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Cognitive Offloading

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Abstract

If you have ever tilted your head to perceive a rotated image, or programmed a smartphone to remind you of an upcoming appointment, you have engaged in cognitive offloading: the use of physical action to alter the information processing requirements of a task in order to reduce cognitive demand. Despite the ubiquity of this sort of behavior, it has only recently become the target of systematic investigation in and of itself. Here we review research from a number of domains focusing on two main questions: a) what mechanisms trigger cognitive offloading, and b) what are the cognitive consequences of this behavior? We offer a novel metacognitive framework that integrates results from diverse domains and suggests avenues for future research.

Offloading Cognition

A moment's reflection on our day-to-day cognitive lives reveals the intimate relation between human cognition and manipulation of the body and objects in the physical environment. We tilt our heads while trying to perceive ambiguous images, we gesture while imagining spatial transformations, and we rely on smartphones and search engines to store and retrieve information. In other words, we often think using our bodies and the external world. This ability to flexibly deploy ad hoc mixtures of internal and external processes in pursuit of our cognitive goals likely represents a defining feature of what it means to be a successful cognitive agent in a complex environment [1-4]. One critical function that these mind/body/world interactions afford is **cognitive offloading** - the use of physical action to alter the information processing requirements of a task in order to reduce cognitive demand (see also computational offloading [5]; epistemic actions [6]). Our unaided mental abilities have well-known limits (e.g. we can only accurately perceive a relatively small region of the visual field [7] and can only hold a limited amount of information active in memory [8]). Offloading cognition helps us to overcome such capacity limitations, minimize computational effort, and achieve cognitive feats that would not otherwise be possible. Consistent with this notion, cognitive offloading has been demonstrated to improve performance across a number of domains (e.g., perception [9]; memory [10]; arithmetic [11]; counting [12]; spatial reasoning [13]).

The term cognitive offloading has long existed in the conceptual repertoire of cognitive scientists and the phenomenon it refers to is ancient (e.g., finger-counting and abacuses in numerical cognition, systems of knots or quipus for memory [14]). However, cognitive offloading has rarely been the target of systematic experimental investigation in and of itself. This has now begun to change. This change has been precipitated by an increasing interest amongst cognitive scientists in "wider" conceptions of cognition (e.g., embodied, embedded, extended, and distributed approaches [2-3, 15-20]). In addition, increased interest in cognitive offloading is emerging at a time when the opportunity to offload cognition onto technological prostheses has reached a kind of fever pitch – the potential consequences of which (both bad and good) have not gone unnoticed by the general public ("Is Google Making Us Stupid?"; [21]). Thus research on cognitive offloading offers both a deeper understanding of the physically distributed nature of human cognition and translational insights into its potential use (and abuse) in our day-to-day lives. Here we review recent research investigating cognitive offloading across three different domains, focusing on two fundamental issues: (a) what factors influence the likelihood of individuals offloading cognition versus relying on internal processes alone, and (b) what are the cognitive consequences of this behaviour?

Thinking with the Body

Cognitive offloading can be roughly subdivided into actions that offload cognitive demands onto-the-body and into-the-world. We turn first to the former. Recent research in cognitive science has focused on how we actively use our bodies in the "here-and-now" to reduce cognitive demand. For example, we use our eyes to index locations in space [22], we use our fingers, point, or nod our head to mark positions in sequential tasks [12, 23], we move our hands to externalize thoughts [11, 24-25] and to simulate spatial transformations [13], and we move or shift our body to simplify perceptual computations [9]. In each of these cases an action is spontaneously performed in the context of an ongoing cognitive act in order to generate some form of cognitive savings.

A straightforward example of this type of cognitive offloading is **external normalization**. For instance, when individuals encounter a rotated stimulus (e.g., a tilted book) they often physically tilt their head to normalize its orientation. This behaviour is an example of external normalization and can be considered a means of offloading **internal normalization**, which is an internal transformation (in this case mental rotation) that aligns a representation of a stimulus with a representation stored in memory [26-27]. Indeed, external normalization can reduce the costs of stimulus rotation [9]. One of the major tasks in understanding cognitive offloading is to determine the factors that influence whether some external means is integrated into the performance of a given cognitive act or not. In the context of external normalization, one of the critical factors is internal demand. Specifically, individuals are more likely to spontaneously physically rotate as the display becomes more disoriented or as the number of items in the display increases [9]. Critically, both of these manipulations also increase stimulus-rotation costs (i.e., internal demand; see Box 1 and Figure 1 Panel A for a general description of this methodology). Thus, as the internal demands associated with stimulus rotation increase, the likelihood of spontaneous external normalization also increases. This general pattern has now been observed across several domains (e.g., external normalization [9]; prospective memory [10]; short-term memory [29]; co-speech gesture [30]; co-thought gesture [13]; see Figure 2 representative examples).

While the relation between internal demand and cognitive offloading is robust, they are nevertheless dissociable. This was revealed in an investigation of external normalization using arrays of words wherein both the words and the frame (i.e., the overall structure of a multi-element array) were rotated, versus arrays where the words were rotated but presented within an upright frame ([32]; see Figure 1 Panel A). These two conditions yield similar rotation costs and similar responses on a physiological measure of demand [32-33]. Yet spontaneous rates of external normalization are much higher when both the words and frame are rotated compared to when only the words are rotated. This dissociation is argued to arise because individuals rely on an erroneous metacognitive evaluation of demand. This evaluation may be led astray by intuitive beliefs regarding the effects of stimulus rotation, or a history of external normalization with displays featuring word and frame rotation. Consistent with this account, individuals incorrectly report that rotated word and frame displays are more time consuming and error-prone, and judge these displays to be more effortful to read than displays with only the words rotated [32].

Putting Cognition Into-The-World

Like offloading cognition onto-our-body, offloading cognition into-the-world is a ubiquitous part of our everyday cognitive lives [4, 14, 34-35]. A key way in which we offload cognitive processes into-the-world is by using it as a repository of representational information, thus eliminating the need for an internal representation. For example, individuals might write down [29], type into a computer [36-37], sketch [38] or in some other manner alter the environment in order to record information that needs to be remembered [14, 39]. We discuss examples of this below.

Offloading Memory - Prospective Memory

We rely on memory not just to recall information from the past, but also to execute intended behaviours in the future. Our ability to remember delayed intentions is termed ‘prospective memory’ [40-41]. Everybody is familiar with its fallibility: failures of prospective memory probably comprise a majority of self-reported everyday memory problems [42]. What makes remembering delayed intentions particularly difficult is that, in many cases, our intentions are not effectively triggered by perceptual cues in our environment, and therefore action must be self-initiated. It is therefore unsurprising that people have long supported prospective memory by using external tools to supply perceptual cues that can trigger intended actions. Examples include tying knots in handkerchiefs, placing reminders in the environment (e.g. post-it notes or task-relevant objects), or – in recent times – using smartphones or wearable devices that can provide time-, location- or person-based reminders [43-44]. This form of cognitive offloading – acting on the environment to create external triggers for delayed intentions – has been referred to as '**intention offloading**' [10, 45]. Laboratory studies of prospective memory have generally considered our tendency to outsource intentions to external tools as a source of noise that obscures 'real' prospective memory processes, and prevented individuals from setting external reminders [e.g. 46]. However, intention offloading is likely central to our ability to remember intentions in the real world, and hence an important topic for investigation. This process was investigated empirically in a recent series of behavioral [10, 45] and neuroimaging [47] studies illustrated in Figure 1 Panel B.

Like tilting one's head to read rotated text, intention offloading is influenced by the internal demands that would otherwise be necessary (see Figure 2). Individuals are more likely to offload intentions when their memory load increases or when they encounter interruptions; both of these factors impair performance when offloading is prevented [10]. However, and again analogously to external normalization, intention offloading is not only driven by objective need but also by a potentially erroneous metacognitive evaluation of demand. This was demonstrated in a study where individuals remembered delayed intentions both with and without the ability to set reminders, and also provided predictions about their performance. Individuals with lower confidence in their memory abilities were more likely to spontaneously set reminders, even after controlling for any influence of objective ability (which also predicted intention offloading [45]). Interestingly, this relation with metacognitive confidence is domain general. When individuals performed a separate perceptual judgement task where accuracy was held constant with a staircase procedure, individuals with lower confidence in their perceptual judgements set more reminders in the intention offloading task [45]. Thus, intention offloading is related not only to individual differences in objective ability but also to domain-specific and domain-general metacognitive confidence.

Once an individual has opted to offload, what are the consequences for information processing? In the context of intention offloading, placing information into the external environment brings several potential benefits. One of the most salient is that offloaded representations may be more durable and less prone to distortion than those stored internally, leading to an increased likelihood of intention fulfillment [10, 45]. However, it is important to note that individuals also set reminders in conditions where doing so led to no objective increase in accuracy [10, 45]. This also occurs in the context of external normalization [9]. This tendency to engage in offloading despite it not benefiting performance may result from (1) an undetected performance benefit (2) a bias against cognitive effort (see Box 2) and/or (3) an erroneous metacognitive belief that the offloading will in fact benefit performance. Support for the latter interpretation comes from recent research examining offloading in a short-term memory task [29]. Participants were allowed to offload to-be-remembered materials (i.e., by writing them down) and did so about 40% of the time when they had to remember only two items, a memory load at which performance was already at ceiling without offloading. Critically, individuals erroneously judged that offloading would improve their performance in this latter condition. Thus, the putatively superfluous offloading (observed across a number of domains) underlines again the importance of metacognitive beliefs in cognitive offloading.

Offloading Memory - Transactive memory

While research reviewed thus far has focused little on the cognitive consequences of offloading, recent research on transactive memory has made this issue its primary focus. In '**transactive memory systems**', knowledge is distributed across two or more individuals such that the system as a whole knows more than any one individual [52-54]. Recent research has extended this notion of socially distributed memory to human-technology transactive memory systems [36, 55-59]. Our ability to reliably store and (almost) instantaneously retrieve information has changed drastically with the advent of the computer and the Internet. Consequently we can now offload much of what in the past would have been stored internally.

To examine the idea that offloading might impair our memory, in one study individuals were presented with a series of trivia statements to remember and had to type them into a computer. In addition, half the individuals expected that the information would be saved and half expected it to be erased [36]. Recall tests demonstrated that those in the latter condition had better memory than the former. The authors argued that memory-encoding demands were offloaded onto the external store leading to memory impairments when it was not available ([36]; see Box 3 for additional costs of cognitive offloading). Interestingly, these offloading-based memory impairments can be accompanied by enhanced memory for other information. For example, when individuals saved an initial list of words it enhanced memory for a second list [37]. The authors argued that saving reduced the likelihood that the first list of words interfered with memory for the second (i.e., reduced proactive interference; see also [60])

Offloading memory demands in a transactive system is not a "free pass" in terms of mnemonic requirements. Rather, a defining attribute of a transactive memory system is a shift from remembering "what" to remembering "where." For example, when you offload information about a meeting to a file on your computer, you no longer need to remember the content of the file, but you do need to remember where to find it. Consistent with this idea, saving an external file can lead to an enhanced ability to recall where to find information, at the expense of remembering what it actually is ([36]; for an alternative explanation see [60]). Similarly, when faced with a failure to recall memory content, thoughts about memory location can be primed relatively automatically. This was demonstrated in a study where individuals answered easy or difficult trivia questions, then completed a variant of the **Stroop task** [36]. Stroop-like interference from words relating to Internet search engines was increased after individuals answered difficult compared with easy questions, consistent with those terms being primed in individuals' minds.

Beyond its influence on memory, being part of a human-technology transactive memory system can also have subtle effects on **metacognition**. For example, searching for information online about one topic can lead individuals to believe that they have more knowledge "in-the-head" and generate more "brain activity" when answering questions about another topic [55]. In a separate line of experiments, individuals who had recently used Google to help them complete a quiz reported higher levels of cognitive self-esteem. They also predicted that they would do better on a subsequent quiz, even without help from external resources [56-58]. These results suggest that participating in a human-Internet transactive memory system can lead individuals to blur the distinction between what they know and what the Internet "knows." However, this outcome does not occur in all circumstances. In another study, participants had to report whether they knew the answer to a general knowledge question or not. In one condition, if participants responded that they did not know the answer, they looked it up on the Internet. In a second condition, if participants responded that they did not know the answer, they simply moved on to the next question. Thus, participants had access to the Internet in one condition and no access in the other. Critically, when they knew they would subsequently have access to the Internet, participants were more likely to answer “don’t know” and reported lower **feeling-of-knowing** to the trivia questions [59]. Thus, Internet access in this context reduced individuals’ willingness to offer an answer to a question based on their own knowledge. Taken together this research underscores the fact that opportunities to offload cognition can affect both lower-level cognitive systems (e.g., memory) and higher-level metacognitive evaluations of those systems (e.g., confidence).

Metacognition of the Extended Mind

The reviewed research suggests that theorising on cognitive offloading may benefit from further investigation of the metacognitive aspects of both the processes that trigger cognitive offloading and the consequences of this behavior. We offer a framework to support this effort here (see Figure 3, Key Figure). This framework describes situations in which there are two or more ways of achieving a goal, one of which involves cognitive offloading and one of which does not. In these circumstances, offloading represents a kind of strategy to achieve some cognitive goal, and follows a strategy selection phase [75-79]. This strategy selection phase is influenced by a metacognitive evaluation of the available options (see arrow A in Figure 3). In particular, it is informed by metacognitive beliefs (relating to the person, task, and strategy) and experiences (e.g., effort; [32, 34, 81-82]) that are associated with internal and more “extended” strategies (i.e., those integrating an external body- or physical environment-based resource). For example, when faced with a need to remember a given piece of information our knowledge regarding our previous success with internal (e.g., metacognitive confidence) and external storage [45, 84-85], our beliefs about the reliability of a particular external store [37], and/or a feeling of fluency could all contribute to whether an individual stores that information internally or offloads the memory demands into-the-world. This framework places at center stage a need for a deeper understanding of the metacognitions associated with cognitive offloading and generates a number of interesting avenues for future research [see Outstanding Questions Box].

It is important to note that the strategy selection phase postulated above does not necessarily imply that individuals are aware of making a choice [see 86-87 for discussion of this issue]. Clearly, there is a range of situations that putatively involve cognitive offloading, some of which involve conscious deliberation and others of which do not. For example, gesture, which is often associated with cognitive offloading, can occur without individuals necessarily being aware of it. On the other hand, choosing between navigating based on stored knowledge versus plugging a set of coordinates into a GPS device is likely more strongly associated with a phenomenology of deliberation and choice. Thus, an important question within the proposed framework will be to examine the extent to which different forms of cognitive offloading involve conscious deliberation or not and how these cases are similar or distinct.

Our framework also attempts to capture the downstream effects of cognitive offloading on how we think. As reviewed above, recent work has demonstrated that the experience of offloading cognition [55-58] and the opportunity to do so [59] can in and of itself alter our thinking about our internal capacities (i.e., our metacognitions; see arrow B in Figure 3). For example, offloading information retrieval onto the Internet can inflate our estimates of our own knowledge [55-58]. In addition, this work has demonstrated that cognitive offloading can have both costs and benefits with respect to basic cognitive processes (see arrow C in Figure 3). For example, offloading to-be-remembered information can both aid and impair retrieval from internal memory stores [36-37]. It should also be noted that, beyond reducing cognitive demand, offloading could also qualitatively change the processes involved in thinking, communicating, and learning, potentially with both positive and negative consequences [13-14].

The metacognitive framework offered here also highlights potential interactions between offloading and the mechanisms that trigger this behaviour. For example, deciding whether to rely on a GPS device for the location of a friend's house versus our internal memory will be informed by beliefs in each method's relative accuracy (a computation that will likely favour the former strategy; arrow A). The tendency to offload wayfinding to the more accurate GPS will likely reduce both our internal spatial memory for that location [arrow C; 61-63] and our metacognitive confidence in it (arrow B), which will in turn increase the likelihood that we choose to rely on the external artefact in the future (arrow A). Thus the model predicts a kind of self-reinforcing pattern that will produce a drift away from reliance on internal capabilities when situated in an environment with effective cognitive technologies (see [88] for an example of this kind of drift in the context of Inuit wayfinding). Understanding the long-term cognitive consequences of this drift represents an important area of future research.

Practical Implications

Research investigating cognitive offloading has clear practical implications - two of which we highlight here. First, individuals with impaired unaided cognitive ability may particularly benefit from cognitive offloading. How can those who would benefit the most be encouraged to do so [89]? The metacognitive model of cognitive offloading put forward in this article suggests that compensatory offloading strategies are most likely to be adopted in individuals with metacognitive awareness of their impairment. This implies potential challenges in populations with metacognitive difficulties, for example in cases of acquired brain injury where there can be a mismatch between an individual's metacognitive evaluation of their abilities - built up over a lifetime - and the post-injury reality [90-91]. Improving metacognitive insight in cases such as these could lead to more appropriate compensatory offloading [92]

The second general area in which research on cognitive offloading has important practical implications is education [11, 24, 93-94]. There has long been interest in the potential utility of educational interventions and aids that allow children to offload some of the cognitive demand while learning (e.g., manipulatives; [93-94]; calculators [95-96]). For example, gesture helps children learn by "lightening the load" [11] and, interestingly, this benefit appears to outstrip that garnered by offloading demands onto external manipulatives [97]. The latter suggests the need to consider whether different forms of offloading might have different educational consequences. Critically, any benefit of offloading will be contingent on the fact that the demand being offloaded is unnecessary with respect to the learning goal (see [98] for relevant distinctions between necessary/intrinsic/germane and unneccesary/extraneous load in learning). In addition, it is important that what is "saved" by offloading is redistributed productively rather than being re-allocated to superfluous activities [e.g., intentional mind wandering [99]; see Box 2 for a similar issue in the case of automating driving].

Concluding Remarks

Cognitive offloading represents one of the quintessential examples of how we use our body and objects in the external world to help us think. As such, understanding this phenomenon provides a window into the distributed nature of human cognition. It is clear from the present review that offloading can take many forms, but that common patterns exist across domains. In particular, the evidence reviewed above shows that internal demand and metacognitive evaluations of demand play a critical role in offloading. Furthermore, cognitive offloading can have downstream effects on our low-level cognitive capacities and our subsequent metacognitions. We have suggested that an important future direction for this research will be to better understand the metacognitive processes involved in cognitive offloading and have offered a framework to guide this effort. Beyond metacognition, there is a clear need to better understand how offloading demands onto various technologies (e.g., computers, Internet, GPSs) impact our organic abilities both in the short- and long-term. The latter represents a particularly pressing concern both for researchers and society in general as our lives come to be more cognitively entangled with these technologies. Conducting this needed research, however, is not without challenge. For example, investigating cognitive offloading often requires allowing research participants to move their body and manipulate and interact with their environment. Methods in cognitive science, however, have traditionally been designed to restrict this type of natural behaviour [100-101]. Thus, understanding cognitive offloading will require an expansion of the cognitive scientist's methodological toolbox. This and other challenges notwithstanding, future research investigating cognitive offloading promises a deeper understanding of one of the defining attributes of human cognition.

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Glossary

Cognitive offloading: The use of physical action to alter the information processing requirements of a task in order to reduce cognitive demand.

Internal normalization: Use of an internal transformation (i.e. mental rotation) to align an internal representation of a stimulus with a representation stored in memory.

External normalization: The use of physical action (e.g. head tilt) to align a stimulus with a representation stored in memory.

Intention offloading: Creation of a cue in the external environment to trigger a delayed intention.

Transactive Memory System: A memory system composed of a group that collectively encodes, stores, and retrieves knowledge.

Stroop Task: A reaction time task involving conflict between two stimulus dimensions (e.g. the color and meaning of word stimuli).

Metacognition: Higher-order thinking, or "thinking about thinking", to enable evaluation and control of one's mental processes.

Feeling-of-Knowing: Predictions made by an individual about whether they will be able to retrieve specific information.

Figure 1 Caption. Paradigms for investigating cognitive offloading. Panel A: In the external normalization paradigm [9] participants read arrays of words that are presented in upright or rotated orientations. When faced with rotated words, participants can align them using internal cognitive processes ('internal normalization') or physical action ('external normalization'). Panel B: In the intention offloading paradigm [10] participants use a mouse or touchscreen to drag numbered circles in sequence to the bottom of the screen. They are also instructed at the beginning of the trial that one or more of these circles should be dragged to an alternative location. They can either remember these intentions internally or offload them by dragging target circles towards their intended location at the beginning of the trial. In some ways this is analogous to everyday offloading behavior such as leaving an item by the front door so that we will remember it when leaving the house. For a demonstration of the task, please visit "http://samgilbert.net/offloadDemo.html". Illustrations modified with permission from [9] and [47].

Figure 2 Caption. Relation between Internal Demand and Cognitive Offloading

There exists a consistent relation between the amount of internal demand, as indexed in a condition where offloading is restricted, and the amount of spontaneous offloading behavior observed in a condition where the behavior is not restricted. This has been demonstrated across a number of different domains. With respect to external normalization (Panel A) as the internal costs of stimulus rotation increase when individuals are forced to remain upright (i.e., see rotation costs in ms/degree in "Restricted Motion Conditions"; larger values represent greater costs), the likelihood that an individual spontaneously physical rotates increases (i.e., see "Free Rotation Conditions"; larger values represent a higher frequency of offloading; [9]). In intention offloading (Panel B) and short-term memory (Panel C) as the unaided memory performance decreases (see "Accuracy without intention offloading" in Panel B and "Accuracy: No Choice" in Panel C), the likelihood that an individual spontaneously offloads the memory demands into the environment (i.e., setting reminders; writing the to-be-remembered items down) increases (see "Intentions offloaded when possible" in Panel B and "Choice Behavior" in Panel C; in both cases higher values represent a higher frequency of offloading; [10, 29]). Graphs modified with permission from [9], [29], and [45].

Figure 3 Caption: A metacognitive model of cognitive offloading

We propose that selecting between offloading and relying on internal processes is influenced by metacognitive evaluations of our (internal) mental capacities and the capacities of our extended mental systems encompassing body and world (arrow a). An example of this would be evaluating our unaided spatial memory and a GPS system when deciding how to navigate to a friend's house. In addition, engaging in either internal or extended strategies can influence subsequent metacognitive evaluations (arrow b). For instance, after successful use of a GPS system we may come to believe that it is a more reliable guide than our unaided memory. Offloading can also directly impact our lower-level cognitive processes (arrow c). An example of this would be a reduction in our internal spatial memory for a location after reliance on GPS navigation.

Box 1. Methods: The Choice/No Choice Paradigm

Research on cognitive offloading has relied heavily on variants of the Choice/No Choice paradigm [31]. The application of the paradigm is straightforward: In some conditions participants are forced (i.e., they have no choice) to employ a particular strategy and in others they are free (i.e., they have the choice) to select amongst a set of available strategies. Each condition and the comparison between conditions provides answers to theoretically interesting questions. In addition, these conditions are typically paired with one or more other manipulations that influence some variable of interest (e.g., memory load). Below we provide an illustrative example using offloading memory onto an external medium (e.g., a piece of paper, a computer).

No Choice – Internal: Individuals are tasked with remembering a given piece of information without being able to store it externally. This condition provides a measure of performance when the individual has to rely solely on their internal memory.

No Choice – External: Individuals are tasked with remembering a given piece of information and must store it externally. This condition provides a measure of performance when the individual uses external memory. It is important to note that unlike the No Choice – Internal condition this condition cannot ensure that the information is not also stored internally. The comparison of the two No Choice conditions provides a measure of the relative effectiveness of storing information internally and externally. This comparison is often made as a function of some other variable (e.g., the amount of to-be-remembered information).

Choice: Participants are allowed to freely choose between storing information internally or externally. This condition provides a measure of the spontaneous offloading of memory demands onto the external medium. Again, how the spontaneous offloading of memory demands changes as a function of some other variable (e.g., the amount of to-be-remembered information) is typically of interest. This condition also provides a measure of performance when the individual uses their “preferred” strategy.

Challenges: The choice/no choice paradigm is not without challenges. As noted above, attempting to force individuals to adopt a strategy might not be effective in some circumstances. In addition, forcing individuals to use a particular strategy could introduce demands associated with having to inhibit the use of another possibly preferred strategy. For example, restricting individuals from gesturing could impose its own load associated with inhibiting naturally occurring gestures [11].

Box 2. Perspectives on Cognitive Impartiality

In discussions about cognitive offloading a central question arises with respect to whether the cognitive system has an inherent bias away from certain types of effort. For example, in selecting between storing information in short-term memory (i.e., in-the-head) or writing that information down (i.e., in-the-world; [29]) individuals are selecting the type of effort that will be required to carry out the task – more internal or cognitive effort in the former case and external or perceptual-motor effort in the latter case. Two views have dominated discussions of this issue (see [2] for further discussion). On the cognitive impartiality view the cognitive system has no bias or is indifferent to the type of effort required. For example, according the Soft Constraints Hypothesis [48-49] it is not the kind of effort but rather the amount of time required that determines the preferred solution (i.e., the solution with the shorter time being the preferred one). An alternative view, which might be called the "cognitive miser" view, is that individuals have an inherent bias against expending cognitive effort. There has been much recent work on individual's tendency to avoid this type of effort [50-51]. One influential theoretical position that embodies this view is the Minimal Memory view [22] according to which the cognitive system is biased toward minimizing demands on memory (even in the face of potentially greater perceptual-motor costs). Between these theoretical signposts likely lay a number of interesting alternatives, for example, individuals may have idiosyncratic biases in one direction or the other, or variable task-dependent biases. Future work aimed at adjudicating between these and related views will provide deeper understanding of the how the cognitive system distributes resources across brain, body, and world.

Box 3. Beyond Google: Costs of Offloading

GPS: Many people now travel using global positioning systems. Offloading wayfinding onto such a device has been demonstrated to impair spatial memory [61-63]. For example, in one study individuals who drove a pre-determined route using a turn-by-turn navigation system outperformed individuals who had no aid. However, individuals in the former group had poorer memory for scenes from the route and when asked to drive the route a second time without an aid did more poorly [63].

Cameras: In an examination of the influence of taking a picture on memory, individuals visited a number of objects and either took a picture or simply observed the object [64]. Memory for the objects tested a day later revealed impaired memory for the photographed objects. In a subsequent experiment, taking a picture of only part of the object, rather than the whole object, to some extent ameliorated this cost [64]. It was argued that the act of taking a photograph led individuals to offload the memory for the object onto the camera [64]. The impairment observed here is particularly interesting because individuals did not necessarily expect to have the pictures available during the memory test. Thus, the de-prioritization of information that is potentially available externally might occur spontaneously [65].

Automation: In many cases the decision to offload is not made by the individual. Rather, offloading is "built-in" to the task environment by design. This could reflect a desire to increase usability [66-67] or automate tasks entirely [68-70]. With respect to offloading associated with automation, research has focused on two costs that have been observed across a number of safety-critical situations (e.g., aviation, medicine, driving), specifically, *automation complacency*, the failure to be sufficiently vigilant with respect to the performance of automated processes, and *automation bias*, the tendency to uncritically rely on the output of a automated decision aid [68]. The long-term reliance on automated processes could also lead to cognitive "skill decay" where a developed ability deteriorates over time [71-73]. Recent research has highlighted the fact that the consequences of automation on performance can be tied closely to how individuals allocate resources freed up by automation. For example, driving a highly automated vehicle can improve situation awareness relative to manual driving if individuals are motivated to attend to the environment but can impair it if they decide to devote "freed resources" to driving-unrelated tasks [74].

Figure 1

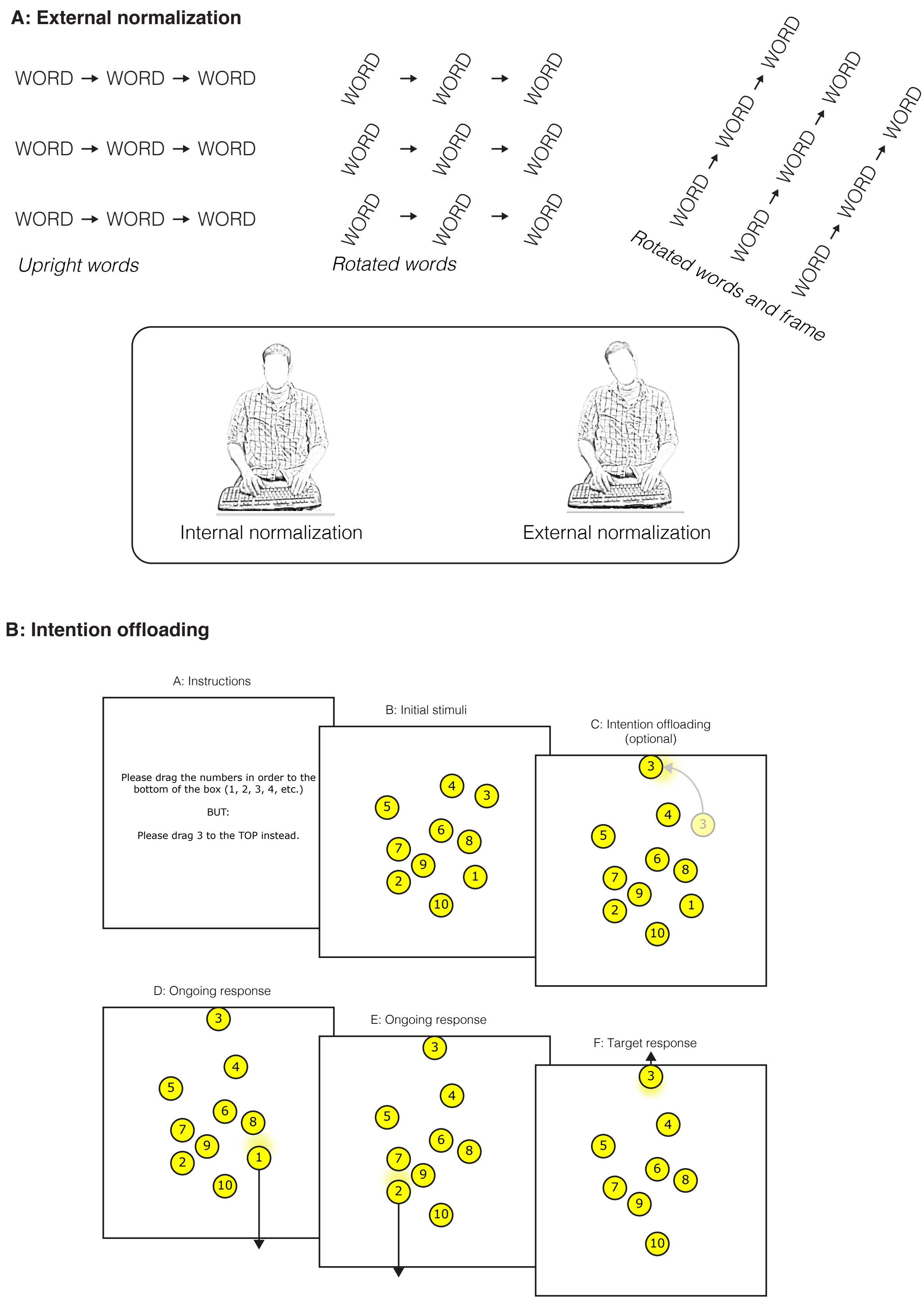

A: External normalization
WORD → WORD → WORD
WORD → WORD → WORD
WORD → WORD → WORD
Upright words
Rotated words
Rotated words and frame
Internal normalization
External normalization
B: Intention offloading
A: Instructions
Please drag the numbers in order to the bottom of the box (1, 2, 3, 4, etc.)
BUT:
Please drag 3 to the TOP instead.
B: Initial stimuli
C: Intention offloading (optional)
D: Ongoing response
E: Ongoing response
F: Target response

Figure 2

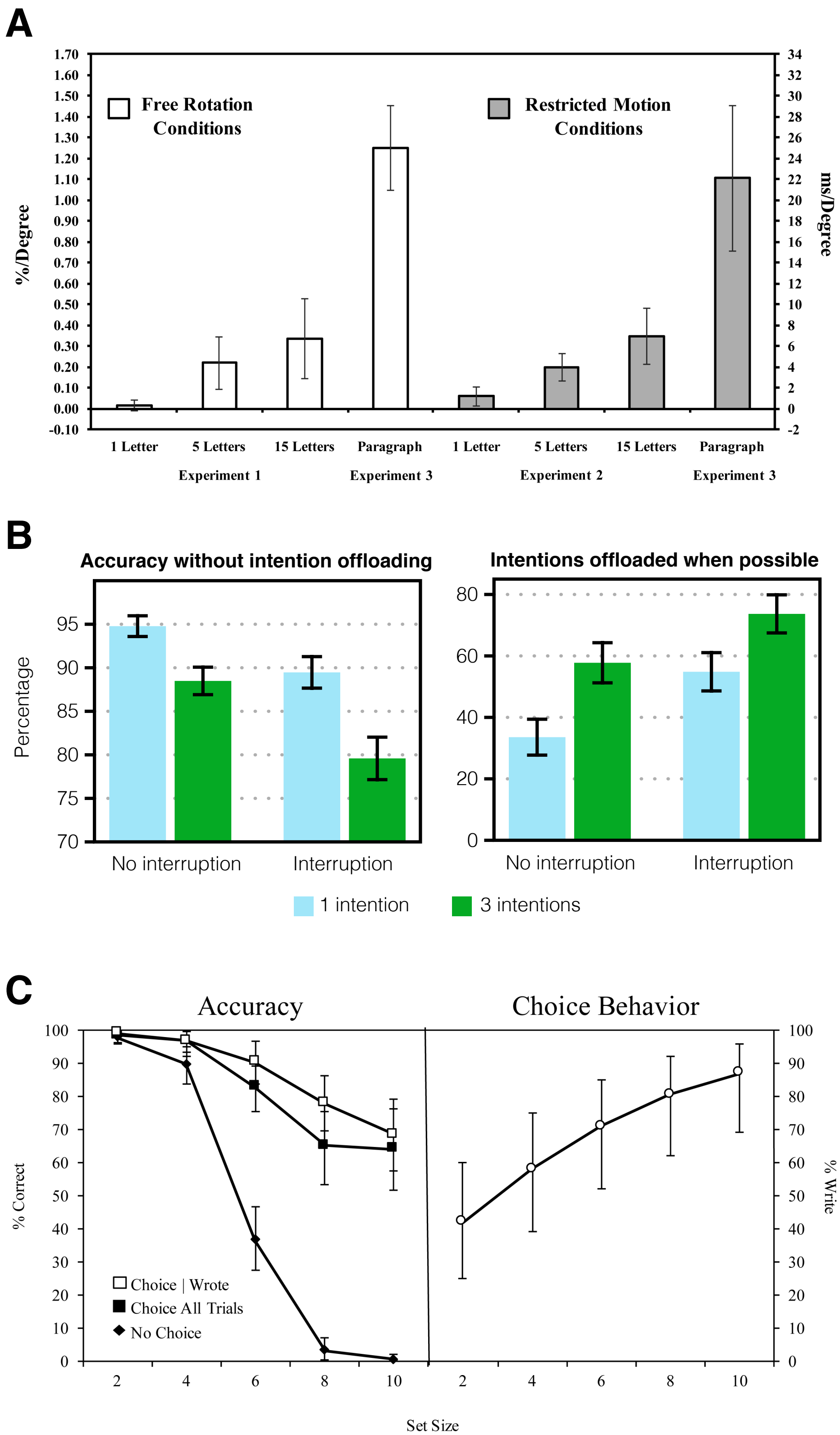
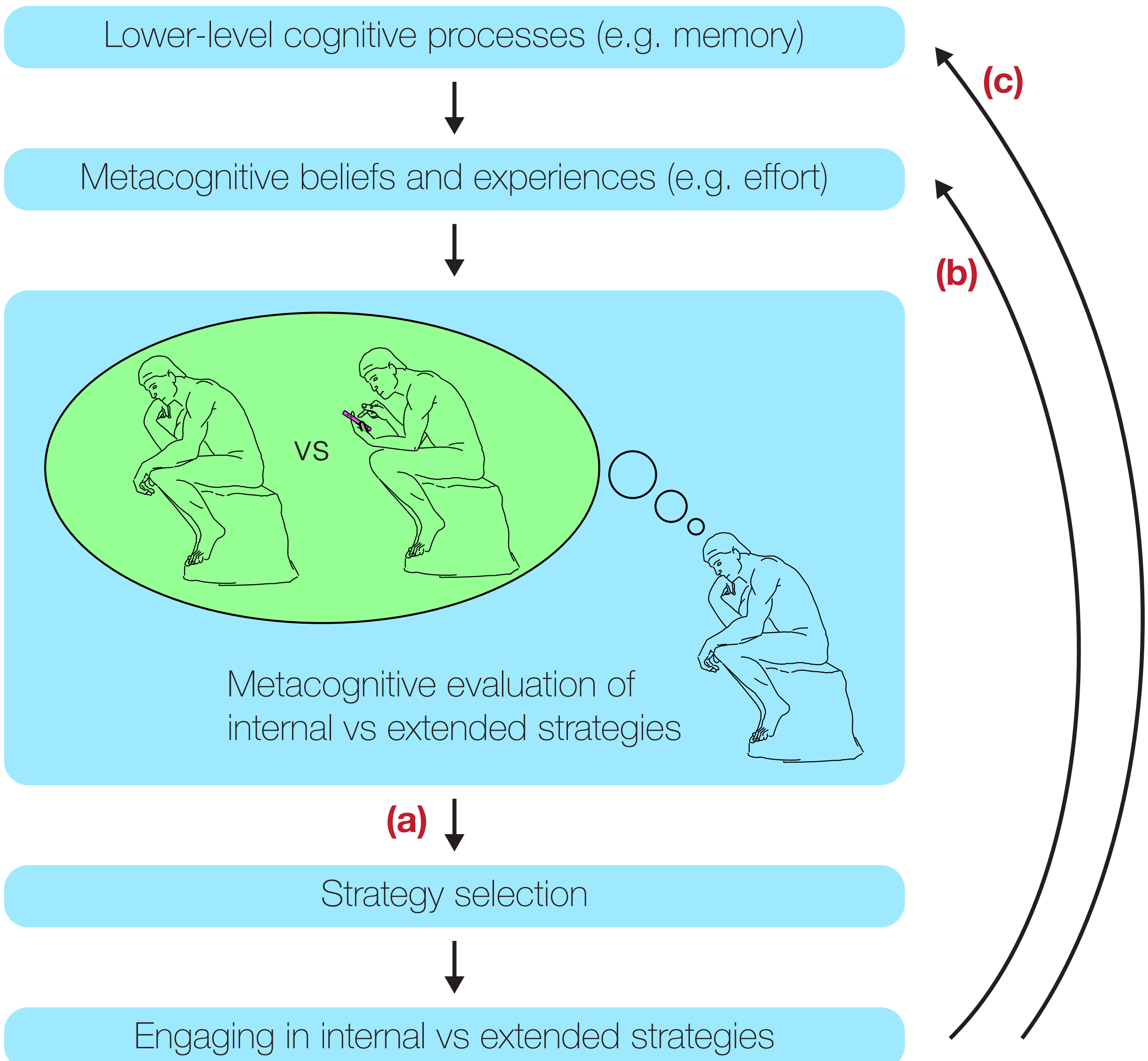

A
%/Degree
ms/Degree
Free Rotation Conditions
Restricted Motion Conditions
1 Letter
5 Letters
15 Letters
Paragraph
Experiment 1
Experiment 3
Experiment 2
B
Accuracy without intention offloading
Intentions offloaded when possible
Percentage
No interruption
Interruption
1 intention
3 intentions
C
Accuracy
Choice Behavior
% Correct
% Write
Choice | Wrote
Choice All Trials
No Choice
Set Size

Figure 3


Lower-level cognitive processes (e.g. memory)
Metacognitive beliefs and experiences (e.g. effort)
vs
Metacognitive evaluation of internal vs extended strategies
(a)
Strategy selection
Engaging in internal vs extended strategies
(b)
(c)