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THEORETICAL NOTE

The Meaning of Attention Control

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Attention control has been proposed as an ability construct that explains individual differences in fluid intelligence. Evaluating this hypothesis is complicated by a lack of clarity in the definition of attention control. Here, I propose a definition of attention control, based on experimental research and computational models of what guides attention, and how cognitive processes are controlled. Attention is the selection of mental representations for prioritized processing, and the ability to control attention is the ability to prioritize those representations that are relevant for the person's current goal, thereby enabling them to think and act in accordance with their intentions. This definition can be used to identify appropriate and less appropriate ways to measure individual differences in attention control. An analysis of various approaches to measurement reveals that the current practice of measuring attention control leaves room for improvement. Aligning our psychometric measurements with a clear, theoretically grounded concept of attention control can lead to more valid measures of that construct.

Keywords: attention, control, individual differences, intelligence, executive functions

The concept of attention control (AC) is the cornerstone of a leading hypothesis about the nature of individual differences in cognitive abilities. Engle, Kane, Unsworth, and their colleagues have advanced the hypothesis that fluid intelligence is AC ability (Engle, Kane, & Tuholski, 1999; Kane et al., 2001; Shipstead et al., 2016; Unsworth, Miller, & Robison, 2021; Unsworth et al., 2014). If we understood the concept of AC better than the concept of fluid intelligence, that would be substantial progress. Unfortunately, I believe that we do not.

This is not because of a lack of knowledge about attention. Experimental psychology and cognitive neuroscience have generated a substantial and solid body of knowledge about attention and the processes that control it. The problem is that AC as an individual-differences construct—a hypothetical latent variable that explains interindividual variation in cognitive performance—is not as precisely defined as it could be. The goal of this essay is to leverage knowledge from cognitive psychology and cognitive neuroscience to clarify the concept of AC as a construct that refers to a cognitive ability varying between individuals. A well-defined concept of AC will provide a clear target for our efforts to measure individual differences in AC, thereby providing guidance on which observable variables can serve as valid psychometric indicators of AC.

The fuzziness of the AC concept arises in part from an ambiguity about whether attention is the agent or the object of control. The proponents of the AC hypothesis often define AC as the ability to control attention. For instance, Unsworth, Miller, and Robison (2021) defined it as "the ability to control our attention to focus on important information and block potential distracting information" (p. 1332). Here, attention is clearly the object of control; it is being controlled. However, in other contexts, authors define AC more broadly as encompassing all controlled cognitive processes. For instance, Draheim et al. (2021) used *attention control* interchangeably with *executive attention* and defined it as: "Broadly defined, executive attention guides the control of thoughts and behavior in a goal-driven manner and is particularly important when there is a conflict between more automatic processes and one's intentions" (p. 242). Here, (executive) attention is the agent; it does the controlling. This is also obvious in Tsukahara et al. (2020), who stated that "attention control is not defined by one specific mechanism or process but rather acts to organize and modulate processes around a particular goal" (p. 3347). Here, attention is described as the agent of organization and modulation of processes.

This ambiguity of attention as an agent and as an object of control is already apparent in one classic work at the foundation of AC theory. Schneider and Shiffrin (1977) and Shiffrin and Schneider (1977) started their conceptual analysis with the concept of a *control process*, as it was introduced in the memory model of Atkinson and Shiffrin (1968). Control processes are processes that control the information flow in the memory system, including rehearsal, search

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in long-term memory (LTM), and "decisions of all sorts" (Schneider & Shiffrin, 1977, p. 2). From there, these authors seamlessly move to the introduction of the notion of *controlled processes*—contrasted with automatic processes—which they define as "a temporary sequence of nodes activated under the control of, and through attention by, the subject" (Schneider & Shiffrin, 1977, p. 2).[1] The term *control process* implies that there is an object of control—something that these processes are controlling. In the theory of Schneider and Shiffrin, they control the flow of information between memory stores. Understood more broadly, they could also control where attention is directed to next. In contrast, the term *controlled process* designates a process that is itself controlled, and the controller is the person. Writers who shy away from invoking the person, or the "subject," as an agent in an explanation of cognition replace it by attention as the agent of control.

The two roles of attention correspond to two concepts of attention. When attention is the object of control, it is usually understood as a mechanism for selectively enhancing the processing of attended information, thereby prioritizing that information over other not-attended information (Carrasco, 2011). In contrast, when attention is the agent of control, it is conceptualized as an executive or supervisory system (Baddeley, 1986; Norman & Shallice, 1980) that selects cognitive operations and overt actions or biases their selection. In the next section, I will explicate the two definitions of attention and the corresponding definitions of AC. I will argue that both approaches to conceptualizing AC can be spelled out in a way that makes them converge so that they largely refer to the same set of cognitive mechanisms and processes. After outlining this concept of AC, I will draw out its implications for how we measure AC as an individual-differences construct.

Table 1
Glossary

Concept	Definition used here
Attention	Selection of a subset of representations for prioritized processing
Control of attention	Guidance of attention "top-down" in accordance with the person's current intention
Controlled process	Cognitive operation or overt action that a person intends to carry out
Guidance of attention	Set of all forces influencing what attention is directed at, including the person's intention ("top-down" guidance), stimulus characteristics such as salience ("bottom-up" guidance), as well as learning and priming throughout the selection history.
Attention control	The mechanisms and processes that control cognition and action through the control of attention, that is, through the selection and prioritization of mental representations for processing.
Self-control	Keeping one's current intentions—which are poised to control attention and cognitive processes "top-down"—in line with one's long-term goals.
Task set	A set of representations for implementing an intention, including representations of what to focus on (e.g., locations, features, feature dimensions in the environment, retrieval cues for relevant memories), a response set (i.e., the set of eligible actions), and the mappings between situations and responses.
Distraction	Failure of control of attention, such that attention is directed to representations that are irrelevant, and potentially misleading, for the person's current goal.

The Concepts of Attention, Control, and Attention Control

Control of Attention

Starting with AC as the control of attention, we can build on the common definition of attention as the selection and prioritization of mental representations for processing (see Table 1 for definitions of concepts central for this essay). This concept has mostly been applied to perceptual attention, that is, attention to stimuli in our perceived environment. Of all the information that our senses provide, we select only a small section for further processing. Meanwhile, researchers have applied the concept of attention as selection beyond perception (for a review, see Chun et al., 2011). Attention to a subset of our memory representations has been argued to constitute the core contents of working memory (Cowan, 1988), and within working memory, attention selects representations for processing (Oberauer & Hein, 2012). The selection of one out of several possible actions for execution has also been described as a form of attention (Chun et al., 2011; Oberauer, 2009).

Not every instance of selective processing is an instance of controlled attention: Selective processing is the default operation mode of the cognitive system; we always focus on some subset of our perceptual and our memory representations (at the exclusion of many others) and do some things (at the exclusion of others). Control of attention is required when we cannot rely on the automatic guidance of attention to achieve our current goals. To clarify the concept of AC, we need to understand what it means to control attention.

For a start, we can say that attention is controlled when the decision what to attend to is determined by a representation of our current goal. This is usually referred to as the "top-down" direction of attention. Controlling selective attention means to ensure that the information most relevant for the current goal is selected. This requires a representation of what is relevant for the current goal. This information is assumed to be given by the current task set (Monsell, 2003), which defines what relevant stimuli and relevant feature dimensions of stimuli are, what the relevant response options are, and how the relevant stimulus information ought to be mapped to the response options.

A failure of AC occurs when other forces attract attention, distracting it from where it ought to be according to the mechanisms of top-down control. Experimental research has identified the conditions under which attention is likely to be distracted, at least for perceptual attention (Awh et al., 2012; Luck et al., 2021). In a nutshell, stimuli attract attention when they meet at least one of two conditions. First, stimuli attract attention when they are perceptually salient. This means that they contrast sharply with other stimuli in the environment with regard to low-level perceptual

[1] The term *node* refers to unitized representations in the network of LTM representations.

features (e.g., a red apple among lots of green apples; a high tone embedded in a sequence of low tones). Second, stimuli attract attention when they match our *attentional-control settings*. Folk et al. (1992) originally defined the attentional-control settings as a representation of the features that characterize task-relevant stimuli. As such, these settings serve to guide perceptual attention to stimuli relevant for the current task. Later, Folk and Remington extended the concept of attentional-control settings to incorporate everything that is important to the person (Luck et al., 2021). This includes chronic goals (e.g., a casino attracts a gambler's attention), self-related information (e.g., one's name spoken at a party attracts attention; Cherry, 1953), and features of stimuli that we have learned to focus on throughout our attentional-selection history (e.g., stimuli that have been search targets for thousands of trials of a consistent-mapping visual-search task become powerful distractors; Shiffrin & Schneider, 1977).

Hence, representations of our goals are involved both in the top-down control of attention and in causing failures of top-down control. To resolve this apparent paradox, we need to distinguish between a representation of the current goal that the person has decided to pursue right now and the person's chronic goals. For instance, when a person is determined to work on an article, the alert to an incoming text message is a potential distraction, even though the message alert is highly distracting only because the person has the chronic goal of keeping up to date with their text messages. The concept of attentional-control settings of Folk and Remington includes both the person's current goal and their chronic goals. The concept of a *task set* as used in the action-control literature (Meiran, 1998; Monsell, 2003) is better suited to draw this distinction: The currently operative task set—the one currently held in procedural working memory (Oberauer, 2009)—represents the person's current goal by specifying the relevant stimuli, and stimulus feature dimensions, to focus on (in the environment or in memory), the set of possible responses, and the mapping between stimulus categories and responses.

One implication of this analysis is that, to speak of the success or failure of AC, we need to assume that the person has made up their mind about what their current goal is. When the person is in a predecisional state, deliberating about what goal to pursue, the distinction between controlled and distracted attention is not defined. Another implication is that AC is not the same as self-control. When a person gives in to a momentary temptation, and regrets it later, then their current goal (e.g., eating a piece of cake) is not in agreement with their long-term goal (e.g., eating a healthy diet), but their attention might still have been in line with their current goal all the time. Hence, this scenario exemplifies a failure of self-control rather than a failure of AC.

Control by Attention

Turning to the conceptualization of AC as the control of cognitive processes by attention, we need to clarify what control of cognitive processes means. In the writings of most authors, the definition of *controlled processes* consists of a list of features that sets them apart from automatic processes. Unfortunately, these features do not always go together. When they dissociate, it is unclear whether a process should be called controlled or automatic.

For instance, Barrett et al. (2004) listed "goal directed" as a feature of controlled processes. These authors point out that the capture of attention by stimuli is usually contingent on their match to the person's attentional-control setting, which in turn is usually determined by their current goal. Hence, attentional capture is a process that is influenced by the person's goal, and yet it is not itself an intended process: The person rather intends to avoid being distracted by irrelevant stimuli capturing attention. The problem can be illustrated with a version of the flanker task (Eriksen & Hoffman, 1973), a task paradigm often used to measure AC: Participants are presented with an array of letters, in which one letter (often the middle one in a row of three or five) is designated as the target. The task is to classify the target letter (e.g., press one button in response to A and U and another button in response to M and H). In the *incongruent* condition, the target letter is flanked by letters of the opposite category (e.g., MAM), and responses are slower than in the *congruent* condition when the target is flanked by letters of the same category (e.g., UAU). The flanker letters would not capture attention and not lead to a wrong response tendency in incongruent conditions if it were not for a task set that establishes attentional control settings that make the flankers relevant, and relates them to a response option. At the same time, processing the flankers is not what the person intends to do.

Another problematic case is making a speeded perceptual classification (e.g., giving one response to letters and another to digits): When a person is instructed to carry out one simple action (e.g., pressing a particular button) in response to one class of stimuli and another in response to an alternative class of stimuli, they implement cognitive control by configuring a task set that represents the relevant stimuli and categories and maps them to their appropriate responses. Once that is done, the stimulus elicits the response through a "prepared reflex" (Cohen-Kdoshay & Meiran, 2009; Hommel, 2000). Responding to the stimulus according to the task instruction is an intended action, but at the time of execution, it has some features of an automatic process. For instance, in the flanker task, the task set, once established, translates not only the target but also the flankers into the response that the instruction has mapped to them.

One way to move forward is to define a controlled process by the single characteristic that is closest to the concept's meaning. In their careful analysis of the concept of automaticity, Moors and De Houwer (2006) discussed the lack of control or controllability as one feature of automaticity. They define a controlled act as one that the acting person intends to carry out. Generalizing beyond overt actions, we can say that a cognitive process is controlled if and only if the person intends that process to happen at that time. This definition solves the problem discussed in the preceding paragraph: When attention is captured by a task-irrelevant stimulus by virtue of matching the current attentional-control settings, then that happens against the person's intention and is therefore not a controlled process. In contrast, a correct response to a stimulus, generated by a prepared reflex, would count as controlled because the person intended that response.

Here, we arrive at the same conclusion as above from the analysis of the control of attention: To define control, we need to distinguish between the person's goals in general and the person's current intention—what they want to do right now. A controlled cognitive process, or a controlled action, is one that the person intended to carry out at that time.

Theories in which attention figures as the agent of control are chronically vague about how attention accomplishes control. They usually describe the executive attention system as intervening in situations that demand control, such as novel tasks that require planning a new course of action, or countermanding a routine; correction of errors; and resolution of conflict between action tendencies (Baddeley, 1986; Norman & Shallice, 1980). When attention is conceptualized as an agent controlling our thoughts and actions, it is tempting to think that this agent has a degree of ability to do its job that varies between people and affects how well they can carry out controlled cognition generally. In attempts to dispel the notion of proposing a homunculus responsible for control, some authors have broken down executive attention into a set of processes by which the executive system is assumed to exert control, such as inhibition of irrelevant and potentially distracting representations, coordinating multiple tasks, maintaining information in memory, and others (Baddeley, 1996). This fractionation of executive attention accomplishes little more than creating a troupe of homunculi, each responsible for one function (one for inhibition, one for task coordination, etc.).

Meanwhile, there are multiple computational models that specify some of the mechanisms of control of cognitive processes and actions (Botvinick et al., 2001; J. W. Brown et al., 2007; Haazebroek et al., 2017; Logan & Gordon, 2001; Oberauer et al., 2013; Schmidt et al., 2016; Verguts & Notebaert, 2009; Wiecki & Frank, 2013). In none of these models does attention figure as an agent of control. Rather, the control mechanisms usually operate through influencing, or "biasing", the selection of mental representations (Verbruggen et al., 2014): Control consists of the selection of stimuli relevant for our goals, the selection of goal-relevant information to retrieve from LTM into working memory, the selection of appropriate task rules to implement as a "prepared reflex," and—through the execution of that prepared reflex—the selection of a (mental or overt) action that is likely to achieve our current goal. Selection of representations is the definition of attention, and "biased competition" is one of the leading theories of how top-down influences on attention work (Desimone & Duncan, 1995). Hence, in mechanistic theories of cognitive control, the control of our (cognitive and overt) actions is the control of attention.

To conclude, we find that the two meanings of AC—control of attention and control by attention—when spelled out as precisely as currently possible, converge on largely the same set of mechanisms and processes. They can be described as the mechanisms and processes that control cognition and action through the control of attention, that is, through the selection and prioritization of mental representations for processing. Successful AC means that these processes select the representations that are most relevant and appropriate to ensure that the person's thoughts and overt actions proceed according to their current intention.

The Mechanisms of Attention Control

Scientific concepts are not defined in isolation—their meaning is determined by the role they play in theories. Hence, to arrive at a clear concept of AC, it helps to have a theory of how AC works. To sharpen our concept of AC as an individual-differences construct, it is neither helpful nor necessary to rely on a particular theory or model of AC. It is not helpful because we are far from a consensus on a particular theory. It is not necessary because despite their differences, the existing models of AC, in my reading, agree on some core assumptions of how AC works, and these assumptions are all that we need to define AC as an ability construct. Figure 1 provides a sketch of the mechanisms of cognitive control, distilled from what I perceive as the assumptions shared by contemporary models of control.

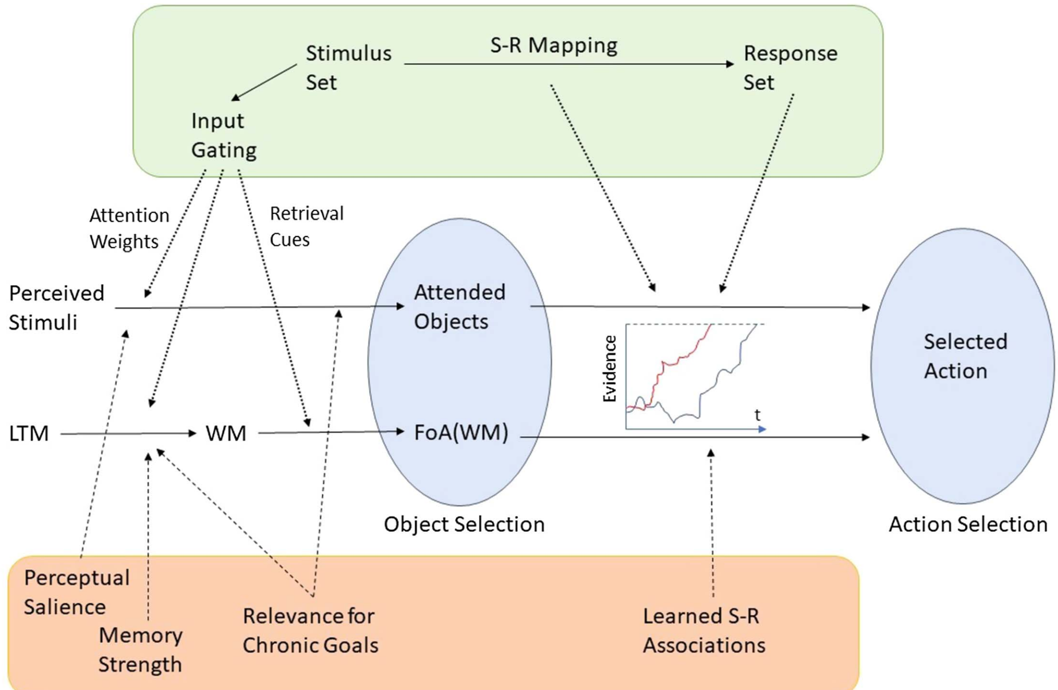
The proximal cause of control is a set of representations of the criteria for selection, which I collectively refer to as a *task set*. The task set includes a specification of what information in the perceived environment is relevant, which controls perceptual attention. It consists of a list of relevant stimuli, or a categorical description of relevant stimuli in terms of features (e.g., all red round things, all sounds in the left ear) or of feature dimensions (e.g., attend to color, ignore shape). The task set also includes a specification of relevant information from LTM that is used as retrieval cues (e.g., the conversation with a friend yesterday; the last studied list of words). These specifications bias the selection of representations from perception and LTM; they jointly influence which representations are selected for being acted upon (the set of *attended objects* shown in Figure 1). Furthermore, the task set includes a representation of a set of possible actions to choose from for accomplishing the current goal, as well as a representation of the mappings between possible selected objects on the input side and possible actions (these mappings are often referred to as stimulus–response, or S–R, mappings). Action selection is often modeled by an evidence accumulation process (Ratcliff & Rouder, 1998; Usher & McClelland, 2001) in which evidence in favor of each action option accumulates over time until a decision threshold is reached by one of them. The S–R mappings can then be thought to influence which selected input information feeds into the accumulator as evidence for a response option.

For successful control, the currently operative task set—the one that has been selected to control ongoing cognitive processes—should be an implementation of the person's current goal. If an appropriate task set for the current goal has been learned, it can be retrieved from LTM, using a representation of the goal (or a cue associated with that goal) as a retrieval cue (Mayr & Kliegl, 2000). Otherwise, a suitable task set needs to be constructed, a process potentially guided through instruction (Meiran et al., 2017). The operative task set configures the action-selection system to select actions in accordance with the person's current intention.

The "top-down" control from the currently operative task set competes with other influences on selection, which I discussed above: Salience of stimuli, as well as the broader attentional set (Folk et al., 1992) reflecting other than the current goals, pull perceptual attention toward potential distractors; similar forces (i.e., memory strength, match of memory representations with currently attended stimuli, as well as relevance of memories for chronic goals) facilitate retrieval of potentially distracting memory traces; and strongly learned S–R associations that go against the S–R mappings in the task set can bias action selection toward an unintended action. The influence of the task set has to win the competition against these forces for control to succeed.

Based on this outline of the mechanisms of control, we can identify two broad classes of causes of AC failure: (a) AC is likely to fail when the person has incorrect, or imprecise, knowledge of the selection criteria. For instance, when learning how to classify a set of stimuli, the person first needs to learn the relevant feature dimensions, and how to best weight and combine them for optimally discriminating between stimuli of different categories (Ashby & Maddox, 2005). Similarly, if a person does not know

Figure 1
The Mechanisms of Control of Cognition and Action



Note. Cognitive operations and overt actions are controlled by a set of representations, collectively referred to as a task set (green frame). The task set contains a specification of relevant input ("input gating"), which determines attentional biases for perceptual attention and retrieval cues for accessing LTM (to retrieve relevant information into WM), as well as for accessing information within WM (to be brought into the FoA). The outcome of this attentional selection is the selection of one or a few objects to which the system applies an action, which can be a cognitive operation (e.g., adding something to a number, mentally rotating a visual object) or an overt response. Action selection is based on a representation of the set of suitable actions (response set) and mappings between input categories and responses (commonly referred to as S–R mappings) in the task set. Selection of overt responses is often modeled by evidence-accumulation models; the figure illustrates the trajectory of evidence for two alternative responses (blue vs. red); the accumulated evidence first reaching a threshold (dotted line) determines the response. Selection of cognitive operations could occur in the same way. Not included in the figure is the selection or construction of the task set, which can be retrieved from LTM in response to a task cue (if it has been learned), or composed out of known building blocks according to an instruction. The influence of the currently operative task set is potentially in conflict with other sources of influence on attentional selection, some of which are shown within the orange frame at the bottom of the figure. S–R = stimulus–response; LTM = long-term memory; WM = working memory; FoA = focus of attention. See the online article for the color version of this figure.

which action is best suited to achieve their goal, given the perceived situation, then their actions are unlikely to achieve their current goal. (b) AC is more likely to fail when the strength of top-down influences from the task set (i.e., the dotted lines from above in Figure 1) is relatively weak compared with the competing forces acting on the selection of representations (i.e., the dashed lines from below).

Failures of control due to imperfect knowledge are unlikely to be the source of individual differences in a hypothetical general AC ability for two reasons. One is that knowledge is, by definition, specific to each situation and each goal and therefore cannot underlie a general ability. Another reason is that when a person controls their attention on the basis of incorrect knowledge, it is ambiguous whether this could even be described as a failure of AC. For instance, consider a person searching for a letter box, and believing erroneously that all letter boxes are red. Although the person is likely to fail in achieving their ultimate goal of finding a letter box, they can be said to be successful in directing attention to red objects.

This leaves the ratio of the strength between top-down influences and distracting influences on attentional selection as the most plausible locus of a general AC ability within a model of the mechanisms of AC as outlined above. To assume that a general ability to control attention and action that varies between people exists, one has to assume that people differ in the ratio of the strength of these two kinds of forces in a way that cuts across different situations and different goals that the person pursues.

It might seem that there are two ways to improve that ratio, either downregulating the distracting forces or upregulating the controlling influence of the operative task set. The idea that people differ in the ability to downregulate distracting influences is reflected in the assumption of individual differences in cognitive inhibition ability (Conway & Engle, 1994; Friedman & Miyake, 2004). The challenge for cognitive control through the inhibition of potential distractor representations is that the cognitive system must know what the potential distractors are in each situation. That knowledge is a part of the knowledge in the operative task set: Knowing what to select for entails knowing what to select against (though that knowledge is often quite unspecific: "everything else"). The upregulation of the selected representation and the downregulation of potential distractors are two sides of the competitive process that implements selection in perceptual attention (Beck & Kastner, 2009), memory retrieval (Lewis-Peacock & Norman, 2014), and action selection (Teodorescu & Usher, 2013). Inhibition is not driven by a force separate from the top-down influence of the operative task set. Increasing the amount of inhibition is tantamount to increasing the influence of the task set on selection.

What Attention Control Is Not

A good definition of AC also specifies what AC is not. Successful AC must not be equated with the speed and effectiveness of cognitive processes and actions, and conversely, not every cognitive error must be interpreted as a failure of AC. As a construct describing individual differences, AC refers to differences in the ability to prioritize the processing of relevant information over irrelevant and potentially distracting information, but not to differences in the ability to process the prioritized information efficiently. For instance, consider a study with the Stroop task or the flanker task, in which we measure the rate at which people extract information from the target (i.e., the print color of a Stroop stimulus or the central stimulus of a flanker-task display), and the rate at which they extract information from the distractor (i.e., the word form in the Stroop task or the flanker stimuli in the flanker task). Estimates of these information-extraction rates could be obtained by estimating the drift rates of evidence accumulation from the target and the distractors, respectively, using an evidence-accumulation model for conflict tasks (e.g., Lee & Sewell, 2024). Suppose we do this for two people, Anna and Ben, and find that Anna has drift rates of 2 and 1 for the target and distractor information, respectively, whereas Ben has drift rates of 2 and 0.5. In this case, Ben should be credited with better AC because he is better able to prioritize the target over the distractors. Consider a third person, Carla, who has drift rates of 3 and 1.5, respectively. Compared to Anna, Carla's higher drift rate for targets will enable her to respond faster and with more accuracy to targets in isolation, and also to congruent trials in the Stroop and flanker tasks (even more so, because for Carla choosing the correct response receives a larger boost from the distractors than for Anna). However, as Carla and Anna have the same target-to-distractor ratio of drift rates, Carla should not be credited with better ability to control perceptual attention.

Mashburn et al. (2024) have argued that individual differences in drift rates—including in tasks without perceptual distractors—could reflect individual differences in the ability to maintain attention to the task. This might be correct, but it is a hypothesis about the causal relation between AC ability and the evidence accumulation rate in decision tasks, and we should test it empirically. It does not follow from the meaning of AC that it is related to the rate of evidence accumulation in decision tasks, and therefore, we must not use drift rate estimates as indicators of AC.

A failure of attentional selection reflects a failure of AC when its cause is too weak top-down control, but not when it is caused by poor discriminability between the targets of selection and distractors. For instance, when the target of perceptual selection is precisely specified as a bar oriented 30° to the right and the distractors are tilted 29 or 31° to the right, failure to selectively prioritize the target is a failure of selective attention due to poor discriminability, rather than due to poor AC. Likewise, AC describes the ability to direct our attention to the relevant information in LTM through the appropriate retrieval cues, but even with a retrieval cue that optimally separates the target from competing memory representations, retrieval of the target information can still fail due to poor discriminability between targets and distractors (e.g., trying to remember where one parked the car in the University parking lot exactly 1 year ago), trace corruption, or simply because it has not been encoded properly, and these failures are not failures of AC.

When information relevant for carrying out a task has been lost from working memory when it is needed, that is not a failure of AC. Some theorists argue that the maintenance of information in working memory depends on AC (Barrouillet et al., 2004; Kane & Engle, 2002), but these are theoretical assumptions about the causal role of AC in working memory; they are not implied by the definition of AC. In other words, if these theories are correct, we can causally explain failures of retrieval from working memory by failures of AC but that is not the same as saying that such failures are, by definition, failures of AC.

Unsworth and Miller (2021) and Tsukahara et al. (2020) have argued that AC ability includes not only the ability to selectively focus attention on relevant information but also the ability to focus on relevant information with high intensity. I can think of two ways to conceptualize this intensity. One way is to define it as the efficiency with which a person extracts and processes information on which they focus their attention. This efficiency can be described by the drift rate of evidence-accumulation models applied to situations with minimal distraction. I am not aware of any evidence that people can control this efficiency, once they already focus their attention on the target information. Therefore, I see no room for a second dimension of an ability to control the intensity of attention, separate from their ability to control the degree of selectivity of attention. The other interpretation of the intensity of attention is as mental effort (Unsworth & Miller, 2021). I have no doubt that people can control the degree of effort they put into a cognitive activity, thereby influencing how efficiently they pursue it. However, the degree of effort a person invests into an activity is not a reflection of their ability but of their choice. Shenhav et al. (2017) defined effort as the relation between what a person can maximally achieve with respect to a given task or goal, and what they actually achieve—the more effort they choose to invest, the closer their actual achievement approximates the maximum. If people differ in their ability to ramp up the intensity of attention, then that ability would enter the equation on the side of determining maximal achievement and not on the side of determining their effort. If the intensity of attention is defined as the effort a person invests, then it is a motivational variable and it makes no sense to subsume it in an ability construct.

Finally, the ability to control attention must be distinguished from the capacity of attention. The assumption that there is a capacity limit to attention is supported by the observation that performance declines as we have to attend to more than one source of information at the same time. For instance, the detection of a target stimulus is impaired when we need to monitor two streams rather than one stream of stimuli for a target (Duncan et al., 1997). An even more severe limitation arises when we need to identify two targets simultaneously (Duncan, 1980) and when we try to make two action decisions at the same time (Pashler, 1994; Tombu & Jolicoeur, 2003).

The drop in performance from single- to dual-channel monitoring, or from single- to dual-task decision demands, could reflect an ability to control attention so that it is optimally divided between the two perceptual channels or between the two decision tasks. In that case, individual differences in the cost of dividing attention would reflect individual differences in AC. Alternatively, the divided-attention cost could simply reflect the fact that attention has a limited capacity that, when divided, results in less efficient processing. We should be able to distinguish between these scenarios: If dividing attention depends on AC, then performance in single- and divided-attention conditions should load on separate factors because the divided-attention condition uniquely reflects variability in AC. In contrast, if performance scores in both conditions depend on the same ability to efficiently process attended information, they should load on a single factor. Evidence so far speaks for the latter scenario (Lansman et al., 1983).

Measuring Attention Control

The definition of AC that we have arrived at carves out a fairly circumscribed cognitive function. That is useful in two ways. First, it conceptually distinguishes AC from other cognitive-ability constructs, such as information-processing rate and working-memory capacity. Such a conceptual distinction enables us to investigate the relation between AC and these other constructs as an empirical question. Second, a definition of AC that demarcates clear boundaries is useful because it provides guidelines for how to operationalize AC for measurement. To measure AC, we need an observable behavioral indicator that varies between individuals, such that a large proportion of that variance reflects variance in the ability to control attention. Ideally, the indicator would be construct pure (or "process pure," as most authors say), that is, it reflects only variance in AC plus noise. That is an unrealistic demand, and fortunately, it is not necessary (Wittmann, 1988): A certain proportion of the variance of AC indicators is likely to be *unwanted variance*, that is, systematic variance unrelated to the construct of interest (here, the AC ability). It includes method variance (i.e., variance due to how people respond to a particular test or measurement method), as well as other cognitive abilities and noncognitive person variables. If the unwanted variance components are relatively small and have little overlap between different indicators of AC, then we can average them out by aggregating multiple AC indicators.

To create a test of AC, we need a task that places a high demand on AC, so that AC is an important limiting factor for performance. This means that two people differing in AC, with otherwise identical abilities, differ substantially in their performance. We cannot know in advance to what extent AC is a limiting factor for performance in a task. We can find out by comparing the task with an assumed high demand on AC to a comparable task version with a low (or ideally, no) demand on AC. If AC is an important limiting factor in the high-demand task version, then performance in that task version should be, on average, substantially worse than in the corresponding low-demand condition. More importantly, there should be substantial individual differences in the degree to which the added AC demand impairs a person's performance compared with the low-demand task version.

The paradigmatic case of a failure of AC is distraction. Hence, a situation with high demand on AC is one in which there are strong distractors. Assuming that in a cognitive test situation, the person has the intention to do the task, a distractor is any mental representation of task-irrelevant information. A strong distractor is a distractor representation that has a strong potential to capture the person's attention in the context of the current situation. A situation with low demands on AC is one that, ideally, contains no distractors, though that is impossible in practice: Even if we place the person in a dark and soundproof room in which only task-relevant stimuli can be perceived, the person's mind generates its own distractors, such as episodic memories, future plans, and imaginations. However, we can create situations in which the distractors are less strong and use it as a control condition.

When measuring AC through contrasting a strong-distraction to a low-distraction condition, another important condition for valid measurement is that the distraction must be unambiguously dysfunctional. This is not typically the case in everyday life: We are distracted primarily by stimuli that are relevant for our chronic goals. Often, attending to distractors while pursuing our current goal enables us to notice an opportunity for pursuing another goal, or a danger to an important chronic goal (e.g., our survival). In such cases, being distracted could not plausibly be considered a failure of AC. In a controlled testing environment, we can maximize the chance that the tested person adopts the given task goal as their current goal and avoid distractions that make it reasonable to abandon that goal. That gives us a chance to introduce distractors that are unambiguously dysfunctional. However, as we will see in the examples discussed next, sometimes the task environment itself can make partially attending to the distractors functional for maximizing performance, which could undermine the validity of using a person's distractibility as an indicator of poor AC.

Control of Perceptual Attention

Much research on individual differences in AC has used the strategy sketched here, drawing on paradigms from the experimental psychology of perceptual attention, such as the flanker task, the antisaccade task, and the Stroop task (Heitz & Engle, 2007; Kane & Engle, 2003; Kane et al., 2001).

For instance, in the Stroop task, participants are asked to name the print color of color words. Response times and error rates are larger for incongruent stimuli, in which the meaning of the color word mismatches the print color (e.g., the word BLUE in red ink) compared with congruent stimuli (e.g., the word BLUE in blue ink). This Stroop interference is usually explained by the assumption that word reading is automatic, which is descriptively correct—the person reads the word meaning although, for all we know, they do not intend to—but begs the question why people are distracted toward attending to, and hence processing, the word meaning. The distracting force of color-word meaning is at least in part due to the fact that the response set for the given task consists of color words. Participants are not tempted to read noncolor words. That is why naming the print color of noncolor words (e.g., HOUSE in blue) is often used as a neutral control condition. Even color words that do not correspond to an ink color used in the experiment (e.g., the word PINK in green ink, when no word in the experiment is printed in pink) elicit only half of the Stroop interference as color words referring to often-used ink colors (for review, see MacLeod, 1991). Hence, distraction arises not only because reading words is chronically relevant for people in literate societies but also because color words are rendered relevant as responses in the task set for the current task. Hence, the challenge for AC is to direct dimensional perceptual attention toward the color dimension and away from the dimension of the word form, while maintaining attention to color words as potential responses. The size of the Stroop interference effect, measured as the difference in response time and error rate between the incongruent condition and a control condition with minimal demand on AC, can be used to gauge how much AC is a limiting factor for the incongruent Stroop task. Individual differences in the size of the Stroop effect can be used to measure individual differences in AC.

What is a suitable control condition that imposes minimal demand on AC? In contemporary studies, the Stroop task is administered as a random sequence of trials with half congruent and half incongruent stimuli, and the Stroop effect is calculated as the performance differences between these conditions. One potential problem with this method is that it is not entirely dysfunctional to attend to the distracting information (i.e., the word form), because on half the trials, it provides rapid access to the correct response. Relative to neutral conditions (e.g., naming the colors of noncolor words), there is often a small facilitation for congruent trials (MacLeod, 1991). When the proportion of congruent trials is increased, the Stroop interference effect increases. Kane and Engle (2003) interpreted this as a result of temporary goal neglect when the goal to avoid processing the word meaning is not regularly reinforced through the experience of incongruent trials. An alternative possibility is that participants cease to downregulate processing of the word meaning because the cost of attending to the word meaning on the few incongruent trials no longer outweighs the benefit of doing so on the many congruent trials. If that is the case, attention to the word meaning can no longer be interpreted as a failure of AC.[2] To ensure that being distracted by the word meaning is unambiguously dysfunctional, a control condition with minimal AC demand should be a neutral condition, such as naming the print color of noncolor words or pseudowords—the latter would even remove the challenge of suppressing the tendency to read the word, which might arise from the chronic relevance of words in our lives.

Another popular task used for measuring AC is the antisaccade task. In this task, participants are asked to fixate the screen center, and when a cue stimulus appears peripherally on one side, they are to rapidly shift their gaze to the opposite side. In the original version of the task, performance was measured as the speed and accuracy of the contralateral saccade. In individual-differences research, a manual-response version has mostly been used, in which participants must identify a stimulus (e.g., a character) in the location contralateral to the cue, which is presented only briefly and then masked. As the target stimulus is small and appears far away from the fovea, one has to move one's eyes toward it before it is masked to have a chance of identifying it. The antisaccade task can be used to measure AC because the sudden onset of the cue automatically attracts visual–spatial attention for two reasons: A sudden stimulus onset on a homogeneous screen is salient, as it stands out against its spatial and temporal context, and it is a relevant stimulus in the antisaccade task because it informs the person about when and where to move their eyes. In addition, eye movements have a strong automatic tendency to follow visual–spatial attention (Deubel & Schneider, 1996). Overcoming that tendency and moving visual–spatial attention—and hence, the eyes—in the opposite direction is a prototypical case of controlling the orientation of one's attention. The pro-saccade condition, in which the person is instructed to move their gaze toward the cue, could serve as a control condition that does not require control over one's attention because one can rely on the automatic attraction of attention to the cue. Unfortunately, researchers using the antisaccade paradigm for measuring individual differences in AC rarely use a pro-saccade control condition to isolate the contribution of the control of attention to task performance (for exceptions, see Kane et al., 2001; Rey-Mermet et al., 2019).

A more recent approach is to use people's ability to selectively encode target stimuli into working memory, filtering out distractors. Vogel et al. (2005) introduced a version of the change-detection paradigm in which participants saw an array of two blue and two red bars in various orientations. They had to remember the orientations of the bars in one color and ignore those in the other color. Memory was tested by asking whether, in a second array, the orientation of one of the target bars had changed (the distractor bars never changed). Vogel and colleagues measured an electroencephalogram signature of working-memory load, the amplitude of the contralateral delay activity. The contralateral delay activity amplitude for two targets + two distractors was in between that for two targets and four targets (both without distractors). Vogel and colleagues computed an index of filter efficiency *F*:

$$F = \frac{CDA_4 - CDA_{2+2}}{CDA_4 - CDA_2}. \qquad (1)$$

This electrophysiological filter index correlated with people's capacity estimates from the no-distractor conditions. An analogous filter index based on memory performance could be a good indicator of the ability to control perceptual attention as the gate into working memory, but this has rarely been done (for one example, see Arnell & Stubitz, 2010). A few studies used a simpler contrast to quantify the cost of filtering by subtracting contrasting conditions without from conditions with distractors (Fukuda & Vogel, 2009; Krieger et al., 2019; Mall et al., 2014; Shipstead et al., 2014); these studies found diverging results regarding the relation of filtering ability to working-memory capacity. Draheim et al. (2021) proposed to simply use performance in a condition with distractors (their *selective visual-arrays* task) as a measure of AC without any attempt to remove variance due to the ability to maintain items in working memory in the absence of distraction. As I will explain below, this practice is problematic.

One difficulty of measuring the ability to control selective perceptual attention is that people are generally so good at it that there is little variation between individuals. Beginning with early research on dichotic listening, selective attention has often been found to be extremely effective (Moray, 1959; Rock & Gutman, 1981). In other words, for healthy individuals, most irrelevant stimuli are very weak distractors; the effect of their presence on performance is small, and when we try to measure individual

[2] Kane and Engle (2003) made an effort to mitigate that risk by instructing them to ignore word meaning in every trial and that they were only interested in their performance in the incongruent words.

differences in its size, most individuals will show floor effects. The situations of interest for investigating individual differences in AC are the exceptions to this rule, that is, situations where the distraction effect is large. These are mostly cases where the distractors are somehow related to the person's goals and interests (Folk et al., 1992), such as hearing one's own name in the unattended ear of a dichotic-listening task (Conway et al., 2001; Moray, 1959). Even larger distraction effects might be generated when the task set for the given task itself renders the distractors relevant, as is the case in the Stroop task and also the Eriksen flanker task. However, even these effects are fairly small in healthy adults, which makes it difficult to measure them reliably (Rouder et al., 2023)—an issue to which I will return below.

One exception appears to be irrelevant speech, or irrelevant complex sound sequences (Jones & Macken, 1993; Salamé & Baddeley, 1982), which substantially disrupt performance in verbal working-memory tasks and other verbal tasks. Individual differences in the size of that distraction effect can be measured with good reliability (Körner et al., 2017), and therefore, the irrelevant-sound effect could be a further suitable indicator of AC.

Rather than the cost of distraction as an indicator of AC, we can also measure how much people benefit from a cue that they can use to direct perceptual attention to the relevant information. People with better AC ability should be better able to use such cues and hence benefit more from them. This strategy has hardly been used so far. Kane et al. (2006) have introduced a visual-search task in which the relevant subset of the search display was cued in advance. However, in their task, there is no control condition without a cue, and hence, it is not possible to measure how much people benefit from being cued compared to not receiving a cue. AC can therefore only be measured by overall performance in the cued search condition (e.g., Unsworth, Robison, & Miller, 2021), which conflates variance in AC with variance in search and decision efficiency. Carlisle (2023) has developed a more suitable experimental task: Participants search for a target in a set of stimuli with different colors; a precue identifies either the color containing the target (positive cues) or the color of a large subset of the distractors that do not contain the target (negative cues). Both cues yield large benefits in response time (RT) and accuracy compared to a condition with an uninformative cue. These benefits differ substantially between individuals and can be measured with reasonable reliability (Chidharom & Carlisle, 2024), rendering them promising indicators of AC.[3]

The same strategy could also be applied to the manual-response antisaccade task, in which the person must identify a briefly presented target on the left or the right. In the antisaccade condition, a cue indicates the target location to be on the opposite side. Compared to a neutral-cue condition in which the target could appear on either side, a person with good AC should benefit from the cue in the antisaccade condition. A person with poor AC should not and might even show a cost of attending to the wrong side if their attention is captured by the cue. Hence, the performance contrast between an antisaccade cue and a neutral cue could measure AC over a broad range from positive to negative values, making it well suited for reliable measurement.

Control of Attention to Memory Representations

Extending the scope beyond perceptual attention, we can also investigate AC for attention to representations in working memory. For instance, in the retro-cue paradigm, participants are initially instructed to remember a set of stimuli; usually simple visual objects presented in a spatial array. About 1 s after array offset, one stimulus is cued as the most likely one to be tested, usually by highlighting its location in the array. Valid retro cues improve performance, whereas invalid retro cues that point to another item than the target often impair performance compared with a no-cue control condition (Griffin & Nobre, 2003; Landman et al., 2003; Souza & Oberauer, 2016). Several explanations are discussed for the retro-cue effect, but they have in common the assumption that attention is directed toward the cued item's representation in working memory. The ability to direct one's focus of attention effectively, and selectively, to the cued item is an instance of the ability to control attention. Hence, individual differences in the size of the retro-cue effect should be a good indicator of that ability, though they have rarely been used as such (Astle et al., 2012; Souza & Frischkorn, 2023).

When doing so, we need to take into consideration the same concern that I raised above in the context of the Stroop task: When a retro cue does not always point to the test target, the person has to balance the goal of prioritizing maintenance and processing of the cued item with the goal to also keep the not-cued items sufficiently strongly in memory, as there remains a chance that one of them will be tested. Focusing attention on the cued item usually entails a performance cost when a not-cued item is tested (Souza & Oberauer, 2016), and hence, these goals are to some extent in conflict with each other. Individual differences in how people balance these two opposing goals will contribute to differences in the retro-cue effect. Only with a 100% valid cue, it is unambiguously rational to focus attention maximally on the cued representation in working memory, so that the size of a person's retro-cue effect can be interpreted as their ability to control attention in working memory.

Control of Attention to Action

Following a similar rationale, the task-switching paradigm could be used to isolate AC. In the task-switching paradigm, there are two (or sometimes three) task sets that the person must switch between from trial to trial, typically in response to a cue identifying the task for each upcoming trial (Allport et al., 1994; Mayr & Keele, 2000; Monsell, 2003). This implies that two or three tasks, and the stimuli to which they can be applied, are chronically relevant for the person in the experimental setting and therefore are prone to attract attention. A person who is good at controlling their attention should be good at focusing attention to the currently relevant task set, and the stimuli it applies to, and avoid distraction from the representations of the other tasks, and from stimuli that these other tasks could be applied to. An appropriate control condition would be a situation in which only a single task is relevant in the entire experimental session. The difference in performance between the task-switching setting and the single-task setting is known as mixing cost (Meiran et al., 2000). Individual differences in mixing costs

[3] Li et al. (2022) have investigated individual differences in a similar search paradigm, in which participants had to find one of two targets, one in a larger and the other in a smaller subset. They measured the proportion of trials in which participants chose the optimal strategy to search only the smaller set. Individual differences in strategy optimality were highly reliable but did not correlate strongly across different task versions (see also Clarke et al., 2022). This paradigm might reflect individual differences in strategy choices rather than in the ability to control attention.

have occasionally been investigated (Yehene & Meiran, 2007) but are not considered as indicators of AC.

More often, researchers have used the switch cost—the performance difference between switch and repetition trials in the task-switching setting—as an indicator of cognitive flexibility. For instance, Miyake et al. (2000) used the switch cost to measure *shifting*, one of three components of their model of individual differences in executive functions. The switch cost could be a good measure of cognitive flexibility, but it is probably not a good indicator of AC, for the following reasons. In the task-switching setting, a person needs to optimize two opposing goals: Working efficiently on the currently relevant task and being able to flexibly shift to the other task when needed. To maximize the first goal, the relevant task set should be selected strongly, and the irrelevant task set deselected as much as possible, potentially by inhibiting it (Mayr & Keele, 2000). However, to be ready to seamlessly switch to the other task, it is better to not select the current task set too exclusively—because that makes it more difficult to downregulate it when a switch is demanded—and to maintain the currently not relevant task set at a relatively high level of accessibility—so that it can be selected to become operative quickly. Goschke (2000) referred to this as the *stability-flexibility dilemma*; Herd et al. (2014) demonstrated it in a computational model. A person who prefers to resolve that dilemma more in favor of stability will gain speed and accuracy as long as the task repeats, at the price of needing more time for switching the task, compared to a person who resolves the dilemma more in favor of flexibility. Depending on whether a person prioritizes stable efficiency on a repeated task or high flexibility for switching between tasks, the performance difference between switch and repetition trials can be described as a task-repetition benefit or a task-switch cost. The size of that cost/benefit in a person does not reflect how good or bad their AC is but rather whether they prefer to use AC to maximize stability or to maximize flexibility.

Another popular paradigm for measuring the ability to control actions is the stop-signal task (Logan & Cowan, 1984). Participants are instructed to carry out a speeded perceptual decision as their primary task, which is to be executed on every trial except when a stop signal (e.g., a tone) is presented, in which case the response is to be withheld. The later the stop signal is presented relative to the imperative stimulus for the primary task, the lower the chance of successful stopping. The stopping probability is well described by a race model in which go processes (leading to the response for the primary task) and stop processes (leading to an interruption) run in parallel. Stopping succeeds if the stop process is completed before the go process reaches a "point of no return". Using this race model, the duration of the stopping process can be estimated (Logan & Cowan, 1984; Matzke et al., 2013), and this estimate has been interpreted as an indicator for the efficiency with which a person can control—in this case, inhibit—their overt actions. Recent research has revealed that an important limiting factor for stopping success is the ability to detect and rapidly process the stop signal (Chatham et al., 2012; Matzke et al., 2017). This means that the ability to stop one's action in the stop-signal paradigm is not some power of inhibition, but rather reflects the degree to which perceptual attention is directed toward detecting the stop signal and prioritizing it for processing. Stopping an action is not qualitatively different from selecting and executing an action: Both rely on establishing an operative task set that directs attention to the relevant stimuli and links them to the appropriate response—in the case of stopping, the response is the suspension of execution of the planned overt action.

Using stopping success, or stopping speed, as a measure of AC faces a similar problem as using task-switch cost. In the stop-signal paradigm, participants need to balance two conflicting goals: Efficiently carrying out the primary task and maximizing the stopping success. If they emphasize the first goal, they direct perceptual attention primarily to the imperative stimulus, thereby maximizing the speed of processing it. Because dividing perceptual attention between two input channels diminishes processing efficiency in each, this comes at the expense of attention to the stop signal, increasing the chance of "trigger failures" (Matzke et al., 2017). Moreover, maximizing the processing speed for the primary task decreases the chance that a stop process, even if triggered, wins the race. Conversely, a person emphasizing successful stopping can do so only at the expense of reduced attention to the imperative stimulus of the primary task. Prioritizing one or the other goal is an equally appropriate form of AC, but they result in very different measures of stopping speed or stopping success. Therefore, the indicators from the stop-signal task that are currently in use are probably not valid measures of AC ability. A more appropriate measure could be achieved by comparing overall performance—in both the primary task and the task of stopping—in a condition with occasional stop signals, compared to a control condition in which the person never needs to stop. The drop in overall performance in the stop-signal condition compared to the condition without stop signals can be interpreted as the difficulty of dividing attention between two concurrent tasks (the primary and the stopping task). A person with good AC should potentially be able to handle that demand better, and hence, experience a smaller drop in performance between these two conditions.

Another way to measure AC through challenging action selection is to create a situation with a strongly distracting action option. Such tasks have been used in the child development literature on executive functions, but to my knowledge not used in research on individual differences in AC among adults. For instance, in the happy–sad task (Lagattuta et al., 2011), participants see a random sequence of happy-looking or sad-looking cartoon faces (smileys), and they ought to say "sad" in response to a happy face and "happy" in response to a sad face. Hence, the correct response has to be selected against a strongly learned competitor. No control condition has yet been developed for this task. For instance, a suitable control could be the assignment to say "happy" in response to a neutral cartoon face in orange and say "sad" in response to a neutral face in green. Tasks like this have been described as "Stroop like," but they differ in an important regard from the Stroop task: Attentional selection cannot be accomplished by selection of a perceptual stimulus, or feature dimension, because the same stimulus features that determine the correct response according to the task rules are the ones that are associated with the strongly competing action option. AC rather has to work on action selection. This might be harder than perceptual selection, and that would be a good basis for creating a substantial challenge to AC, through which we can maximize the variance in task performance that is due to individual differences in AC. A promising finding from the study of Lagattuta et al. (2011) is that even young adults made about 10% errors in the happy–sad task.

Sustained On-Task Attention

Sustained attention can be understood as another instance in which AC is needed to keep attention to the currently relevant task representation and the task-relevant stimuli. Maintaining attention consistently on the same task over several minutes or even hours is difficult, especially when the task is simple and repetitive. The challenge for AC arises from the fact that while a person pursues one goal, they still have many other goals and interests that are only temporarily shelved. These goals and interests still contribute to the person's attentional set. As a consequence, environmental stimuli, as well as self-generated representations (e.g., episodic memories, future plans) that relate to the person's chronic goals, have the potential to attract their attention (Shepherd, 2019; Unsworth & McMillan, 2014). In this regard, the setting in which we ask a person to pursue a single task for one experimental session is analogous to the task-switching setting, though on a slower time scale of switching, and with less experimental control over the alternative goals and tasks.

Failures of sustained on-task attention have been measured in two ways. One is to interrupt participants occasionally with thought probes, asking them whether their attention is on the task, or on other matters (McVay & Kane, 2009). The other is to detect fluctuations in task performance, such as unusually slow, or fast, response times (deBettencourt et al., 2019; Unsworth et al., 2010) or exceptionally poor accuracy (Adam & Vogel, 2017), as indicators of attentional lapses. Both methods are less than ideal for measuring individual differences in failures of sustained attention (Welhaf & Kane, 2024). Self-reports are probably contaminated by differences in metacognitive awareness of attentional lapses and biases in reporting them. The interpretation of performance fluctuations is ambiguous. Because information processing in the brain is inherently variable, performance fluctuations arise from moment-to-moment variability in the efficiency of all cognitive processes, and these fluctuations are difficult to separate from fluctuations arising from lapses of attention. For instance, the worst-performance rule (Larson & Alderton, 1990)—the finding that the slower quantiles of an RT distribution in a simple speeded task correlate more strongly with intelligence than the faster quantiles—has been interpreted as evidence that particularly slow responses reflect to a large extent lapses of attention, of which less intelligent individuals have more (Löffler et al., 2022). However, the diffusion model of response times in simple decisions (Ratcliff & Rouder, 1998) generates trial-by-trial variability in response times through the inherent noisiness of information processing. In individuals with a lower drift rate (i.e., slower accumulation of decision-relevant information), this noise results in larger response-time variability. With the assumption that information-accumulation speed is related to intelligence, the diffusion model predicts the worst-performance rule without additional assumptions about attentional lapses (Ratcliff et al., 2008). This example shows that intraindividual performance fluctuations cannot unambiguously be interpreted as indicators of AC failures. Latent variables measuring sustained attention through self-report on the one hand, and performance variability on the other, share about 10% of their variance (Welhaf & Kane, 2024), implying that a large proportion of the systematic variance is method specific, and therefore probably unrelated to AC. As Welhaf and Kane (2024) argued, that shared variance is unlikely to be fraught with the method-specific sources of unwanted variance and could therefore be a good measure of sustained-attention ability.

Another way to measure the ability to sustain attention over longer durations is through the amount of performance decline over prolonged work on a low-demanding monotonous task (Luna et al., 2022; Thomson et al., 2014). Using the overall decline in performance from start to end of measurement is problematic because it is confounded with the beneficial effect of practice. To deconfound the decline of sustained attention from practice effects, it would be necessary to run several long blocks of trials, separated by breaks that restore the ability to sustain attention. The decline of sustained attention can then be measured as the average within-block decline across blocks. Higher AC would be reflected in a shallower decline within blocks.

How Not to Measure Attention Control

A definition of AC as an individual-differences construct should be sufficiently clear and precise to provide guidance for how to measure it. In the preceding section, I have applied the definition that I propose to a number of ways in which we can measure AC. Some of them have already been used frequently in individual-differences research on AC, whereas others have rarely or never been used and could be opportunities for future exploration. I hope that this discussion has demonstrated the usefulness of the proposed definition.

An important requirement for measuring AC is that we create a contrast between a condition with a strong challenge to the AC ability—such as a strong distractor—and a comparable condition with little—ideally no—challenge to AC. Individuals with high-AC ability should show a relatively small performance cost in the high-AC-demand condition relative to the low-AC-demand baseline. To measure that ability, we should therefore measure an individual's performance cost, for instance, by calculating the difference in performance between the two conditions or by fitting a bifactor model.[4] Analogously, when we gauge AC through the ability to use informative cues relative to a baseline with uninformative (or absent) cues, we should use an individual's performance benefit from the informative cue to measure AC.

In recent years, researchers have increasingly expressed frustration with the use of difference scores, and similar methods to control for performance in low-AC-demand conditions (e.g., estimating the residual variance), because it is difficult to obtain reliable indicators of AC in this way (Draheim et al., 2019, 2021; Weigard et al., 2021; Yangüez et al., 2024). To escape this psychometric problem, these authors have advocated using performance in a task that requires the control of attention as a measure of AC. This has already been the road taken by most researchers who use the (manual-response) antisaccade task to measure individual differences in AC. They use the accuracy in the antisaccade condition as an indicator of AC. Similarly, memory accuracy in the selective visual-arrays task

[4] A bifactor model is a structural equation model that can be applied to performance scores from multiple pairs of one high-AC-demand condition and a corresponding low-AC-demand condition. Performance in all conditions loads on a general factor that represents the variance shared between high- and low-AC conditions, and performance scores only in the high-AC-demand conditions load on a second factor that reflects the residual variance in those conditions, which represents to a large degree variance in AC.

(Draheim et al., 2021; Martin et al., 2021) is used as an indicator of AC. Sustained attention ability is also often measured by just taking the performance score in a task that challenges sustained attention. For instance, in the sustained attention to response task, a go/no-go task, one often used indicator of sustained attention is the accuracy on target trials (Draheim et al., 2021; Unsworth, Miller, & Robison, 2021).

Draheim et al. (2021) and Burgoyne et al. (2023) have extended this approach to conflict tasks (i.e., flanker, Stroop, and Simon tasks). Draheim et al. (2021) constructed versions of flanker and Stroop tasks in which the stimulus presentation time, or the response deadline, was adapted according to the person's accuracy, combined for congruent and incongruent trials. The indicator of AC ability was the person's time after adaptation, which reflects the time they need to achieve a criterion level of accuracy, averaged over congruency conditions. Draheim and colleagues also included performance in the selective visual-arrays task as a measure of AC without controlling for performance in the nonselective version of the arrays task. Burgoyne et al. (2023) constructed a set of new versions of conflict tasks in which the stimulus configurations could be congruent or incongruent on two dimensions independently, resulting in four possible combinations. These tasks, referred to as Flanker Squared, Stroop Squared, and Simon Squared, respectively, were scored through points that participants earned by doing many trials accurately within a limited time allowance. Burgoyne and colleagues used points in all four congruency conditions equivalently as measures of AC.

This practice is problematic if variance in AC determines only a small proportion of the variance in task performance. If most of the systematic variance in an indicator is unwanted variance—that is, variance unrelated to the construct we intend to measure—then it becomes increasingly difficult to average out that unwanted variance through aggregation of multiple indicators, because averaging out works only to the extent that the unwanted variance is uncorrelated across different indicators. The larger the proportion of unwanted variance in each indicator, the larger the risk that a substantial amount of unwanted variance is shared among most or all of the indicators we use to measure AC.

Using overall task performance as an indicator of AC is less problematic if it reflects AC ability to a large degree. If that is the case, then performance in a condition with high demand on AC should reflect a large degree of variance not shared with a corresponding low-AC-demand condition because the latter is expected to reflect virtually no variance due to AC. In that scenario, the correlation between performances in the two conditions should be moderate to low. If that were the case, the difficulty of obtaining a reliable difference score would be substantially mitigated. The reason why differences between experimental conditions are plagued by reliability problems is not so much the fact that differences between two variables inherit the error variance of both variables. The main reason for the reliability problem is that performances in conditions with high- and low-AC demand are usually highly correlated. As a consequence, subtracting one from the other removes most of the systematic variance. The remaining systematic variance—the variance in the size of the Stroop effect, the flanker effect, and other experimental contrasts for measuring the effectiveness of AC—is often very small, because these effects are very small on average (Rouder et al., 2023). Therefore, the ratio of systematic variance to error variance is highly disadvantageous for psychometric purposes.

This analysis shows that the reliability problem of difference scores for measuring AC is not simply a technical problem. The root of the problem is the high correlation between conditions with high demand on AC and control conditions with minimal demand on AC. The high correlation implies that performance in the high-AC-demand condition shares most of its variance with performance in the low-AC-demand condition. Unless we made a mistake in constructing the low-AC-demand condition, that shared variance is not variance in AC. Therefore, the problem is that performance in the tasks that we use to measure AC reflects variance in AC only to a very small part. That is the reason why we need to control for variance in the low-AC-demand baseline.

Looking at the problem in this way, it should be clear that to jettison any attempt to isolate the variance of AC (through difference scores or other statistical techniques) is a move in the wrong direction. What researchers should instead do is design task conditions that maximize the challenge to AC, so that the proportion of variance due to AC in task performance is maximized. Efforts in doing that within conventional conflict tasks have already yielded some success (Kucina et al., 2023).[5] In addition, we should explore new experimental contrasts that reflect AC and yield larger experimental effects, such as mixing costs in task switching, the irrelevant-speech effect, cued visual search, retro-cue benefits in working memory, and others proposed above.

A possible line of defense of using performance in both high-AC and low-AC demanding conditions as indicators of AC could be to argue that the low-AC demanding conditions—such as the congruent trials in a Stroop or flanker task, or the nonselective visual-arrays task—also rely on AC to some extent, and therefore, controlling for performance in the low-AC-demand condition (e.g., through a difference score) would remove variance of the construct of interest from the indicator of AC. The assumption that the low-AC-demand condition of a task also relies on AC should be tested for each task. If it turns out to be correct, it could imply that the task is unsuited for measuring AC, but it does not imply that using overall performance across all experimental conditions is a suitable measure of AC. These implications can be demonstrated through a simple simulation. Variance in performance in both experimental conditions (Ψ_1 for high-AC-demand and Ψ_0 for low-AC-demand) is composed of three sources: variance caused by the influence of the intended construct on performance (AC), variance due to other systematic influences that are unrelated to the construct of interest (X), and normally distributed noise with standard deviation σ:

[5] Critics of difference scores for measuring AC have argued that computing difference scores of response times relies on Donders' additive-factors logic (Mashburn et al., 2024), and the preconditions for applying that logic often do not hold. That is a misunderstanding of the rationale of difference scores in psychometric research, invited by the fact that most psychometric measures of AC are based on response times in tasks derived from experimental psychology. The rationale of using difference scores in psychometric measurement is not to isolate the duration of a component process but to isolate a source of variance that is not shared between two conditions. This rationale can be applied to any performance score, not just response times, and it is not limited to computing the difference between two conditions—other methods for isolating sources of variance, such as bifactor models, are available, and arguably preferable.

Table 2
Validity (Correlation With the True Variable AC) and Contamination With Unwanted Variance (Correlation With True Variance Unrelated to AC) for Three Indicators of Attention Control

α_0	Validity Ψ_0	Validity Ψ_1	Validity $\Delta\Psi$	Unwanted Ψ_0	Unwanted Ψ_1	Unwanted $\Delta\Psi$
0	0.00	0.41	0.57	0.89	0.82	0.00
0.1	0.09	0.41	0.49	0.89	0.82	0.00
0.2	0.18	0.41	0.39	0.88	0.82	0.00
0.3	0.27	0.41	0.27	0.86	0.82	0.00
0.4	0.34	0.41	0.14	0.84	0.82	0.00
0.5	0.41	0.41	0.00	0.82	0.82	0.00

Note. α_0 is the weight of AC-related variance in the low-AC-demand condition; Ψ_0 and Ψ_1 are the performance scores in the low-AC-demand and high-AC-demand conditions, respectively; and $\Delta\Psi$ is the difference between them. AC = attention control.

$$\Psi_1 = X + \alpha_1 \mathrm{AC} + \sigma^2,$$
$$\Psi_0 = X + \alpha_0 \mathrm{AC} + \sigma^2. \quad (2)$$

Ideally, α_1 is high and α_0 is 0, with a low value of σ. A realistic—though somewhat optimistic—scenario is $\alpha_1 = 0.5$ and $\sigma = 0.5$. We can ask what happens when α_0 is increased so that Ψ_0 also reflects some variance of AC. Table 2 shows the results of a simulation (N = 1,000) in which I increased α_0 stepwise from 0 to 0.5. The left part of Table 2 shows the validity of three possible indicators of AC; Ψ_0, Ψ_1, and the difference score $\Delta\Psi = \Psi_1 - \Psi_0$. Validity is defined by their correlation with AC. The right side of Table 2 shows how much each indicator reflects unwanted variance, that is, variance due to systematic influences other than AC, measured through their correlation with X.

The simulation confirms the suspicion that, as Ψ_0 reflects an increasing amount of variance in AC, the validity of the difference score declines. However, that decline is not an instant drop to zero: As long as Ψ_0 is influenced by AC substantially less than Ψ_1 is, the difference score still has a useful degree of validity. It is useful because it is not contaminated by systematic variance unrelated to AC. Its only contaminant variance is noise, which can be averaged out by combining multiple indicators of AC. In contrast, the validity of both Ψ_1 and Ψ_0, although exceeding that of the difference score in some scenarios, is less useful because these scores are strongly contaminated by unwanted variance. To the extent that the unwanted variance reflects influences that are shared by many or all tests for measuring AC, it cannot be separated from variance due to AC. Using these scores, we end up measuring an unknown mixture of AC and a collection of unknown other cognitive abilities.

Discussion

I proposed a clarification of the concept of AC as an individual-differences construct with the aim to provide a clearly circumscribed target for the measurement of AC. This aim is motivated to a large extent by the concept of validity as explicated by Borsboom et al. (2004): A test is valid to the degree that it measures the construct it is meant to measure. In statistical terms, this means that a test is valid to the degree that variance in the test score is caused by variance in the target construct. It follows that, to develop a valid test, we need to have a good idea of what the target construct is, and how it affects the behavioral variable that we take from the test as an indicator of the construct. In other words, to measure AC, we need a theory that says what AC is and how it affects behavior in our test situations.[6] Drawing on experimental research on attention and cognitive control, I proposed the sketch of a theory of AC that serves that purpose. I demonstrated how the theory can be applied to analyze existing methods for measuring AC and to develop new ones. I tried to compose this theory out of assumptions that I perceive to be largely uncontroversial, so that the definition of AC that flows from it, and the guidelines for measuring AC, could be broadly accepted. Of course, there is room for alternative theories of AC, in which the meaning of AC would be different. Once such an alternative theory has been developed, we will probably have to distinguish between different constructs labeled "attention control". As long as each of them is conceptually clear, that is not a problem.

An important function of a definition of AC is to draw a clear boundary between AC and other individual-differences constructs. That is best achieved when we also conceptually clarify those other constructs. For instance, we could build on evidence-accumulation models of rapid decision making (S. D. Brown & Heathcote, 2008; Ratcliff & Rouder, 1998; Usher & McClelland, 2001) to define an ability to efficiently extract information from stimuli, or from memory, and accumulate it as evidence in favor of one or the other response option, reflected in the drift rate of these models. Drift rate estimates correlate substantially between different decision tasks (Ratcliff et al., 2010; Schmiedek et al., 2007), which renders the rate of information extraction and accumulation an attractive candidate for a general ability construct. Another candidate for an ability construct could be memory strength, as defined in models of episodic memory (Anderson & Lebiere, 1998; Shiffrin & Steyvers, 1997; Wixted, 2007) and working memory (Oberauer & Lewandowsky, 2019; Schurgin et al., 2020).

These conceptual distinctions do not preclude the possibility that we find the different constructs to be highly correlated. Some theories predict such correlations—for instance, the executive attention theory of Engle and Kane postulates AC ability to be the main cause of the ability to maintain representations in working memory (Engle, Tuholski, et al., 1999; Kane & Engle, 2002) and, as such, predicts that individual differences in AC and in the strength of working-memory representations should be substantially correlated. By conceptually distinguishing the AC construct from a construct of working memory strength (or capacity), we can use the correlation between measures of these constructs as evidence speaking to such a theoretical assumption. If we do not draw such a conceptual

[6] In this regard, I agree with Burgoyne et al. (2023): "Measurement and theory are entwined" (p. 26). Whereas they emphasize that theory development requires solid measurement, I complement their argument by pointing out how solid measurement requires theory.

distinction, but rather define working memory capacity and AC as the same construct, then their relation is no longer a testable conjecture but a matter of definition. A high correlation between measures of working-memory capacity and AC ability would then be expected by virtue of them measuring the same construct; finding that correlation wanting would imply that at least one of the tests lacks validity.

A precise definition of AC helps to avoid overextension of the concept. Overextensions can easily happen through the association of poorly defined concepts. For instance, Weigard et al. (2021) start their article arguing that the ability for "top-down control" "has been theorized to contribute to the broader construct of 'self-control'" (p. 1). They go on to argue for using the drift rate of the diffusion model (Ratcliff & Rouder, 1998) as an indicator of "self-control" based on their reasoning that:

> Drift rate is … the ability to rapidly and selectively extract goal-relevant information from a stimulus for the purposes of generating an appropriate response. Self-control is (.) often conceptualized in terms of effectively pursuing goals. … Thus, there is a theoretical link between the construct of "cognitive efficiency" as defined by drift rate, and the broader concept of self-control. (p. 2)[7]

Their "theory-driven approach" (p. 7) is nothing but a chain of association from "self-control" to "effective goal pursuit" to "effective extraction of goal-relevant information" to the drift rate of the diffusion model. Based on the present conceptual analysis, it should be clear that the ability to limit information processing to relevant input (an aspect of AC ability) is conceptually different from the ability to efficiently extract and process information (as represented by the drift rate of the diffusion model; that model does not include the assumption that information is extracted "selectively").

The risk of conceptual overextension is high for a concept such as AC because performance in most cognitive tasks requires attention, or control, or both. This makes it easy to claim with some plausibility that performance in any task that requires, or at least benefits from, attention or cognitive control measures AC. This appears to be the tacit rationale for propagating the use of task performance in experimental tasks from attention and cognitive control research, without contrasting conditions with high versus low demand on AC. Experimental tasks such as the Stroop and the flanker paradigm have a long history of being used as paradigms for investigating selective attention and cognitive control. This gives using any performance score from these tasks as an AC indicator credibility by association, even if that score lumps together performance in conditions with high AC demand and conditions with minimal AC demand (Burgoyne et al., 2023; Draheim et al., 2021). Had someone proposed to measure AC by the time that a person needs to determine whether a lineup of identical arrows points left or right, that would probably not have been accepted as a valid indicator of AC. However, that is effectively what is measured by the congruent trials—which make up 2/3 of all trials—in the Flanker Deadline task proposed by Draheim et al. (2021) as a part of their toolbox for measuring AC.

If performance in any task that requires at least some attention, or control (or both) can be declared to measure AC, we would practically extend the concept of AC to include virtually all cognitive tasks that we could use to test cognitive ability. Every such task requires a minimum of attention because participants need to focus on the relevant stimuli (as opposed to, for instance, the white wall of the lab) and select the appropriate task set and the appropriate response set (i.e., implement the task instructions). Every such task also requires cognitive control because when we test a person's ability we ask them to adopt the task goal as their current goal and act in accordance with that goal. Hence, whenever we instruct a person to do a task, their action on that task is by definition a controlled action. Using this broad conceptualization of AC, the common variance of all possible indicators of AC is the common variance of performance in all possible cognitive tests. This common variance is known as the *g* factor in intelligence research. Hence, by adopting the practice of operationalizing AC as the ability to carry out controlled cognitive operations, we equate the general AC ability—the shared variance among all indicators of AC—with the *g* factor. In other words, AC has become a new word for intelligence.

Relabeling intelligence as AC might have rhetorical advantages as it allows researchers to distance themselves from the dark aspects of the history of intelligence research, but it does not advance our scientific understanding of individual differences in cognitive abilities. In particular, the hypothesis that AC lies at the core of fluid intelligence becomes empirically empty, because the two concepts are defined in such a way that they have equivalent extensions.

[7] Although Weigard et al. (2021) did not use the term "attention control," other authors interpret their concept of "self-control" as AC (Mashburn et al., 2024; Tsukahara et al., 2024).

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