TOWARDS A UNITARY APPROACH TO HUMAN ACTION CONTROL

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Abstract

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, 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 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 (a) represented by codes of their perceptual effects; (b) selected by matching intention-sensitive selection criteria; and (c) 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 actions that are triggered by external stimuli (Box 1). In the following, we will briefly review the key criteria that have been considered defining for distinguishing between goal- and stimulus-driven behavior: independence from intention, insensitivity to reward,

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 [1]. He suggested that the power of will, which was assumed to control goal-directed action, can be best investigated by putting it into opposition to 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 [2,3]. Hardly any psychological subdiscipline can do without numerous dual-route action-selection models, and highly comparable models have been suggested to account for phenomena like stimulus-response compatibility [4], executive control [5], addiction [6], moral reasoning [7], decision-making and reasoning [8], and numerous aspects of social behavior [9,10]. All these, and many other dual-route models distinguish between one system that is responsible for actions that can be considered intentional, rational, socially or morally acceptable, functional and/or constructive, while the other system is responsible for actions that can be considered impulsive, socially or morally inacceptable, 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 fast 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 because all of that.

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 [11], 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 [12]. More specifically, overwhelming evidence suggests that the "automatic" route is moderated, presumably even controlled by goals [13-15], while the "intentional" route shows numerous characteristics that are commonly associated with automaticity [16].

and irrationality, of which the first 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 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.

Glossary

Compatibility/congruency effect: 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 irrelevant), they are taken to demonstrate the automaticity of distractor processing and, thus, a lack of action control [4].

Effect representation: According to ideomotor theorizing [33,56], actions are represented in terms of their sensory effects, that is, by codes of the re-afferent information 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 of the internal reactions to such feedback, including affect and perceive 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) [56,58]. Event files are taken to represent both perceived events (i.e., stimuli) and produced events (i.e., actions).

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.

Metacontrol: A theoretical concept that refers the fact that action control can vary in "style", as evident from observations that action control can emphasize speed or accuracy, persistence or flexibility, and exploitation or exploration [66]. 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 [67]. It thus controls how control is performed, hence the term *meta*control.

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 another color than the to-be-named one, which constitutes a compatibility/congruency effect.

Independence from intention

The key criterion to tell 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, which are commonly taken 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 the 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.

First, note that conflict-inducing tasks have the nominally irrelevant stimulus (the distractor) vary frequently—which is known to attract attention [17] and introduce stimulus uncertainty that only the processing of this very stimulus can reduce [18]. Under such conditions, any system that aims at optimizing information processing should be expected to make use of the fact that the nominal distractor actually predicts correct performance in 50% of the trials, and thus try sparing time and effort by considering which response the distractor suggests. As the sum of distractor-induced improvement and impairment is commonly close to zero [e.g.,19], 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 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 altogether, 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 [20], affective primes [21], or presenting an incongruent trial right before the respective trial [22]. Changing the informational value of irrelevant stimulus information systematically increases or reduces, eliminates, or even reverses its impact on response selection [23,24].

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 incompatible stimulus-response mappings (a compatibility effect that is considered to reflect automatic, stimulus-induced response conflict [4]) disappears if compatible and incompatible mappings are mixed or if the mapping is presented after the stimulus [25]. Likewise, both behavioral and electrophysiological indicators of the spatial compatibility effect disappear if instructions specifying the stimulus-response mapping are presented after the stimulus [26]. If stimulus-response compatibility phenomena reflect automaticity, we need to conclude that automaticity does not exist without a corresponding intention that apparently enables it [13]—it is a "prepared reflex" [14].

Insensitivity to reward

Cognitive-behavioral approaches [27,28] consider behavior 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—the assumption being that approaching food after being sated 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 [29], like social affiliation, obedience, and ethical considerations [30], power and achievement [31], or novelty seeking [32], 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 eliminate all others as well. For instance, lighting and smoking a cigarette is a complex multi-step 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, so that the attempt to control "desire" by manipulating (one kind 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 [33] 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 [34,35], 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 [36,37], and predictive-coding approaches [38] 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 kind 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 effective reward. Indeed, humans consistently monitor even irrelevant sensory effects of their actions and show the same electrophysiological reactions to non-predicted effects as they would show for an actual error [39].

Third, even though "goal-guided" and "stimulus-driven" behaviors have been argued to activate partly dissociable neural networks [40], the observation of such dissociations does not necessitate a categorical distinction between different kinds 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 spot, stronger emphasis on one motive is likely to involve different neural structures than emphasis on another. If each observation of a non-overlapping neural activity were 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 kind of experimentally-controlled external reward is unlikely to justify the distinction between goal- and stimulus-driven, or intentional and automatic behavior. Even more problematic, as external rewards tend to undermine the importance and contribution of internal goals and values [29], studies in which the sensitivity to external reward is considered 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, as the addictive behavior is commonly satisfying 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 [41]. The key criterion for considering behavior irrational is thus not related to the functionality of the behavior given an individual’s particular goal, 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 sort [42]. Action selection usually emerges from competition between alternative options [43], 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 [44]. The widely-shared assumption is that these kinds 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 are associated with highly risk-taking behavior [45]. 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 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 the inability to consider known risks in action planning and decision-making [46], or the fact that other (social) goals are more important than rule-following [41,47]. 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 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 with other reasonable and evolutionary justifiable goals such as eating attractive food [48], or having interesting sexual experiences with attractive partners [49-51]. 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 for one's health, considering one outcome of a choice between respective options more rational than another seems rather 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, which fails to provide scientifically defendable 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. While 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 provides sufficient reasons to consider it as goal-dependent and intentional versus automatic and habitual. While our arguments are partly different from previous critics of the intentional/automaticity division, we are not the first to argue against the division as such (see Box 1; [52]). The common conclusion from the criticism is the assumption that what looks like two separate categories is in fact a continuum, ranging from more or less intentional to more or less automatic behavior [53-55]. While that provides more theoretical flexibility, it is hardly a principled solution, the more so as agreed-upon criteria for where to place a given behavior on the assumed continuum are still lacking. But what 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 determine) 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 with the definition of automatic behavior, or actions that are complex, slow, and novel, which is more likely to fit with 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. And yet, we consider all behaviors as goal-directed, if they only satisfy some criteria held by the agent—which arguably applies to all human behavior investigated so far.

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: [56,57]), 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" [58] have two (empirically separable: [59]) functions: (1) 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 [60]; and (2) 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 [57]. 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.,61]).

Figure 1 illustrates how previous experiences of grasping a cup might be represented (just 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.

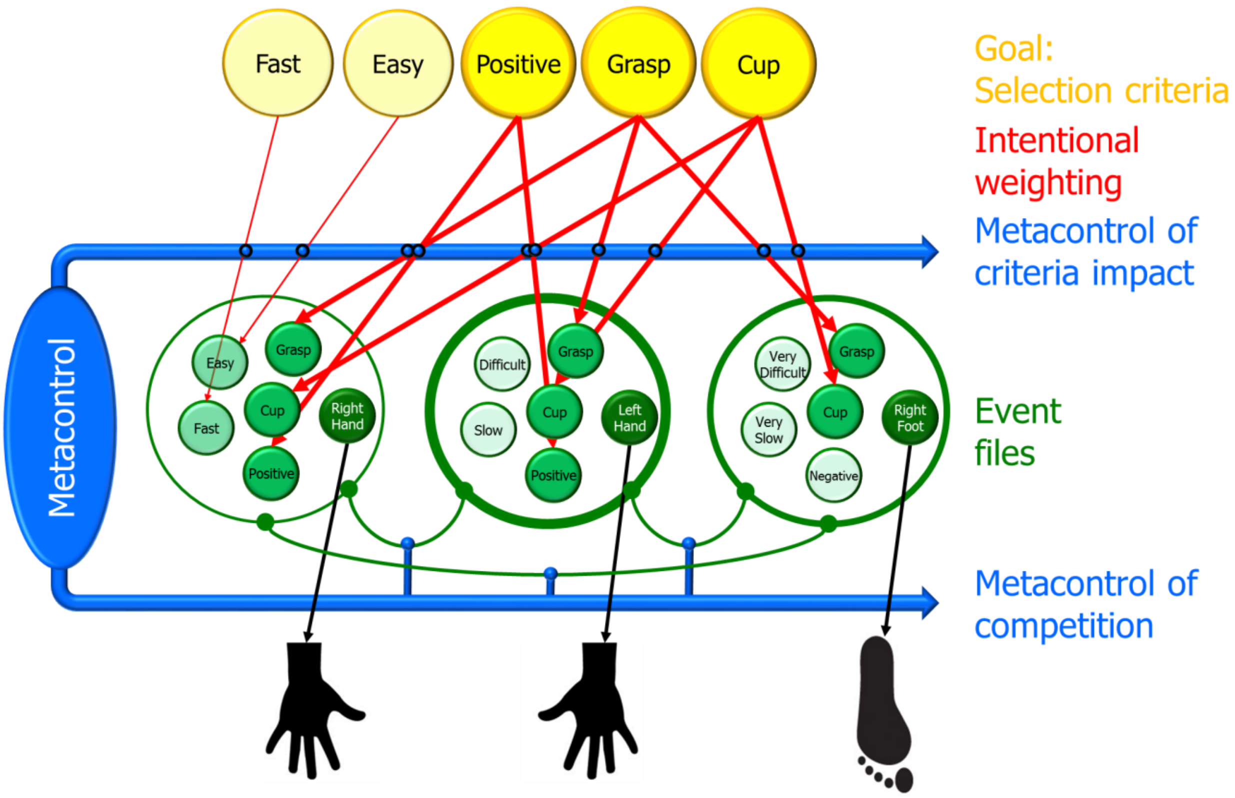

Figure 1: Schema illustrating the unitary model of action control. Actions are represented by bindings of sensorimotor features (**event files**) that compete for action control (as indicated by the mutually inhibitory connections). The example shows some selected features of actions suitable to grasp 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 with 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** consist of **selection criteria** that operate **intentional weighting** (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**, which varies between high persistence (maximizing impact and competition) and high flexibility (minimizing impact and competition).

As shown in Figure 1, our approach assumes that actions are represented by event files that integrate motor patterns with codes of their sensory consequences (i.e., effect-representations; see Box 2) and selected by finding the action that best matches the currently intended effects (i.e., the action goal; see 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

Box 3: How actions are selected (dynamic constraint-satisfaction)

Event files ([58], Box 2) allow for 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 [62].

Selecting a response can thus be considered a dynamic process of uncertainty reduction [32], that is more or less constrained by selection criteria and that eventually leads to the selection of one 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 [63], or the transformation of mere intention to implementation intention [64]. It involves the "intentional weighting" of feature dimensions that are expected to be relevant for the task or suggested by the context [65], which in turn leads to a greater impact of codes defined on this dimension.

Figure 1 indicates that 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—e.g., 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.

process was originally triggered by exogenous or endogenous events, as both operate by selecting goals but not actions. We further assume that adaptive agents actively control the degree to which endogenous or exogenous events impact their performance—a process that we call metacontrol, as it determines how, according to which "style" action control is performed [66,67]. 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, as events that are irrelevant for the current goal might be very relevant for other, possibly more important goals and motives of the agent. Truly adaptive behavior rather calls for a ("metacontrol" [66]) system that manages to find the right balance in the dynamic interplay between extreme “persistence” and extreme “flexibility” of information processing [68,69]. As indicated in Figure 1, metacontrol 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 metacontrol 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 metacontrol state to another, individuals can systematically increase or reduce the impact of endogenous and exogenous sources of information [66,67].

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 [67]): Performance-contingent *reward* seems to increase persistence (at the expense of flexibility) and, thus, the focus on task-relevant information [68,70], as does *conflict* [71] or conflict-induced negative affect [72]. Performance-unrelated positive *mood* has the opposite effect by increasing flexibility [73], but also distractibility [68]. *Selection uncertainty* may increase flexibility, so to allow more information to reduce uncertainty [74]. Another factor may be *time* [54]: early decision-making phases may be dominated by quickly-available, but not necessarily relevant, information while later stages are dominated by relevant information, which 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 [54].

The assumption that metacontrol allows for the flexible adjustment of the way of how, and the degree to which internal and external events contribute to action control accommodates for findings showing that people prefer uncommon or novel actions to reach a goal under some conditions but overlearned, familiar actions to reach the same goal under others. However, rather than 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, 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, while 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 [49,50]. 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 developmental goals of this developmental period [75]; 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 [76-79]. And yet, 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 just prefer making quick decisions based on salient cues [80,81]. In conclusion, while the intentional/automatic dichotomy might keep serving a useful descriptive role, we suggest that the underlying processes are best captured by a unitary model as outlined here.

Outstanding Questions Box

- 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 which format is it coded?
- How, and according to which principles do internal states (like exhaustion of cognitive resources) activate the corresponding selection criteria (like efficiency)?
- How do particular individuals develop particular decision-making and metacontrol 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)?

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