

Opinion

Towards a Unitary Approach to Human Action Control

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From its academic beginnings the theory of human action control has distinguished between endogenously driven, intentional action and exogenously driven, habitual, or automatic action. We challenge this dual-route model and argue that attempts to provide clear-cut and straightforward criteria to distinguish between intentional and automatic action have systematically failed. Specifically, we show that there is no evidence for intention-independent action, and that attempts to use the criterion of reward sensitivity and rationality to differentiate between intentional and automatic action are conceptually unsound. As a more parsimonious, and more feasible, alternative we suggest a unitary approach to action control, according to which actions are (i) represented by codes of their perceptual effects, (ii) selected by matching intention-sensitive selection criteria, and (ii) moderated by metacontrol states.

Dual Routes to Action Control

An old tradition in folk and academic psychology has it that people can perform actions for two different reasons: either because they 'want' to carry out that action or because they 'were driven' to do so by circumstance. Modern psychological jargon translates this into the distinction between actions that are controlled by internal goals and those that are triggered by external stimuli (Box 1). In the following we briefly review the key criteria that have been considered to be defining in distinguishing between goal- and stimulus-driven behavior: independence from intention, insensitivity to reward, and irrationality – the first of which has already been criticized in the literature (Box 1). However, we will argue that all three criteria fail to delineate two, and separable, routes to action control. Accordingly, we suggest giving up dual-route theorizing altogether, and we replace it by a unitary approach to action control that has two key advantages: it goes beyond the mere binary categorization of actions and their underlying mechanisms by drawing attention to the agent-specific adaptive value that possible transitions from 'intentional' to 'automatic' (or vice versa) can have, and it provides a singular mechanism for capturing such transitions – a considerable gain in theoretical parsimony.

Independence from Intention

The key criterion to distinguish between automatic from intentional behavior in laboratory research asks whether the behavior reflects only those aspects of the current environment that are explicitly indicated as relevant in the task instruction (which is thought to establish a corresponding intention). Let us consider the case of **conflict tasks** (see Glossary) which are commonly assumed to assess and indicate true automaticity. For example, the fact that performance in a **Stroop task** is impaired by incompatible word meanings is taken to indicate a lack of control. In other words, the **compatibility effects** that conflict-inducing tasks produce are taken to imply that nominally irrelevant information cannot be prevented from affecting response selection. However, if we take independence from instruction (and/or intention) as a core characteristic of automaticity, it is fair to say that not one case of complete automaticity has been demonstrated so far.

Trends

Human action control and decision-making are traditionally understood as emerging from the competition between will (representing intentionality and rationality) and habit (representing automatized and stimulus-driven tendencies).

This dual-route concept is still dominant in behavioral, clinical, and neuroscientific research.

Criticism has been accommodated by allowing some degree of continuity between the two routes, but without specifying clear-cut criteria to locate behavior on this continuum, however.

We suggest replacing the dual-route model by a unitary model of action control which assumes that goal-directed actions are represented in terms of expected action effects that are selected according to a match between intended and expected action effects.

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Box 1. Dual-Route Models of Action Control

Dual-route models have enjoyed great popularity from the very first systematic experimental approach to action control by Ach [61]. He suggested that the power of will, which was assumed to control goal-directed action, can be best investigated by contrasting it with overlearned habits which were assumed to be driven by stimuli. Action selection was conceived of as emerging from the competition between automatized habits and current goals, with greater contributions of the latter rendering action increasingly reflective and rational. The basic logic of this dual-route architecture of action control has survived until today, even though the terminology has been updated from time to time [62,63]. Almost no psychological subdiscipline can do without numerous dual-route action-selection models, and highly comparable models have been put forward to account for phenomena such as stimulus–response compatibility [9], executive control [64], addiction [65], moral reasoning [66], decision-making and reasoning [67], and numerous aspects of social behavior [68,69]. All these, and many other dual-route models, distinguish between one system that is responsible for actions that can be considered to be intentional, rational, socially or morally acceptable, or functional and/or constructive, while the other system is responsible for actions that can be considered to be impulsive, socially or morally unacceptable, or dysfunctional and/or destructive. A key variable in most models is time and/or context. While the ‘intentional’ route is assumed to be slow and/or heavily task/context-dependent, the ‘automatic’ route is commonly characterized as being rapid and largely independent from task and context – be it because it is too fast to be affected by context information because it is triggered by an external stimulus, because it is located in an independent brain region, or for all these reasons.

Criticism of dual-route modeling is almost as old as the models themselves. Ach’s concept of will struggling against habits was rejected by Lewin [70], based on evidence suggesting that appropriate goal settings can eliminate any impact of habits altogether (e.g., simply intending to move a door handle up rather than down is sufficient to overcome the previous experience of thousands of downward moves). Similar arguments have been brought forward against more-modern dual-route models [71]. More specifically, overwhelming evidence suggests that the ‘automatic’ route is moderated and presumably even controlled by goals [12,13,72], while the ‘intentional’ route shows numerous characteristics that are commonly associated with automaticity [73].

First, note that in conflict-inducing tasks the nominally irrelevant stimulus (the distractor) varies frequently – this is known to attract attention [1] and introduces stimulus uncertainty that only the processing of this same stimulus can reduce [2]. Under such conditions, any system that aims at optimizing information processing would be expected to make use of the fact that the nominal distractor actually predicts correct performance in 50% of the trials, and would thus try to spare time and effort by considering which response the distractor suggests. Because the sum of distractor-induced improvement and impairment is commonly close to zero (e.g., [3]), there is no obvious disadvantage of this strategy either. Hence, conflict tasks merely show the failure of an information-seeking system (such as the brain) to improve overall performance under conditions where the benefits of information seeking are intentionally counteracted by the design of highly artificial experiments. This can hardly be considered as a demonstration of independence from intention. Moreover, conflict tasks are successful in this respect only if they construe the ‘irrelevant’ information in such a way that it fits the intentionally implemented selection criteria for the relevant information to a substantial degree (i.e., by presenting possible targets in the wrong location). Taken together, what is considered a demonstration of ‘automatic’ processing seems to reflect (not overly costly) side effects of intentional processing.

Second, task context has a strong impact on the degree of ‘automatic’ processing, suggesting that the impact of irrelevant information is moderated by, and presumably even relies on, its motivational and informational value and on information-integration strategies sensitive to this value. For instance, the impact of irrelevant stimulus information on performance in conflict tasks can be significantly reduced or even eliminated (at least in healthy students) by providing high incentives [4] or affective primes [5], or by presenting an incongruent trial immediately before the respective trial [6]. Changing the informational value of irrelevant stimulus information systematically increases or reduces, eliminates, or even reverses its impact on response selection [7,8].

Third, demonstrations of ‘automatic’ information processing have been shown to require the implementation of a task intention. For instance, the advantage of spatially compatible over

Glossary

Compatibility effects: effects that are commonly obtained with conflict tasks, showing that performance is slower and more error-prone if distractors are incompatible with the correct response or the actual target stimulus. Given that such effects reflect the processing of a distractor (i.e., a stimulus feature that the task instruction has declared to be irrelevant), they are taken to demonstrate the automaticity of distractor processing and thus a lack of action control [9].

Conflict task: action control is often investigated by means of conflict tasks in which participants respond to a multidimensional stimulus of which one feature (the ‘target’) signals the instructed response while another feature (the ‘distractor’) may suggest either the same (compatible distractor) or another (incompatible distractor) response or target stimulus. The Stroop task is an example.

Effect representation: according to ideomotor theorizing [20,59], actions are represented in terms of their sensory effects – that is, by codes of the re-afferent information that the performance of an action provides. Recent research has shown that people indeed integrate the motor codes driving an action with codes representing sensory aspects of the performed action itself (e.g., proprioceptive and kinesthetic feedback) and about the external events the action produces (e.g., switching on a light, triggering a sound), but also with codes of the internal reactions to such feedback, including affect and perceived agency.

Event file: a theoretical concept that refers to cognitive/neural structures consisting of codes that represent action effects (i.e., effect representations) and related motor codes (of movements/actions that have been experienced to produce such effects) [59,60]. Event files are taken to represent both perceived events (i.e., stimuli) and produced events (i.e., actions).

Metacognition: a theoretical concept that refers to the fact that action control can vary in ‘style’, as evidenced by observations that action control can emphasize speed or accuracy, persistence or flexibility, and exploitation or exploration [43].

incompatible stimulus–response mappings (a compatibility effect that is considered to reflect automatic, stimulus-induced response conflict [9]) disappears if compatible and incompatible mappings are mixed or if the mapping is presented after the stimulus [10]. Likewise, both behavioral and electrophysiological indicators of the spatial compatibility effect disappear if instructions specifying the stimulus–response mapping are presented after the stimulus [11]. If stimulus–response compatibility phenomena reflect automaticity, we need to conclude that automaticity does not exist without a corresponding intention that apparently enables it [12] – it is a ‘prepared reflex’ [13].

Inensitivity to Reward

Cognitive/behavioral approaches [14,15] consider behavior to be intentional and goal-directed, as opposed to automatic and habitual, if it meets two criteria – the belief criterion (knowledge about the current action–outcome relation) and the desire criterion (the wanting of the current outcome). The first is uncontroversial: if goal-directed behavior is assumed to refer to the intentional creation of some noticeable effect, knowledge about the contingencies between the chosen action and the intended effect represents a logical precondition. The second is questionable, however. The desire criterion is commonly assessed by testing whether a given behavior occurs more frequently in the presence of some experimentally controlled external reward that satisfies a current need. For example by comparing approach behavior to food before and after satiation – with the assumption that approaching food after being satiated can under no circumstances be goal-driven. This operationalization may make sense in animal research, where it indeed originates, but it runs into several problems when applied to humans.

First, human behavior is commonly not driven by one but by many overlapping motives [16], such as social affiliation, obedience, and ethical considerations [17], power and achievement [18], or novelty seeking [19], and actions are commonly embedded into larger-scale activities with multiple goals defined at different levels. As a consequence, even successful satiation of one goal or motive is unlikely to also eliminate all the others. For instance, lighting and smoking a cigarette is a complex multistep activity that consists of various subcomponents, all with their own, well-defined goal: approaching it at the right speed and from the right angle, controlling the distance between the thumb and index finger, exerting force to move it out of the package, etc. All these components combine to one act of smoking, which might also have a biographical meaning (e.g., by confirming the self-image of being an urban cowboy) and reassert social group membership. Satiating the smoker might indeed take away one source of reward or satisfaction but leaves most others intact, such that the attempt to control ‘desire’ by manipulating (one type of) reward seems rather shortsighted.

Second, even the least-motivated action still serves the important goal of testing environmental predictions. Various approaches have characterized the human mind and brain as a predictive system in very similar ways: ideomotor theory [20] claims that agents control intentional actions by anticipating their effects, attentional models suggest that agents use event-induced surprises to build internal models that predict the respective event in the future [21,22], cybernetic approaches assume that agents use comparisons between intended and actual action effects to create internal models of their environment and the actions it affords [23,24], and predictive-coding approaches [25] characterize the main activity of the human brain as aiming to minimize surprise, which in turn is achieved by creating increasingly precise predictions of upcoming events. Note that none of these approaches relies on, or considers, any type of ‘external reward’, thus following Tolman’s idea that the acquisition of information, and the resulting reduction of uncertainty, is rewarding in itself. In drive-theoretical terms, this translates into the assumption that information-seeking is a drive that takes the reduction of uncertainty as an effective reward. Indeed, humans consistently monitor even irrelevant sensory effects of their

Metacontrol is the factor responsible for this emphasis and changes therein, and is assumed to emerge from an interaction between genetic predisposition, cultural impact, and current task demands [44]. It thus governs how control is performed, hence the term metacontrol.

Stroop task: the original version of this conflict task requires participants to respond to the color of color words while ignoring word meaning. Performance is usually impaired if the meaning of the word indicates a color different from the color to be named, which constitutes a compatibility/congruency effect.

actions, and show the same electrophysiological reactions to non-predicted effects as they would show to an actual error [26].

Third, even though 'goal-guided' and 'stimulus-driven' behaviors have been argued to activate partly dissociable neural networks [27], the observation of such dissociations does not necessitate a categorical distinction between different types of behavior. As already mentioned, the same action can be motivated by various motives. Given that the information related to different motives is unlikely to be stored in one single anatomical location, stronger emphasis on one motive is likely to involve different neural structures from emphasis on another motive. If each observation of a non-overlapping neural activity were to be sufficient to establish a new category of action control, the resulting action-category system would become as complex as the motivational structure of human agents.

Taken together, the degree to which actions are sensitive to one specific type of experimentally controlled external reward is unlikely to justify the distinction between goal- and stimulus-driven behavior, or between intentional and automatic behavior. Even more problematic, because external rewards tend to undermine the importance and contribution of internal goals and values [16], studies in which the sensitivity to external reward is considered to be a key criterion for defining intentional action must be considered particularly undiagnostic.

Irrationality

Other approaches have treated rationality as the key factor in differentiating goal-controlled from stimulus-driven behavior. For example, in addiction, behavior is often considered to be driven by habitual rather than goal-directed processes if the object of desire is used or consumed 'despite adverse consequences'. Note that this categorization is inconsistent with the previous one because the addictive behavior commonly satisfies both the belief and the desire criterion – somebody addicted to a drug rightly assumes to get a high when taking it and likely enjoys that effect [28]. The key criterion for considering behavior to be irrational is thus not related to the functionality of the behavior given the particular goal of an individual, but rather to whether the consequences of the behavior are inconsistent with either societal convention (not a strong argument for judging individual intentionality) or some other goal of the acting person (e.g., wanting to lead a healthy life). However, given the hierarchical nature of goals, with some spanning seconds and others spanning years, there is hardly any action that does not lead to conflict of that type [29]. Action selection usually emerges from competition between alternative options [30], and it is difficult to see why meeting short-term goals would need to be mediated by different mechanisms than meeting long-term goals.

The opposite of rationality is often referred to as impulsivity, which involves tendencies to act on a whim, showing behavior indicating little or no forethought, reflection, or consideration of the consequences – behavior that is considered situationally inappropriate and risky [31]. The widely shared assumption is that these types of behaviors are more or less independent from intentions. This assumption fits with findings suggesting that incomplete maturation of the frontal areas supporting intentional action is associated with highly risk-taking behavior [32]. However, many standard definitions of impulsivity reflect societal norms rather than neurally plausible categories. The possible consequences of behavior for a given individual are commonly entirely unknown (e.g., whether a specific person would really die sooner because of smoking or drinking alcohol, and how serious the health problems would really be) and, even if individual risk could be calculated, there is no objective procedure to determine how much risk-taking counts as rational.

The behavior of many pioneers, artists, inventors, and adventurers meets many if not all criteria of impulsive behavior, suggesting that the impulsivity criterion has more to do with societal

conventionality and the willingness to follow social rules than with limitations in the control of goal-directed actions. Indeed, recent findings suggest that the apparent risk-taking tendency in adolescents may reflect increased tolerance for ambiguity rather than an inability to consider known risks in action-planning and decision-making [33], or the fact that other (social) goals are more important than rule-following [28,34]. Moreover, there is no *a priori* reason to believe that leading a long and healthy life is a goal that everyone shares, or that everyone values a healthy life more than the excitement derived from not so healthy behavior. Further, there is no objective justification for considering the unhealthy behavior of a given individual as being any less rational than healthy behavior.

Finally, even if everyone does share the conventional goal of leading a healthy life, it remains unclear, both empirically and theoretically, how this goal should be compared to other reasonable and evolutionary justifiable goals such as eating attractive food [35] or having interesting sexual experiences with attractive partners [36–38]. In the absence of an obvious common currency that would allow pitting the (relatively certain) reward taken from unsafe sexual activities against the (relatively uncertain) possible costs to one's health, considering that one outcome of a choice between respective options is more rational than another seems to be somewhat arbitrary.

Taken together, the distinction between more and less rational behavior seems to be strongly colored by the values and societal norms of the researcher, and thus fails to provide scientifically defensible reasons to divide behavior into two categories. Instead, the rationality/irrationality issue seems to refer to behaviors that are more or less acceptable by the relevant social environment. Although social acceptance is an important characteristic of an action, it does not speak to its intentionality or goal-directedness.

A Unitary Approach

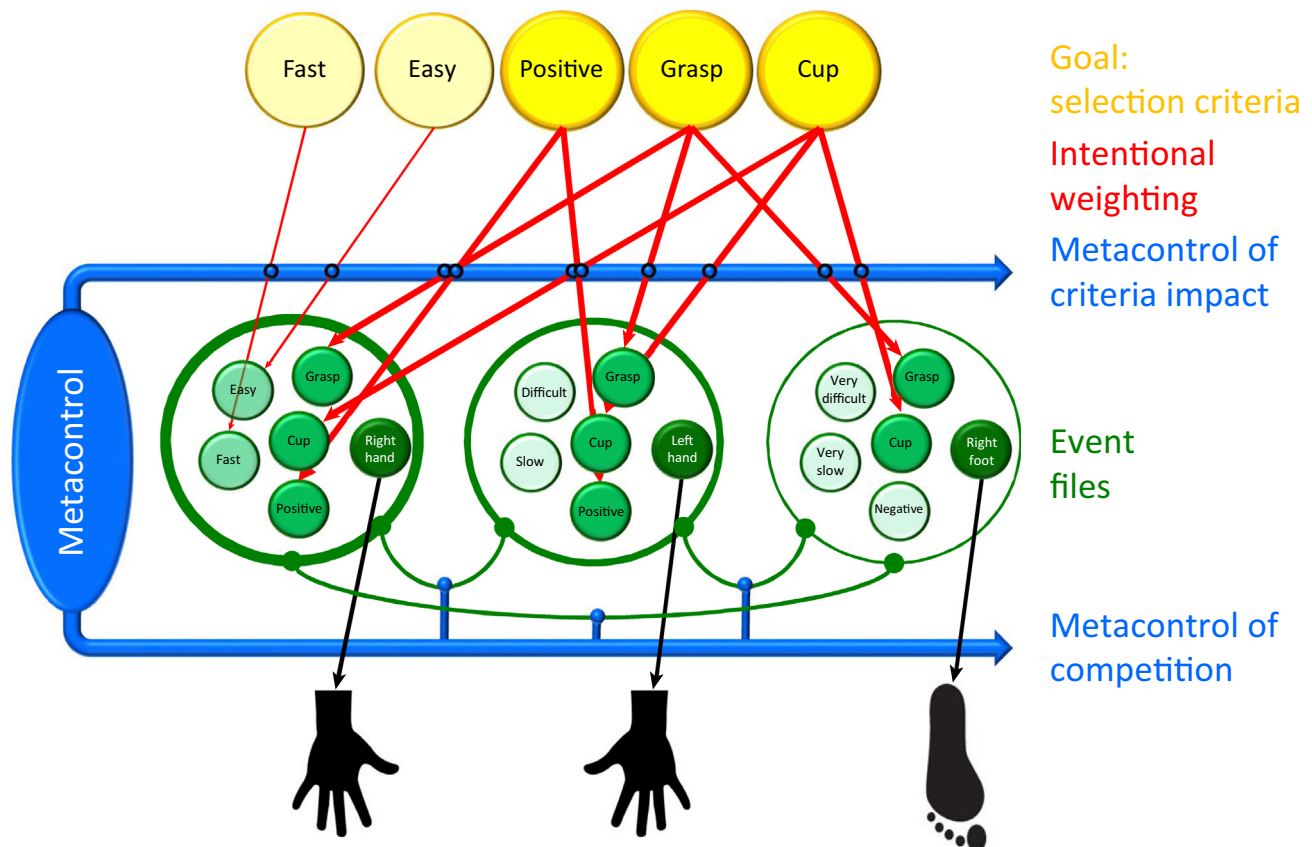
We have argued that neither the dependence on intention, nor the sensitivity to reward, nor the degree of rationality of a behavior provide sufficient reasons to consider it as goal-dependent and intentional versus automatic and habitual. While our arguments are partly different from those of previous critics of the intentional/automaticity division, we are not the first to argue against the division as such (Box 1) [39]. The common conclusion from the criticism is the assumption that what appears to be two separate categories is in fact a continuum, ranging from more or less intentional to more or less automatic behavior [40–42]. Although that provides more theoretical flexibility, it is scarcely a principled solution, the more so because agreed-upon criteria for where to place a given behavior on the assumed continuum are still lacking. What then would be the alternative?

We suggest considering action control as a unitary process. In particular, we suggest that action selection integrates a wide range of information in an attempt to reduce uncertainty regarding (and eventually determining) the most appropriate action. The most appropriate action can satisfy various criteria that together represent the current goal. These criteria might promote actions that are simple, fast, and overlearned, which may often fit the definition of automatic behavior, or actions that are complex, slow, and novel, which is more likely to fit the definition of intentional behavior. Under different conditions, the criteria might favor stimulus-driven over value-driven actions, value-driven over stimulus driven actions, or a mixture of the two action types. Nevertheless, we consider all behaviors to be goal-directed if they satisfy only some criteria held by the agent – which arguably applies to all human behavior investigated so far.

As shown in Figure 1 (Key Figure), our approach assumes that actions are represented by **event files** that integrate motor patterns with codes of their sensory consequences (i.e., **effect**

Key Figure

Schema Illustrating the Unitary Model of Action Control



Trends in Cognitive Sciences

Figure 1. Actions are represented by bindings of sensorimotor features (event files; in green) that compete for action control (as indicated by the mutually inhibitory connections). The example shows some selected features of actions suitable to grasp a cup with either the right, dominant hand (leftmost file), the left, non-dominant hand (center), or the right foot (rightmost file). The remaining feature codes represent past experience of the perceived difficulty and speed (e.g., as indicated by sensed effort, sweat, muscle tension, etc.), and the success of the action (positive versus negative affect). Goals (in yellow) consist of selection criteria that operate intentional weighting (red; i.e., by increasing the weights of intended, as compared to non-intended selection criteria). These are matched against the features included in all available event files, inducing stronger activation (indicated by color intensity) of criteria-matching feature codes and, as a consequence, of the event file containing them. The impact of criteria on the activation of event files and the degree of competition between event files is modulated by metacontrol (blue), which varies between high persistence (maximizing impact and competition) and high flexibility (minimizing impact and competition).

representations; Box 2) and are selected by finding the action that best matches the currently intended effects (i.e., the action goal; Box 3). Depending on the abstraction level of the goal, various event files may become active in the search process, which eventually selects one event file according to a competitive winner-takes-all principle. This search process translates an abstract into a concrete goal, which eventually consists of the effect-representation that is part of the chosen event file. According to this scheme, the goal-directed nature of the action does not depend on whether the action-selection process was originally triggered by exogenous or endogenous events because both operate by selecting goals but not actions. We further assume that adaptive agents actively control the degree to which endogenous or exogenous

Box 2. How Actions Are Represented (Event Files)

Dual-route models aim to explain how actions are selected, but they commonly fail to specify the codes that selection operates on. According to the theory of event coding (TEC [59,74]), actions are represented in terms of the features of their expected sensory consequences (including perceived affect, effort, motivation, etc.) that become integrated with the motor patterns that created these consequences in the past. The resulting sensorimotor 'event files' [60] have two (empirically separable [75]) functions: (i) they store knowledge about the action event over time and can thus serve as standard to compare the expected/predicted outcome of an action with the actual outcome [76], and (ii) activate (i.e., spread activation to) the motor pattern producing an action when one 'intends to' perform (i.e., activates feature codes of the perceptual consequences of) that action [74]. Note that the integration of feature codes and motor pattern provides multiple access to the action, and thus allows activation of the same action for many different 'reasons' (i.e., through activation of different features; e.g., [77]).

Figure 1 illustrates how previous experiences of grasping a cup might be represented (only a few feature codes are shown). The given individual has 'grasped' cups in three different ways in the past: with the dominant (right) hand, the non-dominant (left) hand, and with the right foot. The resulting perceived difficulty, response speed, and affective experience have all been coded into the resulting event file.

events impact on their performance – a process that we call **metaccontrol** because it determines how and according to which 'style' action control is performed [43,44]. It has been argued that adaptive behavior would be ill-served by a cognitive system that carries out goals 'against all odds', irrespective of the current environmental circumstances and their possible implications for other possible goals and motives because events that are irrelevant for the current goal might be very relevant for other and possibly more important goals and motives of the agent. Truly adaptive behavior instead calls for a ('metaccontrol' [43]) system that manages to find the right balance in the dynamic interplay between extreme 'persistence' and extreme 'flexibility' of information processing [45,46]. As indicated in Figure 1, metaccontrol is thought to operate by modulating (increasing or reducing) the impact of goal criteria on action selection and the degree of competition between simultaneously active action representations. A persistence-leaning metaccontrol state strengthens both the impact of the goal criteria on the activation of event files and the competition between them, while a more flexibility-leaning state would weaken both. Moving from one metaccontrol state to another, individuals can

Box 3. How Actions Are Selected (Dynamic Constraint Satisfaction)

Event files [60] (Box 2) allow the selection of actions according to the effects they are likely to produce. Selection thus consists in searching the best fit between the intended effects and the effects that the elements of the available action repertoire (the total of all acquired event files or some contextually defined subset thereof) are known to produce. The criteria guiding the selection may be provided by exogenous sources (e.g., instructions or other context stimuli) or endogenous sources (e.g., elaborate plans, spontaneous impulses, preferences). Whatever the source, what matters is the criteria they specify (the feature values they imply), which may be concrete ('move the index finger of your left hand to press the left key in front of you') or abstract (such as 'do something good', 'be fast', or 'move efficiently'). The less concrete the criteria are, the more event files a match will activate. This induces response uncertainty and competition, the resolution of which requires the specification of further criteria or a randomly determined spontaneous preference [78].

Selecting a response can thus be considered a dynamic process of uncertainty reduction [19] that is more or less constrained by selection criteria and that eventually leads to the selection of a single event file. This process represents the translation of an abstract into a concrete action goal, the transition from a predecisional to an actional phase [79], or the transformation of mere intention to implementation intention [80]. It involves the intentional weighting of feature dimensions that are expected to be relevant for the task or that are suggested by the context [81], which in turn leads to a greater impact of codes that are defined on this dimension.

As shown in Figure 1, the intention to grasp a cup successfully translates into the activation of the criteria 'grasp', 'cup', and 'successful', which in turn recruits all event files sharing these respective features (of the right- and the left-hand action in the example). Constraint satisfaction can (but need not) further be supported by considering additional features, such as maximizing speed and minimizing energy – for example when in a hurry or being exhausted. In the example, emphasizing speed or energy-saving would increase the probability of selecting the right-hand over the left-hand action.

systematically increase or reduce the impact of endogenous and exogenous sources of information [43,44].

Not enough is known about the factors that are driving metacontrol, but recent findings suggest a few promising candidates (in addition to longer-term genetic and cultural biases [44]): performance-contingent reward seems to increase persistence (at the expense of flexibility) and thus the focus on task-relevant information [45,47], as do conflict [48] and conflict-induced negative affect [49]. Performance-unrelated positive mood has the opposite effect by increasing not only flexibility [50] but also distractibility [45]. Selection uncertainty may increase flexibility so as to allow more information to reduce uncertainty [51]. Another factor may be time [41]: early decision-making phases may be dominated by quickly available, but not necessarily relevant, information, while later stages are dominated by relevant information, and this would fit with the idea that selection uncertainty (which should decrease over time) plays an important role. Of particular (theoretical and clinical) interest, the time factor would suggest that slowing down or putting less time pressure on decision-making can make it more 'rational', that is, more dependent on (e.g., socially) relevant information [41].

The assumption that metacontrol allows flexible adjustment of how, and the degree to which, internal and external events contribute to action control accommodates findings showing that people prefer uncommon or novel actions to reach a goal under some conditions, but prefer overlearned and familiar actions to reach the same goal under others. However, instead of attributing this to an unavoidable consequence of the breakdown of endogenous action control and the takeover of stimulus-driven automaticity, we interpret such observations as indicating that selection criteria, such as energy consumption and efficiency, reflect possible shortages of currently available cognitive resources and motivation. In other words, switching to more efficient and overlearned actions is not a bug but an adaptive feature of human cognition. Allowing for various possible criteria that could be concrete ('be fast') or vague ('do something good'; i.e., select an action that has social approval as one of its effects) suggests a unitary action-control model that behaves as a multiple-route model with as many routes as the criteria one applies. Note that our approach incorporates the belief criterion, in the sense that true actions are selected by anticipating their consequences, but gives up the desire criteria – at least as held by traditional cognitive/behavioral approaches. It also avoids cultural and societal biases that confuse the social acceptance of actions with their rationality.

Concluding Remarks

Where does our plea for a unitary approach to action control leave dual-process accounts? Given their folk-psychological appeal, one could view them as providing descriptive, intuitive terminology to characterize actions in terms of social norms and acceptability. For example, although most male students report reluctance to engage in unsafe sex when being asked in a motivationally 'dry' situation, this intention tends to weaken after drinking alcohol and being primed with a movie in which they are seduced by an attractive female student [36,37]. There is no reason to consider the latter behavior 'irrational': many students find their romantic partner in a far from sober state, and partner selection is one of the main goals of this developmental period [52], but it is fair to say that it does constitute a societally less-acceptable behavior. Given that determining the social appropriateness of a given action is likely to take more processing time than considering its immediate sensory consequences, it also makes sense to assume that quickly generated actions might sometimes be less likely to meet social approval than actions selected after extended deliberation. If so, individual preferences for fast versus slow decision-making can be expected to translate into individual differences regarding socially appropriate behavior, including substance abuse [53–56]. Nevertheless, that does not imply that individuals with supposedly 'weaker executive functions' (or less persistence in decision-making) are unable to translate their intentions into action, they merely prefer making quick

Outstanding Questions

How are instructions translated into selection criteria?

Can particular selection criteria be conditioned to particular goals?

How is the efficiency of an action determined, and in what format is it coded?

How, and according to which principles, do internal states (such as exhaustion of cognitive resources) activate the corresponding selection criteria (such as efficiency)?

How do particular individuals develop particular decision-making and meta-control styles?

Can preferences for particular selection criteria be acquired, and what is the role of genetic predisposition?

How can detrimental preferences for particular selection criteria be changed when they are harmful to the individual (and the individual agrees)?

decisions based on salient cues [57,58]. In conclusion, while the intentional/automatic dichotomy might continue to serve a useful descriptive role, we suggest that the underlying processes are best captured by a unitary model as outlined here.

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References

- Goldstone, R.L. *et al.* (1997) Similarity in context. *Mem. Cognit.* 25, 237–255
- Luce, R.D. (2003) Whatever happened to information theory in psychology? *Rev. Gen. Psychol.* 7, 183–188
- Hommel, B. (1993) Inverting the Simon effect by intention: determinants of direction and extent of effects of irrelevant spatial information. *Psychol. Res.* 55, 270–279
- MacKinnon, D.P. *et al.* (1985) The effects of effort on Stroop interference. *Acta Psychol.* 58, 225–235
- Kuhl, J. and Kazén, M. (1999) Volitional facilitation of difficult intentions: joint activation of intention memory and positive affect removes Stroop interference. *J. Exp. Psychol. Gen.* 128, 382–399
- Gratton, G. *et al.* (1992) Optimizing the use of information: strategic control of activation of responses. *J. Exp. Psychol. Gen.* 121, 480–506
- Hommel, B. (1994) Spontaneous decay of response code activation. *Psychol. Res.* 56, 261–268
- Logan, G.D. and Zbrodoff, N.J. (1979) When it helps to be misled: facilitative effects of increasing the frequency of conflicting stimuli in a Stroop-like task. *Mem. Cognit.* 7, 166–174
- Kornblum, S. *et al.* (1990) Dimensional overlap: cognitive basis for stimulus–response compatibility – a model and taxonomy. *Psychol. Rev.* 97, 253–270
- Shaffer, L.H. (1965) Choice reaction with variable S–R mapping. *Exp. Psychol.* 70, 284–288
- Valle-Inclán, F. and Redondo, M. (1998) On the automaticity of ipsilateral response activation in the Simon effect. *Psychophysiology* 35, 366–371
- Bargh, J.A. (1989) Conditional automaticity: varieties of automatic influences in social perception and cognition. In *Unintended Thought* (Uleman, J.S. and Bargh, J.A., eds), pp. 3–51, Guilford Press
- Hommel, B. (2000) The prepared reflex: automaticity and control in stimulus–response translation. In *Control of Cognitive Processes: Attention and Performance XVIII* (Monsell, S. and Driver, J., eds), pp. 247–273, MIT Press
- Balleine, B.W. and Dickinson, A. (1998) Goal-directed instrumental action: contingency and incentive learning and their cortical substrates. *Neuropharmacology* 37, 407–419
- Heyes, C. and Dickinson, A. (1990) The intentionality of animal action. *Mind Lang.* 5, 87–104
- Deci, E.L. *et al.* (1999) A meta-analytic review of experiments examining the effects of extrinsic rewards on intrinsic motivation. *Psychol. Bull.* 125, 627–668
- Heider, F. (1958) *The Psychology of Interpersonal Relations*, John Wiley & Sons
- McClelland, D.C. (1985) How motives, skills, and values determine what people do. *Am. Psychol.* 40, 812–825
- Berlyne, D.E. (1960) *Conflict, Arousal and Curiosity*, McGraw-Hill
- Shin, Y.K. *et al.* (2010) A review of contemporary ideomotor theory. *Psychol. Bull.* 136, 943–974
- Sokolov, E.N. (1963) *Perception and the Conditioned Reflex*, Macmillan
- Lyytinen, H. *et al.* (2012) *The Orienting Response in Information Processing*, Lawrence Erlbaum
- Powers, W.T. (1973) *Behavior: The Control of Perception*, Aldine
- Wolpert, D.M. and Ghahramani, Z. (2000) Computational principles of movement neuroscience. *Nat. Neurosci.* 3, 1212–1217
- Friston, K. (2010) The free-energy principle: a unified brain theory? *Nat. Rev. Neurosci.* 11, 127–138
- Band, G.P.H. *et al.* (2009) Action-effect negativity: irrelevant action effects are monitored like relevant feedback. *Biol. Psychol.* 82, 211–218
- Lee, S.W. *et al.* (2014) Neural computations underlying arbitration between model-based and model-free learning. *Neuron* 81, 687–699
- Kopetz, C. and Orehhek, A.E. (2015) When the end justifies the means: self-defeating behavior as ‘rational’ and ‘successful’ self-regulation. *Curr. Dir. Psychol. Sci.* 24, 386–398
- Kopetz, C.E. *et al.* (2013) Motivation and self-regulation in addiction: a call for convergence. *Perspect. Psychol. Sci.* 8, 3–24
- Bogacz, R. (2007) Optimal decision-making theories: linking neurobiology with behaviour. *Trends Cogn. Sci.* 11, 118–125
- Daruna, J.H. and Barnes, P.A. (1993) A neurodevelopmental view of impulsivity. In *The Impulsive Client: Theory, Research, and Treatment* (McCown, W.G. *et al.*, eds), pp. 23–37, American Psychological Association
- Steinberg, L. (2008) A social neuroscience perspective on adolescent risk taking. *Dev. Rev.* 28, 78–106
- Tymula, A. *et al.* (2012) Adolescents’ risk-taking behavior is driven by tolerance to ambiguity. *Proc. Natl. Acad. Sci. U. S. A.* 109, 17135–17140
- Crone, E.A. and Dahl, R.E. (2012) Understanding adolescence as a period of social-affective engagement and goal flexibility. *Nat. Rev. Neurosci.* 13, 636–650
- Stroebe, W. *et al.* (2013) Why most dieters fail but some succeed: a goal conflict model of eating behavior. *Psychol. Rev.* 120, 110–138
- MacDonald, T.K. *et al.* (2000) Alcohol, sexual arousal, and intentions to use condoms in young men: applying alcohol myopia theory to risky sexual behavior. *Health Psychol.* 19, 290–298
- MacDonald, T.K. *et al.* (1996) Why common sense goes out of the window: effects of alcohol on intentions to use condoms. *Pers. Soc. Psychol. Bull.* 22, 763–775
- Hofmann, W. *et al.* (2011) The great disinhibitor: alcohol, food cues, and eating behavior. In *Handbook of Behavior, Food, and Nutrition* (Preedy, V.R. *et al.*, eds), pp. 2977–2991, Springer
- Kruglanski, A.W. and Gigerenzer, G. (2011) Intuitive and deliberate judgments are based on common principles. *Psychol. Rev.* 118, 97–109
- Cunningham, W.A. and Zelazo, P.D. (2007) Attitudes and evaluations: a social cognitive neuroscience perspective. *Trends Cogn. Sci.* 11, 97–104
- Gladwin, T.E. *et al.* (2011) Addiction, adolescence, and the integration of control and motivation. *Dev. Cogn. Neurosci.* 1, 364–376
- Wiers, R.W. and Gladwin, T.E. (2017) Reflective and impulsive processes in addiction and the role of motivation. In *Reflective and Impulsive Determinants of Human Behavior* (Deutsch, R. *et al.*, eds), pp. 173–188, Psychology Press
- Hommel, B. (2015) Between persistence and flexibility: the Yin and Yang of action control. In *Advances in Motivation Science* (Elliot, A.J., ed.), pp. 33–67, Elsevier

44. Hommel, B. and Colzato, L.S. (2017) The social transmission of metacontrol policies: mechanisms underlying the interpersonal transfer of persistence and flexibility. *Neurosci. Biobehav. Rev.* Published online January 11, 2017. <http://dx.doi.org/10.1016/j.neubiorev.2017.01.009>
45. Dreisbach, G. and Goschke, T. (2004) How positive affect modulates cognitive control: reduced perseveration at the cost of increased distractibility. *J. Exp. Psychol. Learn. Mem. Cognit.* 30, 343–353
46. Cools, R. and D'Esposito (2010) Dopaminergic modulation of flexible cognitive control in humans. In *Dopamine Handbook* (Björklund, A. et al., eds), Oxford University Press
47. Hefer, C. and Dreisbach, G. (2017) How performance-contingent reward prospect modulates cognitive control: increased cue maintenance at the cost of decreased flexibility. *J. Exp. Psychol. Learn. Mem. Cognit.* Published online March 13, 2017. <http://dx.doi.org/10.1037/xlm0000397>
48. Botvinick, M.M. et al. (2001) Conflict monitoring and cognitive control. *Psychol. Rev.* 108, 624–652
49. van Steenbergen, H. et al. (2009) Reward counteracts conflict adaptation: evidence for a role of affect in executive control. *Psychol. Sci.* 20, 1473–1477
50. Baas, M. et al. (2008) A meta-analysis of 25 years of mood-creativity research: hedonic tone, activation, or regulatory focus? *Psychol. Bull.* 134, 779–806
51. Waszak, F. et al. (2003) Task-switching and long-term priming: role of episodic stimulus–task bindings in task-shift costs. *Cognit. Psychol.* 46, 361–413
52. Erikson, E.H. (1979) *Dimensions of a New identity*, Norton & Company
53. Grenard, J.L. et al. (2008) Working memory moderates the predictive effects of drug-related associations. *Psychol. Addict. Behav.* 22, 426–432
54. Hofmann, W. et al. (2008) Working memory capacity and self-regulation: toward an individual differences perspective on behavior determination by automatic versus controlled processes. *J. Pers. Soc. Psychol.* 95, 962–977
55. Peeters, M. et al. (2013) Automatic processes and the drinking behavior in early adolescence: a prospective study. *Alcohol. Clin. Exp. Res.* 37, 1737–1744
56. Wiers, R.W. et al. (2015) On the development of implicit and control processes in relation to substance use in adolescence. *Curr. Addict. Rep.* 2, 141–155
57. Albertella, L. et al. (2017) Selective attention moderates the relationship between attentional capture by signals of nondrug reward and illicit drug use. *Drug Alcohol Depend.* 175, 99–105
58. Le Pelley, M.E. et al. (2015) When goals conflict with values: counterproductive attentional and oculomotor capture by reward-related stimuli. *J. Exp. Psychol. Gen.* 144, 158–171
59. Hommel, B. et al. (2001) The theory of event coding (TEC): a framework for perception and action planning. *Behav. Brain Sci.* 24, 849–878
60. Hommel, B. (2004) Event files: feature binding in and across perception and action. *Trends Cogn. Sci.* 8, 494–500
61. Ach, N. (1910) *Über den Willensakt und das Temperament, eine Experimentelle Untersuchung*, Quelle & Meyer
62. Dolan, R.J. and Dayan, P. (2013) Goals and habits in the brain. *Neuron* 80, 312–325
63. Hofmann, W. et al. (2009) Impulse and self-control from a dual-systems perspective. *Perspect. Psychol. Sci.* 4, 162–176
64. Verbruggen, F. et al. (2014) Banishing the control homunculi in studies of action control and behavior change. *Perspect. Psychol. Sci.* 9, 497–524
65. Wiers, R.W. and Stacy, A.W. (2006) Implicit cognition and addiction. *Curr. Dir. Psychol. Sci.* 15, 292–296
66. Greene, J. and Haidt, J. (2002) How (and where) does moral judgment work? *Trends Cogn. Sci.* 6, 517–523
67. Kahneman, D. (2011) *Thinking, Fast and Slow*, Farrar, Strauss, Giroux
68. Chaiken, S. and Trope, Y., eds (1999) *Dual-Process Theories in Social Psychology*, Guildford Press
69. Strack, F. and Deutsch, R. (2004) Reflective and impulsive determinants of social behavior. *Pers. Soc. Psychol. Rev.* 3, 220–247
70. Lewin, K. (1922) Das Problem der Willensmessung und das Grundgesetz der Assoziation II. *Psychol. Forsch.* 2, 65–140
71. Keren, G. and Schul, Y. (2009) Two is not always better than one. A critical evaluation of two-system theories. *Perspect. Psychol. Sci.* 4, 533–550
72. Hommel, B. (2017) Goal-directed actions. In *Handbook of Causal Reasoning* (Waldmann, M., ed.), pp. 265–278, Oxford University Press
73. Bargh, J. et al. (2001) The automated will: nonconscious activation and pursuit of behavioral goals. *J. Pers. Soc. Psychol.* 81, 1014–1027
74. Hommel, B. (2009) Action control according to TEC (theory of event coding). *Psychol. Res.* 73, 512–526
75. Verschoor, S.A. et al. (2013) From outcome prediction to action selection: developmental change in the role of action–effect bindings. *Dev. Sci.* 16, 801–814
76. Blakemore, S.J. et al. (2002) Abnormalities in the awareness of action. *Trends Cogn. Sci.* 6, 237–242
77. Janczyk, M. et al. (2009) Visual and tactile action effects determine bimanual coordination performance. *Hum. Mov. Sci.* 28, 437–449
78. Lewin, K. (1938) *The Conceptual Representation and the Measurement of Psychological Forces*, Duke University Press
79. Heckhausen, H. (1991) *Motivation and Action*, Springer
80. Gollwitzer, P.M. (1999) Implementation intentions: strong effects of simple plans. *Am. Psychol.* 54, 493–503
81. Memelink, J. and Hommel, B. (2013) Intentional weighting: a basic principle in cognitive control. *Psychol. Res.* 77, 249–259