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Akrasia comes from the Greek term "lacking command" (Heather 2017) and refers to cases where people appear to act against their better judgment or cases of "weaknesses of the will" (Plato 1990; Ribot 1896). In contemporary life, addictions (Heather 2017) and obesity may serve as prime examples: the health dangers related to smoking, drinking, and excessive eating are well known, yet millions continue to engage in these behaviors, at enormous social and economic costs (Effertz and Mann 2013; Willett et al. 2019). Of course, there are examples where people prefer the hedonic short-term effect of an unhealthy choice over the (potential) long-term benefits of a healthier choice, which would not count as *akrasia*. True *akrasia* concerns cases where people fail to understand their own choices: they knew taking a single cigarette after successful abstinence was taking a foolish risk of falling back into smoking, which they really did not want, and yet, that is exactly what they did (cf., Heather 2017).[1]

At first sight, human *akrasia* problems may seem surprising, given that with evolution, progressively more advanced and abstract control mechanisms have developed, built upon simpler reflex-like processes (Pezzulo, Rigoli, and Friston 2015; Smith et al. 2017; Verschure 2016). Higher-level mechanisms can overcome automatically activated impulses, based on contextual signals and long-term goals. This points to what we would call the "control paradox": while humans arguably have the highest level of control over their impulses, they also develop unique problems often attributed to *lack* of control, including addictions and obesity. What could explain this paradox?

The human mind, arguably, has unique powers, related to symbolic processing, social cooperation, higher-order consciousness, and self-control (Dennett 2017; Verschure 2016), which can be used for better or for worse, depending on the perspective taken: uniquely, people can starve themselves while food is available, or sacrifice themselves for an abstract goal (Kopetz and Orehek 2015). At the same time, using their higher-order control and ability to anticipate the future, people also have the ability to overcome unhealthy habits and addictions, sometimes after a flash of insight without professional help (Miller 1998; Heyman 2010). The latter phenomenon is one of the arguments used against the currently dominant view that addictions (Leshner 1997; Volkow, Koob, and McLellan 2016) and obesity (Volkow et al. 2013) are chronic brain diseases (brain diseases model of addiction, or BDMA; see also Heather et al. 2018; Lewis 2016). Relatedly, the importance of language and goal-pursuit in explaining human behaviors may also limit the validity of animal-models for the understanding of addiction in humans (de Wit, Epstein, and Preston 2018).

In the perspective developed here, we first discuss to what extent addiction can be seen as rational behavior and what it would take to define behavior as irrational or a clear instance of *akrasia*. We then link this to a phenomenon described in the animal-literature as sign-tracking (Robinson et al. 2014), and a recently developed experimental psychological phenomenon with similar properties, value-moderated attentional capture (Le Pelley et al. 2015), and cue-reactivity in addiction and related disorders. We will argue that through learning, cues can develop attention-grabbing properties, which bias subsequent behavior. This description differs from dual-process and dual-systems models, because decisions are not taken in a qualitatively different way by addicted vs. non-addicted individuals, but the differences are in the developed cognitive biases which influence decision making, which is also influenced by social and economic circumstances. Hence the approach dovetails with the general approach of social neuroeconomics in this volume.

We will consider the (debated) potential role of consciousness in decision making and will argue that there are different semi-autonomous subsystems active in our brain, and that consciousness plays a role or is closely related to this orchestration of subsystems in order to select goal-directed actions (cf., Dehaene and Naccache 2001; Morsella 2005; van Gaal, de Lange, and Cohen 2012). The brain continuously aims to predict the outcomes of our actions, as an "organ of inference", which constantly fine-tunes its model of the world through perceiving the world and acting upon it (Clark 2013; Solms and Friston 2018). Addictions may develop when actions have an immediate positive effect in a given context, and the individual has a strong sensitivity for cues signaling the possibility of performing this action again. From this perspective, it follows that effective interventions should reduce the sensitivity to these signs, either directly or indirectly, by making alternative actions more attractive.

Addictive behaviors and irrational sign-tracking

At first sight it seems obvious: addictive behaviors must be irrational. If we assume that people want to live a long and healthy life and that they know that cigarette smoking, as a salient example in the Western world, significantly decreases their life expectancy, why would anyone still smoke, or – even harder to explain – start smoking? The answer lies, at least partly, in the time dimension: rewards or losses that occur later in time are generally discounted (Becker and Murphy 2002), a phenomenon known as delay-discounting. We all have a tendency to discount possible future rewards and losses with time, but it is also an individual difference variable (an aspect of impulsivity), which has shown a rather consistent relationship with addiction (meta-analysis; MacKillop et al. 2011). Hence, a brief uplifting from a negative mood may outweigh long-term pains and risks, especially in individuals with a steep delay-discounting function, but that would not necessarily make the behavior irrational (from the first-person perspective). Similarly, many behaviors that seem self-defeating from an outsider's perspective may be perfectly rational from the actor's perspective, once their goals are understood; e.g., martyrdom in cases of suicide-bombing, or status in a peer group in cases of risk-taking, overeating, and addictive behaviors (see Kopetz and Orehek 2015; Stroebe et al. 2017). With regard to this latter example, important health- and wellbeing-related goals often develop during adolescence, a period in which major brain restructuring takes place and peer influence becomes very important, with the rise of testosterone (in boys and girls!) related to increases in motivation to gain social status (Crone and Dahl 2012; Dahl et al. 2018). In the example of smoking (and other risk behaviors) in adolescence, potential gain in peer status may outweigh previously dominant negative attitudes and intentions toward smoking. Viewing rationality from the first-person perspective raises the question of whether someone who entirely neglects possible future consequences of his or her actions should be called rational (Becker and Murphy 2002). For every seemingly irrational behavior, one could, most likely (with or without help from the actor) think of possible goals for which this behavior could be rational. This would potentially make all behavior rational.

A notable exception to this idea of "universal rationality" would be cases where the behavior clearly goes against the activated goal itself. We would argue that the phenomenon of sign-tracking in animal research represents such a case. In a typical experiment, animals learn that a cue predicts reward, which leads to attribution of incentive motivational properties to the cue (e.g., attention, tendencies to approach, licking; Robinson and Berridge 1993; Berridge, Robinson, and Aldridge 2009); in other words, the cue becomes a strong motivational signal or "motivational magnet". In a typical experimental setup to show sign-tracking, reward cues and actual rewards are spatially separated, so that approaching the reward-cue makes the animal miss the actual reward. For example, the reward-signaling cue appears on one side of the cage, while the actual reward is presented on the other side. In such an experiment, moving toward the cue makes the actor miss the actual reward. Interestingly, some animals develop a "sign-tracking" phenotype, approaching the sign (and missing the reward), whereas others develop a "goal-tracking" phenotype, approaching the actual reward rather than the sign (Robinson et al. 2014; Barker and Taylor 2017). Males are more likely to develop sign-tracking than females (Barker and Taylor 2017), a phenomenon which mirrors the higher vulnerability for addictions in males, and the stronger cue-reactivity to addiction cues in males (Kaag et al. 2019). The question is whether the human equivalent of cue-reactivity to addiction cues can really be interpreted as irrational sign-tracking (an alternative possibility is that the sign could activate a relief goal, which would make approaching such a cue less irrational from the first-person perspective). One difficulty in interpreting reactions to drug cues is that their learning history is not under experimental control (as is the case in the sign-tracking experimental setup).

Le Pelley and colleagues have developed an experimental psychological paradigm in humans in which arguably "irrational" sign-tracking behavior can be observed. Participants learn to perform a primary task, which is to find a specific grey target shape amidst a set of similar grey shapes (e.g., a grey diamond amidst grey circles). Among the grey shapes, sometimes a colored *distractor cue* is presented, which signals that monetary reward can be gained on that trial if the participant manages to find the target quickly. The distractor can have one of two different colors (matched for physical salience, say red or blue): one color signals that low reward is available, the other high reward. Importantly, this reward is delivered *only if the participant successfully ignores the distractor cue*: looking at the distractor cancels the reward, termed a reward omission. Under these conditions, paying attention to distractors is clearly maladaptive; in particular, the worst thing participants can do is to look at a distractor in the high-reward color, since that results in loss of a large reward. Yet this is exactly what participants do: they often look at the colored distractor (and the presence of this distractor slows responses to the target), and these effects are magnified when the distractor signals high reward (Le Pelley et al. 2015; Pearson et al. 2015). This Value-Modulated Attentional Capture (VMAC) effect does not depend on verbal instruction and does not disappear with practice (Le Pelley et al. 2015; Pearson et al. 2015), and it appears to be very difficult if not impossible to overcome volitionally (Le Pelley et al. 2017; Most et al. 2007). Moreover, first indications have been found that the VMAC effect is related to actual drug use, in participants with relatively weak working memory abilities (Albertella et al. 2017). A recent study found additional evidence that counterproductive oculomotor capture by high-reward cues is enhanced under high working memory load (Watson, Pearson, Chow et al. 2019). Together, these emerging findings indicate that there are cases of attentional capture by reward cues which may be called irrational in the sense that they directly counter the goal of the actor (ignore the distractor; earn more money), and which cannot be easily explained away by referring to other goals that may play a role in the behavior. Importantly, from the general perspective of social neuroeconomics, cues referring to social rewards have been shown to have a similar influence on attentional capture (Anderson 2016). Moreover, attentional distraction by reward cues has been demonstrated to negatively impact decision making on another task (Itthipuripat et al. 2015). Together, these findings indicate how decision making can deviate from economic optimality through the biasing effect of previous reward history, where reward includes natural and social rewards, as well as drug-induced rewards (cf. also Chapter 4 by Herrmann-Pillath and Chapter 5 by Declerck, this volume).

Traditional accounts of attentional prioritization have distinguished top-down, goal-directed processes from bottom-up, stimulus-driven influences (e.g., a loud noise), but this view has been extended by accounting for the impact of learning history (Awh, Belopolsky, and Theeuwes 2012; Le Pelley et al. 2016; Anderson 2017; Watson et al. 2019a). In particular, sign-tracking and the VMAC effect are important because they show that what aspects of the environment are attended or ignored are shaped by the observer's previous history of reward-leaning. In fact, this is not unique to reward signals: punishment signals are also prioritized (Watson et al. 2019b), as are stimuli referring to the self, as recent evidence indicates (Yin et al. 2018). This shaping of attentional priority may then have important knock-on effects on decision making. Our behavioral choices (e.g., to smoke or go running) are not made in a vacuum. These overt choices represent the final step of a decision cascade; a cascade which begins with gathering information about what stimuli are present in the environment (e.g., cigarettes or running shoes), and hence what our behavioral options are. Attention will play a critical role in this information-gathering process: a stimulus that is prioritized is more likely to feature as a goal of subsequent behavior (and vice versa: if we don't notice that a stimulus is present, it will not feature in our behavioral options). This does not imply that one *cannot* ignore prioritized stimuli, but that it becomes more difficult to do so, which will bias decision making, especially when executive control is relatively weak. This can be either because of relatively weak executive control abilities (trait-variable), or because of state variables, such as after drinking alcohol or experiencing stress (Hofmann, Friese, and Wiers 2009; Wiers et al. 2015; Watson, Pearson, Chow et al. 2019). A recent study introduced a new variety of the VMAC (Albertella et al. 2019), in which after a regular VMAC phase, the two reward distractors change in value, i.e. the participant is told that the cue that formerly signaled high reward now signals low reward and vice versa (still, a reward is given only when the reward signal is not attended and the target is responded to in time). After this change, participants who were still distracted by the cues that signaled high reward in the previous experimental phase (but not any longer) were also the people with highest scores on alcohol use and problems, indicating that adaptive responding after a change in contingencies may be more strongly related to *akrasia* problems than attentional capture per se. That is, while the initial attentional capture by signals of high reward appears to be relatively universal, critical individual differences may emerge when the initial reward-initiated response needs to be down-regulated and an alternative response needs to be activated which is compatible with the long-term goal (i.e., gain points or money in the task, or in real life make a healthy choice in view of long-term health goals, rather than a short-term hedonic choice; see Figure 7.1).

Note that the current perspective of biasing decisions is not equivalent to dual-process models, which have been criticized because of neural implausibility (Keren and Schul 2009), and theoretical problems (Keren and Schul 2009; Kruglanski and Gigerenzer 2011; Hommel and Wiers 2017). The crucial difference is that dual process models postulate the existence of two qualitatively different types of process that underlie and may compete for control of behavior, which are distinguished based on different features, such as symbolic vs. associative (Strack and Deutsch 2004; Gawronski and Bodenhausen 2006) or conscious vs. unconscious (Evans 2008; Kahneman 2003). Here, no claims are made about the symbolic or conscious nature of conditioned reward cues, the

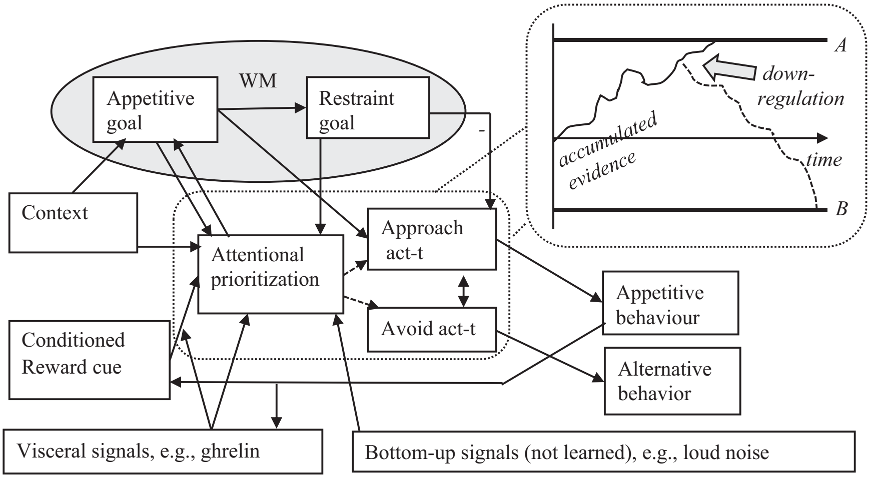

Figure 7.1 Attentional prioritization is influenced by bottom-up signals and by top-down goals, which can be activated by context. Conditioned stimuli also affect attentional prioritization independent of current (restraint) goals (Awh, Belopolsky, and Theeuwes 2012; Le Pelley et al. 2015; Watson et al. 2018). Conditioned reward cues can activate appetitive goals, but can also (indirectly) activate restraint goals (Fishbach and Shah 2006), which may result in adaptive down-regulation of attention for appetitive cues, or suppression of the approach action tendency (act-t), given ample working memory (WM) capacity. Long-term consequence of appetitive behavior is that cues can become conditioned and capture attention and neurovisceral adaptations, which may influence attentional prioritization. Processes underlying (down-regulation) of attentional prioritization and approach action tendencies can be modeled with drift diffusion models (top right dotted zoom-out box), where a choice between two responses is modeled (here, A, choice compatible with short-term relief vs. B, compatible with long-term positive health effects). A conditioned reward cue can bias toward A but is here successfully down-regulated in favor of B.

simple claim is that they can bias decision making, by biasing selective attention and thereby increasing the chance that action tendencies toward them are activated and performed (for preliminary evidence, see Kim and Anderson 2019). This accommodates the findings that even heavily addicted individuals can show goal-directed behaviors (Hogarth et al. 2018; Lewis 2015), even in the presence of their drug of abuse (Hart 2013), which counters the idea of completely reflexive processes in (severe) addiction. Note further that this account also differs from the habit-theory on addiction (Everitt and Robbins 2005), which states that in addiction, goal-directed control is replaced by habitual actions where an eliciting stimulus (cue) inflexibly triggers the associated response (addictive behavior), even when devalued (by outcome devaluation, established for example through pairing the response with shocks or nausea). The issue is that although in human drug addiction, addiction-related cues may bias subsequent decision making, there are many examples of goal-directed decision making to obtain the drug when the habitual action sequence to obtain the drug is not possible (Berridge and Robinson 2003). Moreover, the evidence for habitual decision making in humans is weak at best (Hogarth 2018). By contrast, on the account we advance here, the bias is in the initial information-gathering process, which acts to bias the likelihood that alternative goals will be selected as targets of goal-directed behavior. That is, previous investigations may have been looking in the wrong place: the "habits" may be in attention and activation of action tendencies, rather than (or at least more than) in overt behavior.

Consciousness and action

There are different perspectives on the role of conscious thought in relation to action. According to the everyday "naïve" perspective, our conscious thoughts directly cause our actions: we think of something (e.g., there is no more bread, I need to go to the bakery), and then an action is initiated (I go to the bakery). However, this perspective is demonstrably wrong: the factors people subjectively report to have played a role in their decision making and the factors actually influencing their choices can be manipulated independently (Nisbett and Wilson 1977; Wegner and Wheatley 1999; Wegner 2003). For example, people think they pick a specific product (e.g., cookies) for good reasons (e.g., taste, health, price), but the factors that actually predict the choice are rather different: positioning of the product on the shelf is an example of a strong determinant (Nisbett and Wilson 1977). Moreover, some neurological conditions (e.g., blindsight, neglect) as well as subliminal priming studies in healthy volunteers make it clear that many brain processes operate unconsciously (Roser and Gazzaniga 2004; Kouider and Dehaene 2007; Van Gaal and Lamme 2012). Some theorists have concluded from these findings that conscious thought does not have any direct influence on behavior and merely concerns interpretations of our own behaviors (Wegner 2003, 2004). However, this begs the question of why consciousness evolved.

One possibility is that consciousness developed to resolve conflict: Morsella (2005; Morsella et al. 2015) argued that subjective experiences of conflicting action tendencies and related urges are at the heart of consciousness (for further discussions on the role of consciousness in conflict processing and control, see Sumner and Husain 2008; van Gaal, de Lange, and Cohen 2012). The reason is that multiple, encapsulated systems may produce conflicting action tendencies (e.g., one system suggesting to approach, the other to avoid), orders which cannot be executed at the same time. Hence, coordinated action requires a common (brain-) language for crosstalk, which concerns action-outcome representations. Appetitive urges in addiction or obesity represent a prototypical case, eliciting strong urges to approach, while at the same time the goal to restrain can be activated.

Conscious control can be exerted either in the current moment ("online") or, more indirectly, through feedback mechanisms, which lead to adaptive learning strategies for the next occasion, which would still have adaptive value (Morsella et al. 2015; Hommel and Wiers 2016; Verschure 2016). Online control may fail in light of strong appetitive cues, reflecting that top-down biasing of the decision-making process in the presence of strong attention-grabbing reward cues may be difficult. Therefore, it might be more advantageous to prevent addiction cues from strongly biasing the decision-making process in the first place.

Consciousness and addiction

What do we know about consciousness, addiction cues, and behavior? From the present perspective, learning history will prioritize processing of addiction cues, and more generally any cue previously associated with reward or reward opportunity. This would imply that such cues will attract attention and should pass the threshold for becoming conscious more easily than other cues, similarly to the observation that emotionally laden material crosses the threshold to consciousness more quickly (Gaillard et al. 2006). This would not imply that the subsequent cue-related behavior (engage in the addictive behavior) is the *necessary* consequence, but rather that the decision-making process gets biased in that direction (see Figure 7.1). What do we know about natural addiction-related cues or experimentally manipulated signs of reward in relation to attention and consciousness? The literature on attentional biases for addiction cues has been reviewed elsewhere (e.g., Field et al. 2016; Wiers, Field, and Stacy 2016), as has been the attentional prioritization of experimentally learned reward and punishment cues (Watson et al. 2019a). Here we focus on what we know about conscious awareness of either naturally learned addiction cues or experimentally learned reward cues (Custers and Aarts 2010).

Different paradigms have been used in the literature on consciousness and conditioning, including subliminal presentation of stimuli, autonomic conditioning (conditioned responses assessed from the autonomic nervous system), conditioning in amnesia, and evaluative conditioning (Lovibond and Shanks 2002). In their influential review, Lovibond and Shanks (2002) concluded that there was little evidence for conditioning effects without awareness (see also, Mitchell, Houwer, and Lovibond 2009). The main issue in the literature identified by these authors is that often invalid measures were used to assess conscious awareness. The authors propose four criteria regarding valid assessment of awareness: relevance, immediacy, sensitivity, and reactivity. Relevance means that the measures should tap those aspects of awareness that are relevant for the associative learning task. For example, in many studies using subliminal stimuli, participants are unable to accurately report the identity of the stimulus, but it remains possible that participants are consciously aware of aspects of the stimuli (e.g., differences in brightness) that predict the conditioned response but do not require full awareness of stimulus identity. Immediacy refers to the fact that often awareness tests take place after the conditioning task (to prevent reactivity: participants learning the relationship from the questions), but this is problematic because the relationship may have been weakly represented in awareness at the time of stimulus presentation or the response and then may have been quickly forgotten (Wolfe 1999). Sensitivity refers to psychometric properties of the test used to determine contingency awareness. For example, (forced-choice) recognition tasks are more sensitive than free recall tests, especially regarding contingency awareness. Note that since Lovibond and Shanks's paper, other concerns have been raised regarding subliminal stimulus presentation, especially in relation to brain responses, where the often-used 33 ms presentation of pictorial stimuli has been shown to reach awareness in many participants in some specific situations (Pessoa 2005), which calls for using shorter presentation times and individual thresholding in these cases. In general, the optimal timing for stimulus presentation may be different, depending on the specific stimulus material (e.g., verbal stimuli vs. pictures) as well as the type and parameters of the masking procedure.

In the field of addiction, there has been some research on effects of subliminally presented addiction-related cues. One set of studies has tested effects of briefly presented sexual ("natural reward") stimuli (e.g., Childress et al. 2008; Oei et al. 2014). Childress and colleagues (2008), tested brain-responses (using fMRI) in 22 cocaine-dependent patients using a backward masking paradigm with 33 ms presentations of visual stimuli of one of four categories: neutral, sex, cocaine, and aversive. They tested forced category recognition in an independent sample and later recall in the experimental sample and concluded the stimuli did not reach consciousness (but as we have seen, this may be disputed, based on both the type of tasks used for evaluating stimulus visibility and the exposure time of the stimuli). Sex and cocaine pictures activated a largely overlapping limbic reward circuit, including the amygdala, ventral striatum, ventral pallidum, the insula, temporal poles, and parts of the orbitofrontal cortex, as was found in a previous study using longer exposure times (Garavan et al. 2000). In a follow-up study from the same lab (Young et al. 2014), the same paradigm was used in 23 cocaine-dependent men, who subsequently received baclofen (a GABA-B receptor agonist) or placebo. It was reported that baclofen selectively blunted the early mesolimbic response to cocaine cues (no effects on the neural responses to sex and aversive pictures), which is interesting regardless of the level of conscious awareness reached in different participants (cf., Pessoa 2005).

In a cannabis study from the same lab (Wetherill et al. 2014), 23 cannabis-dependent participants were tested in the same experimental setup, with cocaine pictures replaced by cannabis pictures. Participants demonstrated enhanced responses to backward-masked cannabis pictures compared with neutral pictures in the ventral striatum, amygdala, and anterior insula, again largely overlapping with responses to backward-masked sexual cues. These activations were correlated with craving and years of use. In a follow-up study (Wetherill et al. 2015), using the same procedure now in 44 cannabis-dependent participants (including 20 from the previous study), similar overall findings were reported, but now gender-differences emerged: women revealed greater responses to the backward-masked cannabis cues compared with neutral cues in the striatum, left hippocampus/amygdala, and left lateral orbitofrontal cortex; while for men, this difference was observed in the left striatum and left lateral orbitofrontal cortex. Further, activation in different brain areas to the cannabis (vs. neutral) stimuli was correlated with subjective craving: in women with the bilateral anterior insula and inversely with the left orbitofrontal cortex. In men a correlation was found with activation in the striatum. Together, these findings indicate that sex and addictive substances activate a largely overlapping brain circuit in a fairly automatic manner (with little or no awareness). In an interesting study, it was demonstrated that in men, activation of limbic reward areas to backward-masked sex pictures (presentation duration = 33 ms) is modulated by the cortisol response to stress (Oei et al. 2014). Although no strong conclusions can be drawn regarding true unconsciousness of the stimulus material, because subjects scored just above chance level on a forced-choice recognition task performed after scanning, these findings could stimulate further research into mechanisms underlying the increased use of substances after stress.

In one of the earlier studies, Franken and colleagues (Franken et al. 2000) compared 21 heroin-dependent patients and 31 controls in their attentional bias for heroin-related words, which were presented either subliminally (28 ms), or supraliminally (until response, max 3 seconds). Heroin-dependent patients were much slower to respond to supraliminally presented heroin words than controls, with no difference for the subliminally presented stimuli. Interestingly, in the heroin group, craving correlated both with the responses to subliminal and supraliminal cues. In another early study, Ingjaldsson and colleagues (2003) compared heart-rate responses to supraliminal and subliminal alcohol stimuli in 34 alcohol-dependent patients (18 with high levels of craving and 16 with low levels) and controls. In the subliminal condition, alcohol pictures were presented for 20 ms, followed by a 100-ms mask. Awareness checks were done after a block of stimuli with open questions (weak check), but the authors mention that unawareness in this experimental setup had also been established in a different sample. The high-craving patients showed an immediate heart rate deceleration after exposure to the subliminally presented alcohol pictures compared with control pictures, which was not found in the low-craving alcohol-dependent group and controls (however, the interaction between group and picture type was not reported, which makes the finding more exploratory). The immediate heart rate deceleration was interpreted as a marker of initial automatic attending.

Two studies investigated reactions to cigarette cues at different levels of stimulus awareness. Yan and colleagues (2009) used interocular suppression in 28 smokers and 25 controls and found evidence of an attentional bias for smoking cues in the absence of awareness in smokers only (note, however, that more than 30% of the subjects had to be excluded due to above-chance performance on a forced-choice recognition task). Leventhal and colleagues (2008) used a pictorial subliminal repetition priming task in 113 smokers (of whom 47 were deprived of smoking for 12 hours, and 66 were not), and 56 non-smokers. Masked primes were presented briefly (17 ms) and a speeded classification test did not show awareness. After the task, a (recognition) visibility check was done, and participants who scored above chance level were excluded (9%), but no across-group statistics were reported for visibility (see Shanks 2017, for an elaborative discussion on subject selection procedures). Only deprived smokers showed a processing bias for smoking-related cues. The groups did not show differences in processing of other affective stimuli.

Taken together, although no study passes all the validity checks outlined by several authors (e.g., Lovibond and Shanks 2002; Shanks 2017; Pessoa 2005), it appears fair to conclude that there is suggestive evidence that cues relation to addictive behaviors and natural rewards can elicit responses in a relatively automatic fashion, with low levels of perceptual awareness of the stimulus input. This is in line with the idea that these stimuli get attentional priority, and thus may bias subsequent decision making. In addition, some evidence points to state-modulation of these effects, by deprivation (e.g., Leventhal et al. 2008) and stress (Oei et al. 2014). Future work is needed, however, to determine whether these "biasing effects" are even present when stimuli are presented truly subliminally, because convincing data on this specific point is lacking so far.

The studies reviewed here investigated the influence of attention and awareness on the processing of natural rewards. In the next section we consider what we know about experimentally conditioned stimuli (note that brain responses to monetary cues can be regarded as the bridge here, as these are not intrinsically motivating, but motivational responses must have been learned and can be observed when awareness levels are low (Pessiglione et al. 2007, 2008).

Conditioned reward stimuli

In a series of recent studies, Leganes-Fonteneau and colleagues (2018, 2019) tested how attentional processes and conscious awareness affect the processing of conditioned reward stimuli in an incidental conditioning procedure in which cues were paired with either high or low reward (the conditioning was incidental in the sense that the association between cues and reward was not task-relevant). Participants were divided into an aware and unaware group, based on an expectancy evaluation task performed during the conditioning task (on part of the trials). After conditioning, the high- and low-reward cues were used as targets in an emotional attentional blink task: participants were required to detect these cues when they appeared shortly after either neutral or aversive distractor stimuli in a rapid serial visual presentation stream. In the 43 unaware participants, low-reward cues showed the "standard" emotional blink pattern of poorer detection following aversive distractors than neutral distractors. Critically, this emotional blink was significantly reduced for high-reward stimuli presented during the AB period (Study 1), without effects on subjective pleasantness ratings. These findings are consistent with the idea that high-reward cues receive greater attentional priority and hence are less vulnerable to effects of distraction by salient (aversive) distractor stimuli. In a second study, the authors performed a Bayesian analysis to test the awareness of the contingency in addition to the procedure used in Study 1 (important because the absence of an effect needs to be demonstrated). They again found that in the unaware group, low-reward cues were detected less well after aversive distractors, but this was not the case for high-reward cues. In a second paper (Leganes-Fonteneau et al. 2019), the authors used the same incidental conditioning procedure and categorization of aware vs. unaware participants using a Bayesian approach, and found that conditioned high-reward stimuli showed interference in an emotional flanker task (Nikolaou et al. 2013) in unaware participants, but not in an N-back working memory task; by contrast, the N-back task revealed an effect of high-reward stimuli in aware participants, and these aware participants also rated the high-reward stimuli as more pleasant (which was not the case in unaware participants).

Some other studies have used classical conditioning to experimentally condition formerly neutral stimuli as cues for alcohol (Field and Duka 2002; Mayo and de Wit 2016) or stimulants (Mayo et al. 2013; Mayo and De Wit 2015), with corresponding attentional biases for the thus conditioned cues. While interesting with respect to the development of conditioned alcohol and drug responses, these studies did not include awareness tests and therefore do not speak to the issue of the role of conscious awareness in conditioning alcohol and drug cues. Nevertheless, together, these findings point to suggestive evidence for the processing of conditioned high-reward stimuli in the absence of explicit knowledge about conditioned stimulus-reward associations (see also Bijleveld, Custers, and Aarts 2010), with corresponding effects on attentional prioritization, as has been reviewed recently (Watson et al. 2019a).

Theoretical implications

From the present perspective, the (neuro-)cognitive processes which determine decision making can be categorized into three classes: in addition to the traditional bottom-up and top-down biasing processes (aimed at [long-term] goal-pursuit; Munakata et al. 2011), effects of learned (conditioned) reward and punishment signals should be taken into consideration (Awh, Belopolsky, and Theeuwes 2012; Le Pelley et al. 2015, 2016; Watson et al. 2019a). These can bias decision making, based on learning history (approach reward signals, avoid threat signals), which implies that they receive attentional prioritization and, perhaps in some cases, influence behavior outside conscious awareness. This process is influenced by state variables, including withdrawal effects and stress (see Figure 7.1).

Note that this model is not a dual-process model (there is a single "decision making" box, admittedly still largely black), where the three different types of input are integrated. How exactly this is done and what role consciousness plays here are largely unknown, but the general idea is that decision-making can be modulated by these three types of influences: when there is a loud noise, this will attract attention, as do conditioned reward and punishment cues (modulated by state variables), and finally there is top-down biasing, based on active goals. As noted previously, one outstanding question is to what extent consciousness plays a role in the decision-making process in the moment (in weighing the different inputs to determine behavior) or only indirectly by influencing future occasions (Morsella et al. 2015; Hommel and Wiers 2016). This simple model does include some of the attractive aspects of dual process models, such as the influence of state variables on decision making (Hofmann, Friese, and Wiers 2009), while avoiding some of the neural and theoretical problems of these models (Keren and Schul 2009; Gladwin et al. 2011; Hommel and Wiers 2017). The model should be seen as a sketch of a dynamic model; for example, a conditioned addiction-related cue can attract attention, and this may elicit craving, which is enhanced by elaboration of expected positive effects in working memory (Kavanagh, Andrade, and May 2005); but it may instead also trigger a moderation goal (Fishbach and Shah 2006), which in turn may help to down-regulate the craving (see Figure 7.1).

One interesting question concerns the role of language in learning and decision making, also in relation to continuities and discontinuities across evolution (see Mitchell, de Houwer, and Lovibond 2009, including the commentaries and rebuttal). One of the arguments in favor of propositional models for human conditioning is that many if not all of the conditioning effects in humans require conscious awareness (although this is heavily debated), and that many of the conditioning effects in humans occur both when people *experience* pleasure or pain, and when they are *told* that a stimulus predicts these effects (Lovibond and Shanks 2002; Mitchell, Houwer, and Lovibond 2009). In an interesting recent neuroimaging study, this issue was addressed (Atlas et al. 2016), and it was reported that instructed fear has similar effects as experienced fear-learning on some brain circuits, including the striatum and orbitofrontal cortex, but not on others, including the amygdala. This is a theoretically important area of research, and it could be replicated and extended to reward stimuli. It may also have important consequences for the validity of animal research for human outcomes (de Wit, Epstein, and Preston 2018), and may have important treatment implications (discussed later in this chapter).

The development of addiction

In human behavior, social learning (and language-based learning) is very important. We do not let our children experience how to cross a street; we'd rather instruct them and make sure for a long time they actually follow instructions. When it comes to the development of addictive behaviors, parents and society generally transmit negative messages (although in many cases with some ambiguity, as they often show the behavior themselves but tell their children not to do the same). In any case, in young children, negative expectancies of addictive behaviors are dominant (e.g., Wiers, Gunning, and Sergeant 1998). However, as mentioned earlier, with the onset of puberty and under the influence of testosterone, different goals become more important, such as status in the peer group (Crone and Dahl 2012; Dahl et al. 2018). This may tip the balance and lead to trying out addictive behaviors, which sets in motion a new set of experiential influences on the decision-making process, which, after repeated use may lead to processing priority of cues predicting the addictive behavior (feedback loop in Figure 7.1), through a general mechanism prioritizing cues related to previous rewards. With continued addictive behaviors, typically a number of state-changes occur, including increased stress and negative affect, sometimes linked to withdrawal (Koob and Volkow 2010; Heilig et al. 2010), which can further prioritize conditioned addiction cues in the moment (Oei et al. 2014; Leventhal et al. 2008).

The present perspective could also be seen as an alternative to the brain disease model of addiction, which states that addiction is a chronic brain disease (Leshner 1997; Volkow, Koob, and McLellan 2016), and the other end of the spectrum, which emphasizes that addictive behaviors are not a brain disease but goal-directed behaviors and often discontinued without professional help (Heather et al. 2018; Heyman 2010; Lewis 2015). Apart from severe cases of addiction-induced neuro-degeneration, such as in Korsakov syndrome (Fenton and Wiers 2017), addicted people can still make goal-directed choices, even in the face of an opportunity to use (Hart 2013); but at the same time they also often don't act in accordance with their long-term goals, especially in "hot states", when cues of addictive behaviors are present which are salient due to their reward history and moderated by states in which the addictive behavior was previously employed as a means of relief from an aversive state.

Clinical implications

Regarding prevention, the present perspective would emphasize that delaying experiential learning (hence initiation of the addictive behavior) is an important goal, as there is quite some evidence pointing to stronger reward-learning during adolescence (van Duijvenvoorde et al. 2016), and suggesting that early initiation of the addictive behavior is predictive of later problems (Gladwin et al. 2011; Kuntsche et al. 2013). The question is, of course, how to effectively prevent it. Legislating legal age and taxation have been found to be effective (Room, Babor, and Rehm 2005), and school-based universal prevention has achieved mixed and modest success (Foxcroft and Tsertsvadze 2012), but this can be enhanced when a parent module is added (Koning et al. 2009; Verdurmen et al. 2014; Koning et al. 2015). This type of intervention is targeted at the addictive behavior itself. A very different approach is to enhance self-control and self-regulation processes earlier in development (Dimond and Lee 2011), and one such general training ("good behavior game") in early elementary school found effects in delaying the onset of smoking and drinking in secondary education (Van Lier, Huizink, and Crijnen 2009). In addition to universal prevention, targeted prevention can also be used, specifically targeting individuals with a high risk for developing substance use problems. One successful approach is a personality-focused targeted intervention (Conrod et al. 2006), where young adolescents are selected based on their personality profile (high on one of the risk factors for developing substance use problems later: sensation seeking, impulsivity, hopelessness, and anxiety), who then received a short group-intervention matching their personality, in which their needs are acknowledged (e.g., need to do exciting things for sensation seekers), and more healthy alternatives to meet these needs are discussed (e.g., climbing). This approach has been successful in several randomized controlled trials (RCTs, e.g., Conrod, Castellanos-Ryan, and Mackie 2011; Conrod, Castellanos-Ryan, and Strang 2015).

Once the addictive behavior has established, indicated prevention can be undertaken, for example, motivational interviewing (MI) in heavy drinking students (e.g., Marlatt et al. 1998). In early stages of the addictive behavior, most people can adjust their behavior (using their goal-directed system) with little or no help (Miller 2000). However, in more severely addicted people, professional help can be useful, and different types of psychosocial therapy have been found to be roughly equally (un)successful, with approximately half of the patients relapsing in a year, and 70% in three years (Cutler and Fishbain 2005). From the present perspective, psychosocial treatment works by top-down biasing, either by strengthening goals which are incompatible with continuation of the addictive behavior (MI), and/or by developing strategies (e.g., avoid drinking situations), which are related to top-down control. Top-down control could also be strengthened by training of general cognitive abilities. This type of training has been employed successfully in some studies (Bickel et al. 2011; Snider et al. 2018; Houben, Wiers, and Jansen 2011), but a large study found no effects (Wanmaker et al. 2017), and in the broader literature on cognitive training, generalization to real-world behavior has been problematic (Sonuga-Barke et al. 2013). It could also be enhanced by neurostimulation (Fregni et al. 2005; Gladwin et al. 2012), but findings are at a preliminary stage (Jansen et al. 2013; Fecteau et al. 2010). From the present perspective, this type of training could have an enhancing effect on outcome in people who are motivated to change but have relatively weak abilities for top-down biasing of decision making. The alternative is to focus training on initial reactions to conditioned addiction cues (Wiers 2018), as is done in varieties of cognitive bias modification (CBM; Wiers et al. 2013). From the present perspective, this would come down to aiming to reduce the influence of the conditioned stimuli on the decision-making process. Here also, mixed results have been found (Cristea, Kok, and Cuijpers 2016), but once preclinical proof-of-principle studies are distinguished from randomized controlled trials (RCTs) in clinical samples where CBM is added to psychosocial treatment (Wiers, Boffo, and Field 2018), the pattern is clear: no or very short-lived effects are found in students not motivated to change, but in the clinical RCTs, efficacy of treatment is improved by some 10%, one year after treatment discharge (Wiers et al. 2011; Eberl et al. 2013; Rinck et al. 2018). One important new development is to include personally relevant (often social) alternatives into the decision-making paradigm used in CBM (Kopetz et al. 2017). Recent animal research has also begun to take social alternative reinforcers into account (Venniro et al. 2018), bringing addiction to an important central topic in the newly developing field of social neuro-economics.

Of course there are other ways in which the decision-making process can be influenced, such as medication – although for the treatment of alcohol use disorders, effects of medication as an add-on to psychosocial treatment have been modest (Anton et al. 2006; Beraha et al. 2016) – neurostimulation (separate or during CBM training; den Uyl et al. 2017, 2018), or mindfulness meditation, which, in a proof-of-principle study found effects not by changing the alcohol-approach associations (as is the case in CBM; Wiers et al. 2011) but rather by making participants stop reacting to these associations (Ostafin, Bauer, and Myxter 2012).

Conclusions

In this chapter, we argued that human decision making is influenced by at least three types of input: bottom-up inherently salient stimuli (e.g., a loud noise), top-down goal-directed biasing, and conditioned reward and punishment signals. In addiction, conditioned reward cues can capture attention, and in this way can bias decision making in the direction of the cue with corresponding actions (i.e., addictive behavior), even when this counters other goals. Many cases of seemingly irrational behavior, or *akrasia* (Heather 2017), can be explained by goal conflicts (Becker and Murphy 2002; Kopetz and Orehek 2015; Stroebe et al. 2017). However, as we argued here, this is not the case in the phenomenon of sign-tracking, observed in animal paradigms, and the related VMAC paradigm in humans, where attentional capture and movements toward the sign of the reward make the individual actually forego the same reward. As an addiction develops, cues signaling the addiction are likely to develop the same biasing effects on decision making, which, importantly, does not make the addictive behavior a reflexive outcome (as dual process models and habit theory would state) but rather a more likely outcome of the decision-making process, which brings addiction back to the broader field of neuroeconomics and, when social alternatives are considered, to social neuroeconomics.

Regarding practical implications, there is emerging evidence that sign-tracking develops more strongly when the addictive behavior develops during adolescence; this calls for effective prevention aimed at delaying onset until adulthood, which is not easy to achieve, given also the rise of sensation-seeking in adolescence (Steinberg et al. 2008) and the growing importance of status among peers (Dahl et al. 2018). Finally, regarding treatment, there is emerging evidence that biased processing of addiction-related cues can be directly targeted, which shows promise in the treatment of (alcohol) addiction (Wiers et al. 2013; Wiers, Boffo, and Field 2018; Boffo et al. 2019), when combined with psychosocial treatment. Including socially relevant alternatives may be an important way forward in this type of training, which would place it in the center of the newly emerging field of social neuroeconomics.

Note

1 Note there is continued philosophical debate around the concept of *akrasia*, regarding the question of whether it is possible that people act against their own interests (see, for example, Heather and Segal 2013). We thank Susanne Uusitalo for pointing us to some of these discussions.

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