Knowledge in Motion: How Procedural Control of Knowledge Usage entails Selectivity and Bias

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Abstract

The use and acquisition of knowledge appears to be influenced by what humans pay attention to. Thus, looking at attention will tell us something about the mechanisms involved in knowledge (usage). According to the present review, attention reflects selectivity in information processing and it is not necessarily also reflected in a user's consciousness, as it is rooted in skill memory or other implicit procedural memory forms–that is, attention is rooted in the necessity of human control of mental operations and actions. The main assumption is that what is true of processing in general is also true of knowledge: Its usage cannot be understood, unless we have the means to study all mechanisms involved, including knowledge hidden from direct introspection and knowledge that participants are not willing to share with interrogators. Reviewing work done in this context, I argue that experimental research on selectivity and bias in human information processing is a promising road to learn about the principles governing knowledge (usage) and to reflect upon them.

Key words: Attention; Knowledge; Procedures; Biases; Selectivity

1 Introduction

1.1 Knowledge in Psychology: Truth vs. Introspection

The current review is concerned with the role of attention for human knowledge. I will argue that to understand knowledge, it is necessary to use experimental investigations

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and objective performance evidence from a third-person perspective, and that it is insufficient to rely on introspection and the corresponding reports alone. Superficially, this might seem redundant in light of the many studies that used objective performance measured from a third-person perspective to study knowledge (e.g., Schank & Abelson, 2013; Pylyshyn, 1981). However, until today, vital areas of knowledge research use introspection for far-reaching conclusions, sometimes with seemingly little awareness of the methodological limitations. As an example take experimental philosophy. Whether one refers to knowledge as a justified belief (but possibly a false one) or only as a true belief, beliefs are central to many classical definitions of knowledge (cf. Gettier, 1963). In recent years, experimental philosophers used questionnaires about canonical thought experiments to conclude that human subjects' epistemic, moral and metaphysical beliefs vary significantly as a function of the exact side conditions and the group of test subjects (Knobe & Nichols, 2008). What is often not realized, however, is that questionnaires used to test human beliefs essentially ask test participants to report based on their own introspections. Thus, these questionnaire-based methods simply replace expert's self-introspection about knowledge processes involved in and revealed by thought experiments with potentially more representative introspective data collected from laypersons. If methods of self-introspection are limited, as they are only sensitive to that part of a human subject's own representations that are accessible to consciousness, then these questionnaire methods are limited in the same way as experts' armchair introspections about the conclusions from their thought experiments.

To start with, by some means or another, knowledge is related to truth (e.g., Gettier, 1963; Nozick, 1994; Williamson, 2000). As psychology is not concerned with the exact definition of "truth," pragmatically, knowledge in psychology requires that a mental state or representation exists on the side of the knowledge bearer that corresponds more or less to a (representation of a) state of affairs holding relatively independently of the current state or representation of the knowledge bearer. This second independent representation can be used as "ground truth" for comparison with the current representation. In other words, in the following review, I will use "knowledge" in a generic sense, defined as representations of content that one believes with confidence or that are based on some type of reliable process. For instance, to *know* I willingly broke a social rule at a dinner party, I could compare the intended and the current consequences of my behavior: Based on my memories of past experience, I would know if I had beliefs about what people do in such a situation and if I intended people smiling at me and talking to me or if I intended to annoy them. This example already shows why introspection, the view of one's own mental representations from a first-person perspective, is often involved in research on knowledge. In contrast, from a third-person perspective (from the outside), it would be difficult to know the exact beliefs of the agent, here, what she or he knew in advance, and what she or he intended and, thus, to decide if she or he knew the social rule and broke it willingly, or if she or he was lacking fitting "prior knowledge".

1.2 Types of Knowledge and Experimental Psychology

More systematically, *knowing of* is only one form of knowledge, and introspection is not necessarily the best way to study all of these forms of knowledge in each instance.

What I want to make clear in the present review is that even in cases in which explicit *knowing of* (or, for that matter, *knowing about*; see below) is investigated, introspection is by no means the best way to study this type of knowledge.

To start with, in general, knowledge can be subdivided into at least the following three different types or forms. A first type of knowledge is *knowledge of* something or someone, for example, when I recognize that the green and white object in my garage is a bicycle or when I realize that the person in front of me is my dentist (cf. Zagzebski, 2017). Here, it is already debatable if introspection is always required, as recognition has also been studied by facilitated processing of repeated and, thus, "known" information relative to entirely novel information. For example, if tested, prosopagnosics–that is, patients showing strong deficits in introspective awareness of their own face recognition capabilities and corresponding deficits in explicit face recognition–showed the same performance advantage as healthy controls for already presented faces compared to entirely novel faces in a same-different judgment task for pairs of faces (cf. De Haan et al., 1987).

A second type of knowledge is *knowledge about* something or someone; for instance, the knowledge that a bicycle is a vehicle or the knowledge that a dentist is an academic (cf. Zagzebski, 2017). This is the type of knowledge that is often studied by introspection, for instance, through interrogation or interview (Ericsson & Simon, 1980). A third type would be *knowledge-how*; for example, the knowledge how to ride a bicycle (cf. Pavese, 2017). In the case of knowledge how, or skill knowledge, it is especially doubtful if introspection is the best way of studying this type of knowledge. For instance, amnesics–that is, persons with explicit memory deficits, who are per definition unaware of their own knowledge such that they oftentimes can simply not use this knowledge–show comparatively less deficits of their skill knowledge or knowing how. For example, despite their lack of explicitly knowing that they can successfully perform on a task, amnesics can acquire and retain mirror writing skills at a similar rate and for a similar duration as normal controls (Cohen & Squire, 1980).

Importantly, psychology identifies a number of ways in which these different types of knowledge could interact (Anderson et al., 2004; Neisser, 1976). In particular, both the usage of knowledge-of and knowledge-about requires knowledge-how, because all knowledge use depends on temporally extended processing. This is important in the context of the current review, as this is where attention comes in (see next Section).

As an example for the role of knowledge-how in knowledge-of, take a simple experimental task used in empirical psychology. Akin to knowledge-of or recognition, in a (delayed) matching-to-sample task, participants in such an experiment first have to encode a sample stimulus into memory for later comparison with a second stimulus (e.g., Fuster et al., 1982). For instance, they might see a horizontal line as a sample and are instructed to remember it for later comparison (i.e., matching), following a retention interval, with a second stimulus. To fulfill the task demands and follow the instructions, humans would set up a mental representation or template of the sample for later comparison with the second stimulus. After a temporal delay, a second visual stimulus is presented, for example, a vertically oriented Gabor patch, and participants have to compare it to the template to decide if the second stimulus matches the sample. Depending on whether or not the stimulus matches the template or sample, participants would press one or another button as defined in the instructions. Importantly, these types of processing imply that attention is involved in the usage of knowledge as will be explained next.

2 Attention

2.1 Attention and Selectivity

In the present article, attention is defined as the selectivity of mental and information processing. This also covers instances of selectivity in memory, perception, or reasoning. For instance, in the (delayed) matching-to-sample task described above, participants would have to select the orientation of a line for encoding into memory and for usage in a template for their comparison. The fact that this selection is not self-understood but rather an achievement depending on an active and successful selection, humans and animals can show substantial limitations of performance in the (delayed) matching-to-sample task (Oscar-Berman & Bonner, 1985). In this context, attention is used as a descriptive term to reflect both introspectively felt selectivity in conscious perception, recollection, and thought (cf. James, 1890), as well as "observed" selectivity in objectively measured human performance in corresponding tasks, for example, as humans' accuracy in reporting if they registered any unexpected stimulus in an attentional blindness experiment (Horstmann & Ansorge, 2016; Mack & Rock, 1998).

Importantly, the origins of this selectivity are not yet known, and they are probably heterogeneous. To understand this, consider the following example: To control a pointing action successfully, humans would have to select information about the spatial location of the to-be-pointed-at object. The necessary information about the spatial location is provided by visual input. However, to be of any use for the monitoring and control of the grasping action, the visual coordinates would have to undergo several different transformations, as the rotating shoulder, elbow and wrist–all involved in the pointing action–would carry different spatial degrees of freedom and, thus, require monitoring and usage of different spatial coordinates from the visual input (Soechting & Lacquiniti, 1981). Formally, any such input-output transformation corresponds to a selection or filtering process, where (visual) input and (motor) output are related to one another by a transfer function (see Figure 1).

One can easily see how such transformations of information create different forms of selectivity depending on the exact purpose of information usage. For instance, for focusing of the eyes, visual distance would need to be translated into the rolling of the eyes toward or away from the nose and into the elongation or shortening of the lens (e.g., Mays et al., 1986). In this sense, an appropriate view of selectivity or of attention requires to consider that the possibility of heterogeneous origins, meaning selectivity should not be mistaken to be (only) the consequence of one shared control mechanism (Kahneman, 1973).

This point is crucial to the current argument, because if thinking of attention as being the mere consequence of a limited resource that needs to be shared among different tasks, stimuli, or channels, one can easily miss a critical point: that attention is omnipresent, as it is often more extreme than would be suggested by limited resources alone. Attention, viewed as selectivity in psychological processing, is not just taking a toll on processing efficiency where the conditions are taxing. Humans also routinely show surprising selectivity where this would not be predicted by resource limitations.

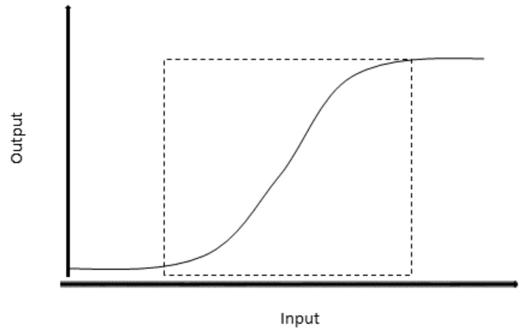

Figure 1: Function relating input to output.

Depicted is an example of an input-output function. Such transfer functions describe which input states correspond to which output states and can take on almost any form. They can be used to describe transformations of sensory input into motor output, but also transformations of one Representation X into a different Representation Y. Critically, such transformations show selectivity. For instance, in the depicted graph, for areas of the transfer function outside of the broken lines, the output is the same, regardless of the exact input value–that is, the input differences of Representation X are lost in the output Representation Y. Such input-output functions, therefore, already illustrate filtering or attention: selection of some inputs and disregard of other inputs.

To understand this argument, take the example of human short-term memory recollection of salient colors in a simple visual memory experiment. Typically, humans can hold an estimated three to four objects (together with their features) in visual short-term mind (Luck & Vogel, 1997). However, if asked to look at either a disk or a ring surrounding the disk, many participants only note the color of the single relevant object and had no recollection of the color of the irrelevant object, so that these participants could only report the color of the disk but not that of the ring if asked to look at the disks (Eitam et al., 2013). (In control conditions, in which participants had to look at both objects, memory of the two color was near perfect.) This point is critical, as the origins of such selectivity have more to do with selection being part and parcel of habitual processing routines, with little introspective awareness of the corresponding limitations on the side of the processing human.

2.2 A Different Perspective

Therefore, in the current review, a different perspective on attention is taken. According to the present view, attention is selectivity following from the fact that some type of features or stimuli are highlighted in an individual's criteria or template representations used in the routine or skilled and, thus, implicit forms of control and monitoring of the success of information processing: By and large, selectivity of information processing owes to the particular way humans make use of information, and this is by far not always something that would be maximally efficient (i.e., that would make use of capacity to maximal degrees) and that humans would notice and be able to report. In other words, what applies to overt actions applies to any temporally extended processing and, thus, to any use of knowledge.

Knowledge processes can carry characteristics of selectivity imposed by the way or means in which the processes are carried out. For example, in the case of knowledge-of, if humans have to keep two templates in mind in a (delayed) matching-to-sample task, they show evidence of selectivity imposed by the neural machinery on which the processes of recognition are carried out. Specifically, in the matching-to-two-templates task, one can observe rhythmic fluctuations between templates – that is, of the use of only one template at a time: When asked to hold two line orientations in memory, participants' average accuracy of performance for stimuli matching to Templates A versus B took turns with about 8 Hz frequency (Pomper & Ansorge, 2021; see Figure 2). This is in line with known oscillations of brain activity in attention-dependent tasks (e.g., VanRullen, 2018), meaning that much as in the case of an overt action, characteristics inherent to the physical device by which a process is carried out – here, temporal synchronization or neuronal activity as a way to organize brain activity – can impose forms of selectivity on processing in the service of knowledge usage and acquisition (VanRullen, 2016, 2018).

In essence, there might be better ways of how humans could strategically organize this type of information processing that make full use of known capacity up to its limits. However, definitely the usage of one template out of two templates at a time would be a successful habitual way to solve the delayed matching-to-sample task, as separate testing of each template in turn could maximize a human subject's certainty about whether or not information regarding each particular template was missed. In other words, rather than relying on their known maximal capacity, humans oftentimes seem to prefer "maximized selectivity" and the fact that the corresponding efficiency limitations are introspectively not noticed might even support their ubiquity.

3 Studying the Role of Attention (Selectivity) in Knowledge

In theory, such characteristics of knowledge and the principles of knowledge use can be studied in one of two ways. First, they can be investigated introspectively. In this case, humans draw on their inner representations of what they perceive themselves they do when using their knowledge. Alternatively or complementary, however, the principles can also be studied from a third-person perspective by observations of characteristics of overt performance reflective of the underlying (use) of knowledge. Here, one would typically employ a performance measure, such as participants' percentage correct responses or response speed, and experimentally vary conditions systematically to investigate which principles are characteristic of knowledge. We have already explained that, intuitively, many intricate knowledge processes that require comparison of several mental representations can most easily be assessed from a first-person perspective. Historically, this has also been the first take on the issue as I will explain next. However, strikingly, only by using the latter experimental third-person perspective methods one can identify important characteristics of the processes involved in knowledge creation and usage. This will be explained later.

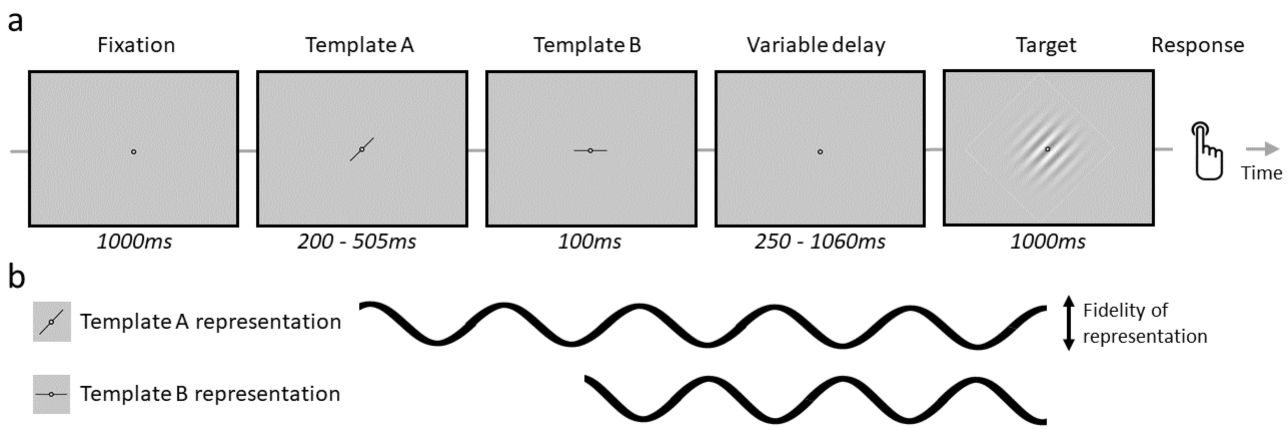

Figure 2: Schematic illustration of rationale and procedure of Pomper & Ansorge (2021).

(a) In each trial, participants saw Samples A and B to encode as Templates A and B, each designating a different target orientation. Following Template B a retention interval of variable duration and a Gabor patch as a target were shown. Participants judged if the orientation of the Gabor matched either the Sample/Template A or B or neither of the samples/templates. Orientations could vary from trial to trial. Figure from Pomper & Ansorge (2021). (b) The fidelity of the visual working memory templates fluctuated over time. Template B, the later starting template, and Template A, the earlier starting template took turns in prioritization.

3.1 Introspection, Again

To illustrate both methods, consider first selectivity in consciousness as studied with introspection from a first-person perspective. In the early days of psychology, when it just calved off of philosophy as an independent academic discipline, scholars understood psychology mostly as being concerned with human consciousness (Wundt, 1896). In this phase, at the end of the 19th century, early psychologists, noticed selectivity among their own thoughts and ideas introspectively. This observation figured in various forms in early consciousness psychology. According to Brentano (1874), for example, each conscious state is characterized by intentional inexistence. Intentional inexistence corresponds to a twofold selectivity, where the inexistential object denotes the specific (and, therefore, selective, i.e., contrasting with other potential) content of consciousness at a particular moment in time, while the intention characterizes the particular (and, thus, equally selective) qualitative way in which the object is referred to in consciousness. Brentano labelled his objects as *inexistent*, as they would have to exist inside of consciousness (i.e. they are *in*-existent objects) only but would not have to exist outside of consciousness (i.e. they may be *non*-existent objects).

When we consider the various forms of intentions by which humans could refer to inexistent objects such as remembered, imagined, dreamt, or perceived, it becomes clear how, for example, an imagined object, such as Pegasus with Headphones being present in each atom, would not have to exist outside consciousness. A closer inspection of the qualitative distinction between intentions would maybe even suggest that the particular intention of imagination is contrastively defined against perception and memory as referring to an inexistent object that is neither "currently present" outside of consciousness in the moment of its experience (as in perception), nor having had to be experienced as present outside of consciousness at some point in the past (as in memories). However, Brentano generally acknowledged a difference between inexistent objects and "their counterparts" outside consciousness, and, therefore, inexistence was characteristic of all conscious objects. This was the case even for perception and memory, although the experienced correspondence between objects inside and outside consciousness might have been higher in the latter cases. Just as a side note, it should be obvious that selectivity in consciousness à la Brentano, thus, also covers typical cases of knowledge.

Take James as a second example for how introspectively felt selectivity in consciousness figured in early psychological theorizing. According to James (1890), humans experience a stream of consciousness, in which the content of consciousness changes across time, implying that at each moment in time, only part of all potential content is selected for consciousness. As a final example, in Wundt's theory of apperception, attention was the productive force that generated conscious percepts out of elementary sensations (Wundt, 1896). In contrast to James and Brentano, Wundt also already relied on "objective", here, experimental evidence from a third-person perspective in addition to introspection. For instance, the so-called "complication experiments" nicely demonstrate the workings of attention as a form of selectivity in the service of consciousness. In these experiments, humans gave bimodal judgments by noticing the time at which they heard a tone by registering and reporting the position of a visual digit swiftly running on a clockface. In one condition of the complication experiments, the times between tones varied unsystematically from one tone to the next, while in the other condition, the tones were presented rhythmically, with a fixed interval between successive tones. It turned out that the visual clockface time at which participants noted (or reported) the tone was shorter under rhythmic than under varying interval conditions.

Researchers such as Wundt interpreted these experimental findings as evidence for the role of attention, here, as selection of sensations, for apperception and consciousness: Participants' report of the visually perceived time of the tone was shorter in rhythmic than in varying conditions, as the exact point in time at which the selection of the auditory sensation was required was easier to anticipate in rhythmic than in varying conditions.

3.2 Experiments (Third-Person Perspective Evidence)

In contrast to these early days, following an era in which psychology was dominated by Behaviorism (roughly until the middle of the 20th Century), with the cognitive turn attention reoccurred as a research topic in psychology once more, but was now defined in operational rather than experiential terms, lending itself more easily to experimental investigation through "objective" performance measures of speed and accuracy observed from a third-person perspective rather than through (additional) introspective (first-person perspective) reports (cf. Broadbent, 1958). An example would be the precision of recall of different messages from attended-to and from unattended-to ears, where a different auditory message would be presented to each ear of the participant in an experiment, but where the participant would have to attend to only one ear and would have to ignore the other ear (Cherry, 1953). In such experiments, it was regularly found that recall of the messages from the attended-to ear was much more accurate than from the unattended ear. Following an information-processing metaphor, under the perspective of cognitive theory, human perception works like the transmission of information from the environment through the senses and towards diverse human processing functions such as memory, action control, or reasoning (cf. Broadbent, 1958).

Critically, already the earliest studies of attention under this cognitive theoretical perspective confirmed selectivity, now of information processing, reflected in objective performance measures (e.g., in the number of recollected stimuli presented to an attended ear versus an unattended ear), rather than in terms of conscious experience as in psychology's early days (Cherry, 1953). In fact, the term consciousness was often not used by these researchers at all–rightly so, as was confirmed in subsequent studies showing that selection in information processing can occur without concomitant awareness of this selection. For example, although experiments on visual search for relevant targets (e.g., searching for a red target stimulus, somewhat analogously to searching for a friend with a red suitcase that you want to pick up at the station) among irrelevant distractors (e.g., searching for the target among green, blue, yellow, or black distractors, somewhat similar to searching your friend among other passengers coming off the same train) are probably typically concerned with the conscious perception of the stimuli in these studies, it was repeatedly shown that visual search can also be (partly) performed on the basis of stimuli of which the human observer remains entirely unaware (Ansorge et al., 2009; Jaśkowski et al., 2002; Woodman & Luck, 2003). This is part of the full performance, as in these cases, evidence shows that attention is directed to only those unaware stimuli that resemble a searched-

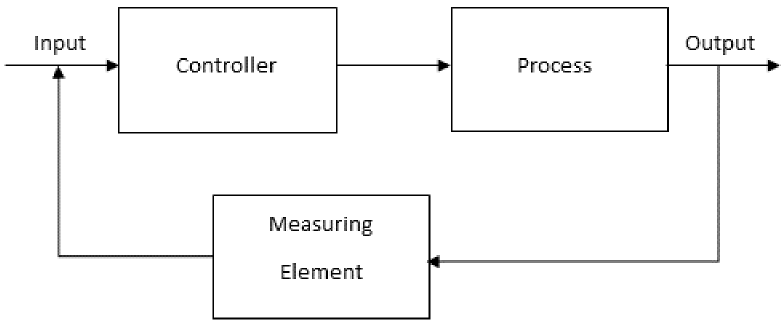

Figure 3: Schematic representation of closed-loop feedback circuit of procedural control.

Procedural control in a closed-loop system works similarly to any feedback loop. The input (e.g., a text) would be checked for fitting content by the controller (i.e., a steering value, e.g., a template to search for references referring to knowledge) to be processed (e.g., read and note references) until a measuring element signals that the purpose is fulfilled (e.g., no further references could be found in a text).

for target feature, though participants do not literally conclude visual search under unaware conditions.

Even though such task performance is not completed, it is clear that this type of selection serves the purpose of the task. The underlying reason is that selectivity of human information processing is adaptive or necessary for control of mental procedures and of actions and that the corresponding purposes of selectivity or of attention can be fulfilled without mediation through conscious representations (cf. Ansorge et al., 2014; Neumann, 1987, 1990). In general, per definition, psychological processing unfolds across time: To serve their various purposes, these processes need to be geared by specified (though changing) criteria defining both critical starting conditions to be met to elicit processing as well as by criteria to stop or alter processing (Anderson et al., 2004; Miller et al., 1960). This is illustrated in Figure 3 and is the general form of any mental procedure, be it an overt action, based on movements of parts of the body, or a covert process, without accompanying body movements (Anderson et al., 2004). For example, if I would want to grasp an apple from a tree, I would have to select one of the apples for an adaptive or successful action: This would be necessary to select the apple's location and its size as steering values of the action to successfully reach in its direction and to open the fingers so that they can grasp the apple (Allport, 1987).

The same type of necessary selectivity applies to covert processing. For example, if I would want to draw a valid conclusion in a categorical syllogism, I would have to select the terminus major of the major premise (e.g., "no line is a *point*"; with the major term in italics) and the terminus minor of the minor premise (e.g., "all *verticals* are lines"; with the minor term in italics) and would have to relate them to one another by the middle term (here, "*line*") to judge if a conclusion (e.g., "no vertical is a point") is true.

Even more important for what follows, each usage of knowledge for just any human mental or information processing purpose requires its encoding into and retrieval from memory. Though it might be an exaggeration to conclude that any limitation of the active part of memory–that is, working memory–involved in such tasks essentially reflects an attentional bottleneck (cf. Barrouillet et al., 2004), selectivity and, hence, attention is a characteristic of any working-memory processes and, hence, of knowledge usage (Oberauer, 2002). Thus, the current perspective denies the strict separation of semantic (knowing-of, knowing-that) and procedural (knowing-how) knowledge and memory (cf. Squire, 1986), as it follows that each usage of knowledge, including its coming to being in one human mind (through encoding it at one point into memory, be it also shortly only) also corresponds to the sketched general architecture of procedures and, thus, requires attention in the form of specific selections gearing the process.

These selections take different forms. The criterion of selection of, for instance, retrieved information may be determined at will as when we deliberately search our memory for what we know about the relation between verticals in particular and lines in general. However, the selection from memory might also occur without our will as when a memory "pops up." For example, when we try to decide if a vertical is a point, we might remember the view of a vertical flagpost from an aerial perspective above, such that the vertical appears as a point. In such cases of automatic retrieval, we sometimes are not certain if the knowledge (or memory content) is adaptive at all. In any case, selectivity would be also implied, as the corresponding memory would not be just of anything. Instead, on closer inspection, it typically turns out that there are semantic connections between our currently intended usage of knowledge and pop-out memories or automatic retrieval of knowledge. In other words, these pop-out memories or automatic knowledge usages are related to our ongoing willed processing but show a degree of generalization of application to semantically related or otherwise similar but not quite currently useful content or context outside the specific instances for which willing retrieval would make sense.

Importantly, here it becomes obvious that processing of knowledge implies a two-step selection: Not only is it necessary to select currently pertaining input from the senses or from memory by means of their comparison to the steering values of the procedures (kept in the controller in Figure 1); it is also necessary to select the steering values themselves (cf. Bundesen, 1990). This is illustrated, for example, in Reason's (1990) error theory of procedural processing. According to Reason, omissions (e.g., walking from one room to the other to fetch a book and coming back without the book) or perseverations (e.g., turning the key a second time to start your car after you have already started the car) as two types of errors reflect the erroneous choice of a procedure's steering value. In the case of the omission, for example, at the time you were in the other room you would have failed to check and make sure that the purpose of coming over was fulfilled, here, to fetch the book.

To understand that the nature of retrieved and used knowledge, thus, depends on the choice of an appropriate steering value is important, as there is evidence that there are biases in the choice of steering values that impact (1) the type of knowledge used or (2) the way that knowledge is used and that can go undetected from an introspective, first-person perspective. This is important, as the choice of the steering values determines how knowledge-related processing is characterized. Thus, such undetected biases in the choice of steering values are a source of constraints on the usage of knowledge and, hence, a factor that requires more investigation and consideration for the optimal usage of human knowledge.

4 Procedures and Selectivity

Above I have argued that attention, understood as selectivity, is a characteristic of procedures as they unfolds across time. In the following, I give two examples of empirical support for this assertion. To note, both examples make clear that introspection or its report alone are probably insufficient to understand the characteristics of knowledge usage.

The first example is from visual search. In visual search, participants search for relevant targets (e.g., ripe berries) among irrelevant distractors (e.g., unripe berries) in their visual environment (Wolfe, 2015). To that end, humans (e.g., participants in an experiment on visual search) select a criterion, template, or steering value that allows them to successfully discriminate between target and distractors such that the targets can be found and the distractors ignored (e.g., the color in the case of the berries where ripe berries are red and unripe berries are green) (cf. Duncan & Humphreys, 1989).

Now it happens, however, that humans do not only have a single (search) intention or that a single (search) intention would translate into different criteria or steering values. Consider the following example: You are at a friend's party and have to search for a bottle opener in her kitchen drawer full of kitchen utensils (cf. Yang & Zelinsky, 2009). In this situation, you cannot easily pick a particular color or shape as a template or steering value to successfully search for the bottle opener, as a bottle opener could take on different colors and shapes. In such situations, humans might want to use several (search) criteria or steering values at the same time (cf. Duncan & Humphreys, 1989; Irons et al., 2011).

From a first-perspective perspective, it is difficult to judge how we might do this. There seems to be general consensus that it is difficult to use more than maybe four such search criteria at the same time, acknowledging the fact that these criteria would have to be kept in an active state (e.g., corresponding to their current usage during search) in working memory (Olivers et al., 2011). As working memory itself has a limited capacity of about three to four features or objects, it seems that some selectivity in the number of currently used steering values or search criteria is implied (cf. Luck & Vogel, 1997). This roughly corresponds to what we would judge introspectively: When we have to keep an arbitrary number consisting of several digits in memory, it should not be too long for its successful retrieval, and three or four such items are definitely manageable, but somewhere beyond maybe seven items, we would definitely have to rehearse the material to some extent to keep it in mind.

4.1 Visual Search Criteria

However, when we conducted an experiment and looked into the capacity of visual search criteria currently in use, we found evidence from a third-person perspective that participants even only used a single search criterion at a time (Büsel et al., 2019). In each trial of a computer experiment, we presented our participants with a visual target at one of several positions and asked our participants to find the target and report its orientation (i.e., if the target, a letter T, was tilted to the left or to the right). In one block of trials, the target always had the same, known color (e.g., it was always red). In the other block of trials, the target could take on one of two known colors (e.g., in half of the trials, it was red, and in the other half, it was green), but which of these colors the target took on in the upcoming trial was not known to our human participants in that experiment. In this situation, we observed switch costs and mixing costs in the condition with two target colors relative to the condition with a single target color, pointing to the participants' usage of only one of these colors as a search criterion at a time (cf. Kiesel et al., 2010; Rogers & Monsell, 1995). In this context, mixing costs denote the longer time needed to search for a target of a particular color (e.g., red) in the two-color blocks than in the single-color blocks, even if the target in a current trial (Trial N) is of the same color as in the preceding trial (Trial $N-1$). Switching costs, in contrast, denote the longer time needed to search for a target of a particular color (e.g., red) in a Trial N if the color in the preceding Trial $N-1$ was different (e.g., green) relative to similar (e.g., red). Especially, the latter switch cost is indicative of the fact that only a single color was used as steering value for search per each trial, so that a change of this steering value delayed searching for the targets.

At this point, it might be objected that switch costs might have reflected participants deliberate checking of which color was presented to increase their certainty. To note, in the context of these experiments, it was not necessary to discriminate between the two relevant colors, as both served the same purpose: To find the target. Thus, it is unclear what would be gained by ascertaining which exact color of the two relevant colors was presented. More importantly, however, from my functional perspective on selectivity, this is not necessarily an "alternative" explanation but possibly an elaboration of the reasons for forms of hyper-selectivity that exceed selectivity predicted on the basis of capacity limitations: A sequential usage of one feature template at a time is probably easier to track for its success in whether the current input matches the feature template and, thus, the usage of a single feature template at a time might indeed serve the purpose of increasing one's own certainty that relevant input was registered. Furthermore, the mixing costs are also indicative of a related cost of having to maintain two steering values, although mixing costs might also be due to longer processing times if central capacities to keep information in working memory are indeed limited. In addition, several lines of evidence agree with our conclusion that only a single steering value could be used actively at any time (Oberauer & Hein, 2012; Ort et al., 2017), and, although some authors believe that maybe more than one steering value could be maintained at a time (Bahle et al., 2020; Kerzel & Witzel, 2019; Pomper & Ansorge, 2021), the number of such simultaneously entertained steering values is certainly finite and, thus, selectivity is always implied.

This extreme hyper-selectivity of only one feature at a time makes clear that knowledge usage comes with constraints that can be easily overlooked if we do think of knowing-that or knowing-of in isolation–that is, without considering that knowing-how, the active processing of the knowledge, is required for our knowledge to come into psychological existence. In addition, with introspection alone, such regularities of knowledge, in this case, its extreme momentary selectivity to a single used feature at a time, are difficult if not impossible to register.

4.2 Polarity-Correspondence Effects

The second example comes from polarity correspondence effects in studies on color-valence associations. As I will explain below, such polarity correspondence effects also reflect a strong form of selectivity. As with the example above, awareness of the polarity correspondence principle is low, such that the corresponding influences have been identified with third-person observations of objective human performance in experiments only. To start with, at least in Western cultures and in more "implicit" classification tasks (i.e., tasks in which a dimension varies but is not itself part of the instructions), red is more likely associated with negative affective valence than green; and, vice versa, green is more likely associated with positive affective valence than red (e.g., Kawai et al., 2021; Kuhbandner & Pekrun, 2013).

In this context, we used an experiment and tested if such color-affect associations could have reflected a polarity-correspondence effect (cf. Proctor & Cho, 2006). In our study, participants had to classify words such as "birthday" or "prison" as positive versus negative (Kawai et al., 2020). These words were equally often presented in red or in green. It turned out that categorization of word valence was faster under congruent conditions, with negative words in red and positive words in green, than under incongruent conditions, with negative words in green and positive words in red, although color was task irrelevant. This reflected an implicit (i.e., not directly explicitly rated) association between color and affective valence, but when a more explicit and introspective judgment of color-valence associations is required, humans also mention associations between red and positive emotions, such as love (e.g., Jonauskaite et al., 2020). So what is going on?

When we looked closer into the experimental performance that reflected a red-negative association, we found out that the effect was restricted to blocks of trials in the experiment in which both colors–red and green–were presented in an intermixed fashion. Between color-homogeneous blocks, in which all negative and positive words were presented in the same color (green in some blocks, red in other blocks), however, no such congruence effect was found: Categorization time for positive words was always lower than categorization time for negative words, regardless of whether the words were green or red.

These findings are in line with the polarity correspondence principle. According to the polarity correspondence principle, humans assign polarities–plus versus minus–to opposing feature values (e.g., red vs. green, below vs. above, etc.) on the same feature dimension (e.g., color, vertical location, etc.). In our study, participants, thusly, assigned positive polarity to the positive words and to the green color and they assigned negative polarity to the negative words and to the red color. As a consequence, congruence relations between valence and color polarity resulted in mixed color blocks. However, in color-homogenous blocks, there was simply no contrasting pole in the color dimension that would have suggested polarity assignments of plus and minus poles to the different colors, hence, no polarity-correspondence effect between colors and affective valence in these blocks. Critical in the context of the current discussion, polarity assignments are a way of selectivity imposed by procedural control, here of dealing with the necessity to decide between alternatives. To understand this, consider the required decision between the different category memberships for each target word as either belonging in the category of positive words or in the category of negative words. To solve this task, participants could first compare each word's meaning to one category definition as a steering value, say the category of positive words. Only then, participants would switch to the second, alternative category definition, say of negative words. This type of decision by sequential comparison of words with alternative categories as steering values would then typically show a bias to start with the positive category and to proceed to the negative category in case the words cannot be classified as belonging to the positive category. Participants would "inadvertently" apply a related type of categorical decision to the irrelevant stimulus dimension, here, to color, if this irrelevant stimulus dimension shares important characteristics with the relevant dimension, here, of suggesting coding alternative features consistently as prioritized/positive or less prioritized/negative poles, too.

Importantly, one can immediately see that, again, procedures, here categorical decisions, would show an extreme form of selectivity–the use of only a single steering value at a time–, just as was observed in the case of visual search. Furthermore, in line with this interpretation, we also found (1) the expected facilitation of the plus-pole decisions (as these would be prioritized in a sequence of two comparisons, with first a comparison to the plus- and then to the minus-pole steering values) and (2) the predicted weaker congruence effect (i.e., incongruent minus congruent decision time difference) for the minus-pole congruent pairs (here: negative words in red) relative to the minus-pole incongruent pairs (here: negative words in green), as in this case facilitation by two minus pole decisions in congruent conditions benefiting one another and, thus, decision time would be undermined by counteracting facilitation of a plus-pole decision for the color of an incongruent comparison case (i.e., for the green color of a negative word) (cf. Lakens, 2012).

5 Automatic Processing: Biased Selections

In general, not all human selections are willingly initiated, and this is also the case for the choice of human steering values for the control of knowledge-related processing. In general, procedures that are elicited relatively independently from one's own will reflect either innate tendencies to prioritize selections or biases based on extended practice of particular procedures (cf. Öhman et al., 2001; Shiffrin & Schneider, 1977). In both cases, the tendencies and biases generalize to novel situations, as long as stimuli fitting to the steering values of the automatized (e.g., highly practiced) procedures are present in these situations that then can activate the corresponding procedures, thereby, reversing the typical order of first selecting a procedure and only then selecting stimuli fitting to the steering values of these procedures.

Many of these automatic selections occur in the context of procedural processing devoted to other purposes and, more importantly, automatic selection can also depend to some degree on the control and use of these alternative procedures. As an example, consider the inadvertent processing of self-related knowledge as being self-related when this knowledge has to be categorized together with knowledge less related to the self. In the Concealed Information Task (CIT), investigators aim at revealing suspects knowledge of identity- or crime-related information that the suspect would rather want to hide from revelation (Seymour et al., 2000; Suchotzki et al., 2017; Varga et al., 2014). For instance, if a murder has been committed, a guilty suspect would have knowledge of the details of the crime, such as the weapon used. However, the suspect would rather want to hide her knowledge during interrogation. Obviously, in such cases, where a person seeks to hide her knowledge, introspection would also work and guilty suspects should be aware of their knowledge, but guilty suspects would maybe not want to report their introspective insights.

5.1 Interference by Self-Related Information in the Concealed Information Test

In this situation, the CIT, an experimental task, could be used to reveal the knowledge. Critically in the context of the present argument, the CIT also reveals important insights on the mechanism by which attention or selectivity operates in the usage of knowledge, namely the above mentioned inadvertent usage of the steering value for the relevant targets to the only personal knowledge of the to-be-concealed crime- or identity-related knowledge. In the CIT, suspects are asked to categorize a number of stimuli, for instance, several potential murder weapon labels (e.g., the words "rope," "gun," "knife," etc.) and a single of these stimuli that is not the true crime weapon would be designated as the target that requires categorization by pressing one key and all other stimuli would require categorization by pressing an alternative key. Among the non-targets, however, there would be two types of stimuli–irrelevants, which were not used for the murder, and the probe, which is the true murder weapon (e.g., "gun"). Only for guilty participants, the probe would stand out as a less frequent stimulus being more related to oneself and known to be associated with the crime among all the irrelevants being less related to the self and the crime, with which latter the probe has to be jointly categorized as irrelevant. In other words, just as the rare target, the probe stands out as relatively rare among the irrelevants by its higher self-relevance.

By this resemblance in terms of its lower frequency, the probe would then invite more target-like categorization and create some response conflict–that is, interference by its resemblance to the target as a rare stimulus inviting more of a target-categorization response than all of the other irrelevants. This self-relevance dependence of the probe categorization difficulty for guilty participants would then show up as a probe-irrelevant reaction time difference, with longer categorization times for probes–with more response conflict–than for irrelevants, with their lower response conflict.

In other words, the inadvertent and unwilled processing of the probe as special among the irrelevants would depend on the way of procedural control or steering values, in which low frequency of occurrence is an (implicit) target-defining feature and the probe resembles this feature, offering itself to selection through the same steering values as are used for the target. In line with this interpretation, using (rare) self-related fillers (e.g., the word "MINE") that have to be categorized together with the target and using frequent other-related fillers (e.g., the word "OTHER") to be categorized together with the probe and irrelevants increases the probe-irrelevant reaction-time difference (Lukács & Ansorge, 2021; Lukács et al., 2017; see Table 1). This finding supports the conclusion that it is the self-relatedness of the probes that makes these items stand out among the irrelevants and that accounts for response conflict. In addition, the probe-irrelevant difference decreases drastically if the frequency of fillers in the target category is increased decreasing their similarity to the rare probes (Lukács & Ansorge, 2021).

Table 1: Reaction times and accuracies from a Concealed Information Test study by Lukács & Ansorge (2021).

	RT mean		Accuracy rate	
	T.-Comp.	T.-Incomp.	T.-Comp.	T.-Incomp.
Probe	519±70	499±54	98.3±2.5	98.8±2.8
Irrelevant	497±55	497±49	98.9±1.7	98.9±1.5
Target	598±53	599±53	82.9±9.6	80.8±12.2
Filler-F	614±54	620±53	83.6±9.9	80.8±10.8
Filler-U	558±65	556±55	94.8±4.6	96.3±2.8
P – I	21.8±34.7	1.7±26.2	−0.55±2.44	−0.06±2.11

Means and SDs (in the format of M±SD) for individual reaction time (RT) means and accuracy rates of Experiment 2 of Lukács & Ansorge (2021); for Probe (participants' own to be concealed names), Irrelevant (other people's names), Target (the designated irrelevant that requires a different response), P – I (individual probe minus irrelevant values); for two Semantic Context conditions (Target-Compatible, where filler items referring to the self and familiarity were categorized together with the probe and irrelevants and filler items referring to others and unfamiliarity were categorized together with the target; and Target-Incompatible, where filler items referring to the self and familiarity were categorized together with the target and filler items referring to others and unfamiliarity were categorized together with the probe and irrelevants). T. = Target; Comp. = Compatible; Incomp. = Incompatible; F = Familiarity-Referring; U = Unfamiliarity-Referring.

5.2 Interference by Information Related to Grammaticalized Distinctions

Having, thus, demonstrated how one's own knowledge (here: knowledge-related stimuli) can influence processing even against one's own will to not reveal such influence, we now turn to the possibility that stimuli can trigger their fitting procedures even in situations in which the procedures are entirely task-irrelevant. This has been shown in studies on linguistic relativity. Linguistic relativity denotes the purported influence of the language that one speaks on perception and processing in general (Sapir, 1941/1964; Whorf, 1956). We studied this influence by comparing Korean speakers' and German speakers' sensitivity to attend to features reflected in grammaticalized–that is, highly practiced–linguistic distinctions (Goller et al., 2020). Korean speakers, but not German speakers, have to discriminate between degrees of spatial fit between objects–tight fits ("nohta") versus loose fits ("kkita")–by distinct verbs. In contrast, in German, the corresponding distinctions can also be expressed either by verbs or by prepositions. However, as the distinction is only obligatory in Korean but not in German, only Korean speakers have extended practice with the distinction, and they need to pay attention to the decisive differences between objects in their environment when it comes to verbal descriptions of these elements.

Critically, if linguistic relativity holds true, the corresponding differences in selecting the relevant information during visual perception between Korean and German speakers should generalize to non-linguistic tasks. Even in such non-linguistic tasks, the corresponding higher bias to pay attention to these features among the Korean speakers should take effect, as it is not necessary that first an intention to use a corresponding feature as a steering value to discriminate if a sentence requires a tight- versus loose-fit verb is necessary: Instead, the mere presence of the corresponding stimuli should be able to trigger the highly practiced procedure. This hypothesis was tested and confirmed in a non-linguistic visual search task for color (cf. Baier & Ansorge, 2019), in which Korean and German speakers were asked to search for a color-defined target (e.g., search for a red target cylinder) among green non-targets (cylinders) and presented a tight-fit or loose-fit singleton distractor (here, a cylinder-piston relationship) away from the target in some of the trials (Goller et al., 2020; see Figure 4).

We hypothesized that, as the distinction between tight- and loose-fit relations is highly practiced among the Korean speakers, their attention should be captured by the fit singletons away from the targets although the fit singletons were completely task-irrelevant and although the color-defined target was never presented at the position of a fit singleton. We expected this capture of attention away from the targets to delay successful target search among the Korean speakers but not among the German speakers, as the latter should be relatively less biased to the same distinction.

This hypothesis was supported by our findings. In comparison to a condition without irrelevant fit singleton, only the Korean speakers but not the German speakers needed more time to find the target in conditions with a fit singleton presented away from the target. This distraction likely reflected the capture of attention away from the target and to the fit singleton. In addition, this interference by the fit singleton was not due to generally more attention capture by just any singleton distractor (e.g., due to maybe generally less ability to control procedures among Korean speakers):

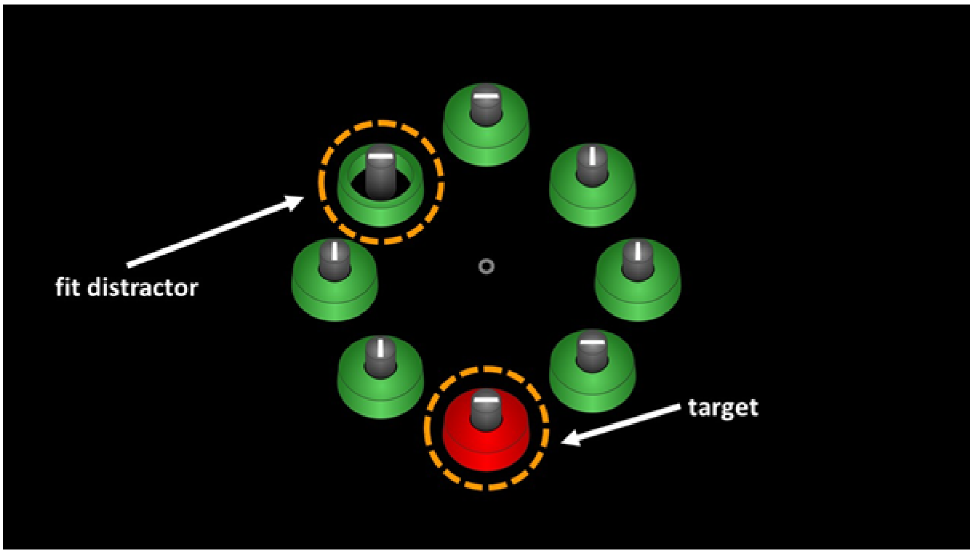

Figure 4: Illustration of a search display from Goller et al. (2020).

The image shows a display with a color-defined target and a fit distractor presented away from the target. Korean speakers but not German speakers needed more time to search for the target with such a distractor singleton in the display than in displays without such distractor singleton. This is in line with Korean speakers highly practiced usage of the fit relations (i.e., if tight or loose) for the choice of the appropriate verbs: a practice that increases sensitivity to the corresponding features even outside linguistic tasks proper, and a practice not shared to this extent by German speakers.

In a control condition, with color singletons rather than fit singletons, in line with prior findings, the same degree of interference was observed relative to a baseline condition without a color singleton among Korean and German speakers (Theeuwes, 1992; Weichselbaum & Ansorge, 2019). In addition, in a further control experiment, it was shown that among Korean speakers interference by a fit singleton was restricted to visual search for color targets among 2D depictions of 3D objects but that the same interference was absent for 2D color targets and distractors. The latter finding supports the linguistic origin of the effect, as the Korean speakers obligatorily use distinct verbs to discriminate between the tight- and loose-fit relations of 3D objects but not of 2D objects. In this way, it was possible to show that the differences between the language groups were not just due to a higher bias toward just any type of spatial context among Asian than among Western samples (Nisbett & Miyamoto, 2005).

6 Conclusion

In summary, humans show biases among the steering values necessary for the control of their procedures. These biases reflect prior knowledge that is sometimes difficult to suppress as seen in the example of the inadvertent processing of probes in the CIT and that is sometimes even difficult to notice without proper objective experimental tests, as indicated by the automatic selection of fit singletons among Koreans. However as reviewed above, experiments at least allow humans to understand the influences of such biases of prior knowledge and on knowledge-based processing. As such experiments help to reflect upon these biases in knowledge-related processing. As all usage of knowledge is through procedures and as each procedure requires some degree of selectivity, experimental research is, thus, a potential way to keep the corresponding biases at check when it comes to the usage of knowledge.

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Conflicts of Interest

The author declares no conflict of interest.

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