Morris & Ward, 2004). Such processing is highly interconnected with motivational and self-regulatory processes, and is also related to other higher cognitive functions such as problem solving (Baker et al., 1996), prospective memory (Winograd, 1988), judgment, and decision making.

However, developing a plan is not a guarantee of its success, and accomplishing our plans and goals typically requires a certain degree of self-regulation that is, as mentioned earlier, strongly connected to our representations of future outcomes (Bandura, 1977; Bandura et al., 2001). For example, it has been argued that people exercise their self-control through anticipated guilt in situations where current temptations pose a threat to their long-term goals and wanted future outcomes (Baumeister, Stillwell, & Heatherton, 1995). In addition, it has been shown that having positive expectations in relation to our goals is associated with higher investments of energy and efforts, as well as more successful performance (Oettingen & Mayer, 2002). However, it is important to distinguish between having specific positive expectations and ungrounded positive fantasies, as the later type of processing is far less beneficial to individuals' performance (Oettingen, 2012). Also, it is important to recognize that our expectations include not only cognitive representations of potential future events, but also the relevant emotional valuations of such events. And, although it has been shown that our predictions of emotional outcomes are associated with numerous biases and errors (Gilbert, Gill, & Wilson, 2002; Gilbert & Wilson, 2009; Loewenstein, O'Donoghue, & Rabin, 2003), they are nevertheless crucial for directing our behavior and choosing our future goals.

Keeping all that in mind, it is possible to conclude that pure expectancy judgments based on individuals' experiences and performance history are highly related to their intentions and behavior (Bandura, 1977; Maddux, 1999; Scheier & Carver, 1992; Taylor & Brown, 1988) and that future orientation represents a very significant factor in human motivation and self-regulation. In order to engage in goal-directed behavior we need to be able to envision the future and its potential outcomes. In the course of this activity, we form different types of explicit and implicit predictions, such as self-efficacy, outcome, and general or generalized expectations (Oettingen & Mayer, 2002) that are all based on some form of previous experience. Such representations of the future influence our judgments, decisions, and current behavior, and allow us to transcend the here and now. However, as will be shown in the next sections, the manner in which we construe our personal future is much more complex and far-reaching as it represents one of the key processes that define who we are.

Before discussing this topic in more detail, it is important to review one additional field of study relevant to future orientation and higher cognitive processes. Specifically, with regard to the influence of future orientation on decision making, in recent years investigators have explored the importance of individual differences related to the way we consider different temporal directions. It has been argued that individuals differ with respect to their time perspective, namely the manner in which they typically assign the flow of personal experiences to temporal categories (Zimbardo & Boyd, 1999). We build different temporal and cognitive frames that determine how we process, encode, and recall the relevant information, thus influencing our judgments and decisions. In some situations, it is useful to base our judgments on recollected experiences, while in others it may be important to be fully focused on the past or to consider what might occur in the future.

Although it has been suggested that individuals should make their judgments in a balanced and flexible manner, based on the contextually appropriate time frame, most people are typically biased towards one of these time frames (Strathman, Boninger, Gleicher, & Baker, 1994; Zimbardo & Boyd, 1999). Among these, the relevance of predominant future orientation and the characteristics of individuals who are willing to base their current decisions on the expected future outcomes have been widely explored. For instance, higher future orientation has been related to responsible health behaviors (Joireman, Shaffer, Balliet, & Strathman, 2012), higher environmental awareness (Joireman, Lasane, Bennett, Richards, & Solaimani, 2001), lower aggression (Moore & Dahlen, 2008), and lower likelihood of procrastinating during learning (Specter & Ferrari, 2000). Furthermore, consideration of future consequences has been associated with effort and persistence (Joireman, Balliet, Sprott, Spangenberg, & Schultz, 2008), a finding that resonates with previously described motivational accounts that emphasize the relevance of expectancies for goal-directed behavior.

Finally, consideration of future consequences has also been related to social cognition and behavior. For instance, it has been shown that a more pronounced future orientation is related to higher organizational commitment and more cooperative behaviors among individuals and groups (Joireman, Daniels, George-Falvy, & Kamdar, 2006; Wolf et al., 2009). This is in line with findings showing the influence of time perception on the pursuit of social goals (Carstensen, Isaacowitz, & Charles, 1999) and suggestions emphasizing the importance of prediction for social cognition (Brown & Brüne, 2012). It is noteworthy that the interest in the relevance of future oriented cognition for social information processing is now growing given that the study of interpersonal expectancy effects represents one of the historically most relevant research domains within the field of psychology (Rosenthal & Jacobson, 1968), as it demonstrated the manner in which our expectations of other people may influence our behavior towards them, as well as their own behavior and future outcomes. Our implicit and explicit representations of the future therefore influence not merely our thoughts and actions, but also that of those around us. And, similar to the previously discussed motor and perceptual domains, the association between future orientation and expertise has also been revealed with respect to higher cognitive and social processes (Boorman, O'Doherty, Adolphs, & Rangel, 2013).

When discussing the neural underpinnings of future oriented processing within higher cognitive, emotional, and motivational processes, it is important to note that these functions have generally proven to be too complex for straightforward neuroscientific explorations. Given such complexity, it is not surprising that planning engages numerous brain regions, among which the prefrontal cortex is typically recognized as the key, albeit not sole, region enabling such processing (Fuster, 2008; Miller & Cohen, 2001; Ruby, Sirigu, & Decety, 2002). The relevance of the prefrontal cortex, namely its ventromedial portions, has also been established for the affective reactions (promotions) associated with future events that constitute an important part of predictions that are crucial for goal-directed behavior (Bechara & Damasio, 2005; Gilbert & Wilson, 2009). In addition, emotional processing has been associated with the engagement of the amygdala and the anterior cingulate cortex (Ueda et al., 2003), while the relevance of the basal ganglia, and especially the ventral striatum, has been established for motivational and reward processing (Knutson & Cooper, 2006; Schultz & Dickinson, 2000). Furthermore, prefrontal engagement has also been associated with individual differences in the dominance of future, when compared to present or past orientation, together with the portions of the parietal cortex and the cerebellum (Wittmann et al., 2011).

Overall, this section presented numerous examples of how expectations influence our goal selection and engagement in different settings. They often determine how we cognitively construe the available information, whether we approach or avoid certain behaviors and how we organize and conduct our actions. All of this indicates that our views of the future often shape our evaluations of the present and the behaviors we choose for the future. Thus, it can be concluded that future orientation represents an inherent part of our judgments, decisions, emotions, and motivations. However, although a lot is known about the cognitive mechanisms underlying the influence of expectations on specific aspects of our thoughts and behaviors, there are still numerous unknowns within each of these specific areas. Even more importantly, a unified view of the role of future orientation in decision making and goal-directed behavior is yet to be developed. In addition, the neural implementation of future orientation in this context represents another area that needs to be advanced in future studies.

PROSPECTION

In comparison to most topics within the broadly conceptualized domain of future-oriented cognition which stem from well-established theoretical and empirical foundations, investigations on prospection are, relatively speaking, still in the nascent phase. Our ability to contemplate future events is formally investigated in psychology and the neurosciences under umbrella terms such as prospection, future thinking, mental time travel, foresight, imagination, prospective cognition, forecasting, and constructive simulation. To date, the empirical focus on prospection has been primarily limited to the personal, episodic, or autobiographical realm.

Behavioral evidence demonstrates that there are strong parallels between the subjective experience that accompanies past and future thinking (D'Argembeau & Van der Linden, 2004, 2012). Positive events are associated with a greater level of phenomenological intensity than negative events in both prospection and retrospection. The same is true of the subjective experience of temporally close events in the past and future, which are also associated with more sensorial and contextual detail, relative to that of temporally distant events. This resonates with findings indicating that more distant future events are somewhat more abstract than those of more proximal events (Liberman & Trope, 2008) and that our imagined future selves resemble other people more than our present selves (Pronin, Olivola, & Kennedy, 2008). Not surprisingly then, the manner in which we value distant outcomes and rewards is quite different when compared to proximal ones (Caruso, Gilbert, & Wilson, 2008; Soman et al., 2005). When discussing the discrepancies between contemplated events in one's personal past and future, one of the central differences is that representations of future events are associated with less detail than that of past events. This happens although our visual–spatial constructive abilities are less burdened when remembering sensory details about events in our past compared to imagining events that could take place in the future (D'Argembeau, Ortoleva, Jumentier, & Van der Linden, 2010). In addition, we interpret future events differently than past events, in that future behaviors are viewed as more intentional than the past ones (Burns, Caruso, & Bartels, 2012). Neuroscientific evidence has consistently revealed that the brain regions that are active when we contemplate personal events in the near or distant future strongly overlap with those that are engaged when we ponder our episodic or autobiographical past. Regions that are part of this brain network include the medial prefrontal cortex, medial parietal cortex, anterior lateral temporal cortex, inferior parietal cortex, and medial temporal lobe structures (Schacter et al., 2007). Notably, the prospection brain network closely corresponds to the brain's default mode network, which is active under conditions of rest and low task load, and is held to reflect processing demands associated with mind-wandering, internal mentation, and stimulus-independent thought (Andrews-Hanna, 2012).

This network of brain areas is also involved in other facets of higher order cognition, like mental state reasoning or theory of mind, moral cognition, and self-referential thought (Buckner, Andrews-Hanna, & Schacter, 2008), all of which involve reasoning about the perception, cognition, or behavior of one's self and/or others. Prominent ideas that have proposed a common factor or functional metric that would explain the involvement of the prospection brain network (in whole or part) in this wide array of mental operations include self-projection (Buckner & Carroll, 2007), mental scene construction (Hassabis, Kumaran, & Maguire, 2007), constructive simulation (Schacter, 2012), proactive associative processing (Bar, 2007), and evaluation (Legrand & Ruby, 2009). Indeed, it is possible that these proposed factors operate collectively to a much stronger extent during episodic prospection and retrospection compared to when engaging in mental state, self-referential, or moral reasoning. For example, thinking about one's personal past or future has been shown to involve an aggregation of factors such as self-referential processing, a subjective sense of time, narrative structure, retrieval of multimodal details, feeling of familiarity, construction or simulation of the hypothetical event in question, and so on (Hassabis et al., 2007).

Due to the considerable overlap in the brain regions involved during episodic prospection and retrospection, a significant challenge that remains for researchers to resolve is what makes these two facets of mental time travel discrete from one another. Is this distinction a purely theoretical one or is it instantiated at the level of dissociable brain functions? If the latter is the case, which facet(s) of the neurocognitive mechanisms that underlie mental time travel allow for the differentiation between past versus future thinking? Apart from the behavioral evidence discussed earlier, there are also neuroscientific grounds that support the presumption that the neural and information processing mechanisms underlying prospection and retrospection are at least partially distinct.

Neuroimaging evidence has, for instance, indicated a stronger engagement of select regions within the prospection brain network during episodic prospection relative to episodic retrospection (Abraham, Schubotz, & von Cramon, 2008; Okuda et al., 2003). Regions such as the anteriormost aspects of the medial prefrontal cortex (Brodmann area 10), which is held to orchestrate the integration of informational output from two or more separable cognitive operations (Ramnani & Owen, 2004), have been implicated in this regard. The neuropsychological evidence from amnesic patients is, however, generally mixed with some studies demonstrating poor episodic prospection in relation to poor episodic retrospection, while others show that this relationship is not as clear-cut (Verfaellie, Race, & Keane, 2012). For instance, the widely investigated patient K.C. is able to discount the value of future rewards, within the range of controls in terms of rate and consistency, although he has episodic amnesia and is unable to imagine future experiences (Kwan et al., 2012).

Apart from trying to determine the specific functions of different regions within the prospection brain network, a novel focus that is slowly gaining prominence in the literature is to gather evidence that will clarify why our capacity to reason and imagine the future has evolved at all. Suddendorf, Addis, and Corballis (2009) have proposed that this ability to simulate our hypothetical future evolved as it enhances fitness by virtue of "enabling action in preparation of different possible scenarios that increased present or future survival and reproduction chances". The accumulating behavioral evidence thus far lends supports to this idea. Future-oriented thoughts have, for instance, been shown to facilitate performance on a prospective memory task (Neroni, Gamboz, & Brandimonte, 2014). Information processing biases that typically accompany future-oriented cognition, such as the retention of positive or neutral information over negative information, allude to the adaptive nature of such operations in that they are conducive to psychological well-being (Szpunar, Addis, & Schacter, 2012). Indeed, insufficiencies at the level of future oriented cognition are particularly relevant with regard to the information processing biases that are typically associated with depression and anxiety disorders (Miloyan, Pachana, & Suddendorf, 2014).

As the field of prospection continues to evolve, several issues have emerged that could critically impact current theoretical conceptualizations of these operations. For instance, many of the key ideas in this domain stemmed from the vast expanse of research on episodic memory. As a result, the temporal factor and the personal factor occupy much of the empirical focus (e.g., the neural and behavioral correlates of immediate versus distant episodic past versus episodic future thinking) and are regarded as the key elements that modulate the neurocognitive mechanisms that underlie future thinking in general. This is somewhat misleading given

Table 1

A general overview of the major brain regions that are involved in future oriented cognition across different domains

Information processing domain	Brain regions implicated in future oriented cognition
Sensory processing & attention	Prefrontal cortex (medial, dorsolateral, orbitofrontal), insula, retrosplenial cortex, parahippocampal cortex
Motor processing	Motor cortex, premotor cortex, striatum, cerebellum
Higher cognition & self-regulation	Dorsolateral prefrontal cortex
Emotional and reward processing	Ventromedial prefrontal cortex, basal ganglia
Prospection	Medial prefrontal cortex, medial parietal cortex, lateral inferior parietal lobe, anterior lateral temporal cortex, medial temporal lobe

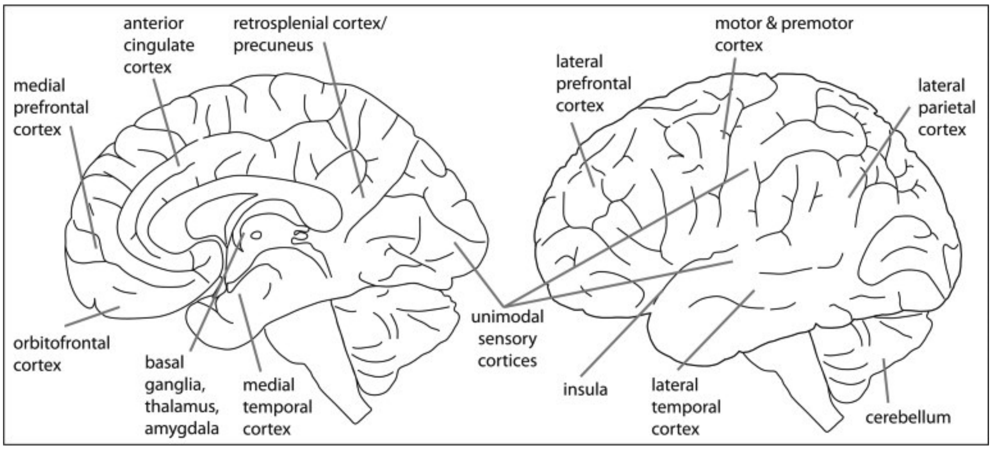

Figure 1. A schematic outline of the numerous brain areas and networks that have been associated with some aspect of future oriented cognition. Figure as originally published in "Prediction, cognition and the brain" by Bubic, A., von Cramon, D. Y., and Schubotz, R. I., 2010, *Frontiers in Human Neuroscience*, *4*, p. 25. doi: 10.3389/fnhum.2010.00025.

that overlapping brain networks are demonstrably involved in other aspects of imaginative thinking that are neither necessarily defined by temporally-based factors, such as theory of mind, moral reasoning, and self-referential thinking (Buckner et al., 2008), nor personally-based factors, such as semantic future thinking (Abraham et al., 2008), counterfactual or "what-might-have-been" reasoning (Levens et al., 2013), and even divergent thinking (Abraham et al., 2012). Recent theoretical proposals have, in fact, called for de-emphasizing the episodic or autonoetic aspects of future oriented cognition and highlight the central role played by semantic memory in the same (Irish & Piguet, 2013; Stocker, 2012).

CONCLUDING REMARKS

A review of future oriented cognitive processes across different domains that include perception, motor behavior, attention, and higher order cognition as well as emotional, motivational, and self-referential processing was presented in this paper. Furthermore, the neural implementation of such processes was discussed, showing the engagement of almost all brain regions and neural systems. Although the focus in this review was placed primarily on the benefits of predictive processes across different domains, it is also important to highlight numerous open issues and challenges that remain for this field. The biggest of these includes rather limited attempts of bridging future oriented processes across different domains of study. Given that researchers typically use many distinct methods for studying predictive processes of various types and temporal structures, it is hard to reconcile manifold views that have emerged in recent decades in this field. In addition, differences in terminology also represent a barrier for developing a more systematic approach for understanding the phenomenon of interest. Finally, the fact that predictive processes may not always be very distinct from other functions that have traditionally been labeled non-predictive also needs to be acknowledged to a higher degree in the years to come.

Despite these challenges, it may still be concluded that future orientation represents a very fundamental characteristic of our cognitive and neural architecture, which is in line with previous accounts that have labeled the mind as an anticipatory device (Pezzulo, Hoffmann, & Falcone, 2007). As the field of future oriented cognition continues to grow in prominence as a driving force for empirical work in psychology and the neurosciences, it is essential to further expand the theoretical conceptualizations of these operations and extend our understanding of their practical implications for everyday living.

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