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# Shared and Distinct Cue Utilization for Metacognitive Judgments during Reasoning and Memorisation

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**Abstract**

Metacognitive research is dominated by meta-memory studies; meta-reasoning research is nascent. Accessibility—the number of associations for a stimulus—is a reliable heuristic cue for Feeling-of-Knowing when answering knowledge questions. We used a similar cue, subjective accessibility (sAccessibility), for exposing commonalities and differences between meta-reasoning and meta-memory. In Experiment 1 participants faced solvable Compound Remote Associate problems mixed with unsolvable random word triads. We collected initial Judgment-of-Solvability (iJOS), final JOS (fJOS), and confidence. Experiment 2 focused on confidence, controlling for potential interactions among judgments. In Experiment 3, participants memorised the same triads and rated Ease-of-Learning (EOL) and Judgment-of-Learning (JOL). SAccessibility was associated with all judgments. Notably, it reliably predicted memory judgments and confidence in provided solutions. However, it was unreliable for judging solvability (iJOS and fJOS). The findings highlight the importance of studying meta-reasoning for exposing biasing factors in reasoning processes and for getting a broad perspective on metacognitive processes.

**Keywords:** Reasoning; Memorisation; Meta-Reasoning; Metacognition; Heuristic cues

The field of metacognitive research deals with the way people monitor their information processing and regulate their cognitive efforts. According to this approach, two levels of processes are involved in any cognitive challenge, the object level and the meta level (Nelson & Narens, 1990). The traditional focus of metacognitive research is learning, and, even more specifically, Memorisation and knowledge retrieval. During learning, object-level processes involve the transfer of information from an external source to the learner's memory system. The meta level of learning regulates these object-level processes by setting goals, choosing appropriate strategies, and terminating activities, based on spontaneous subjective judgments, or *monitoring*, of one's own knowledge (see Bjork, Dunlosky, & Kornell, 2013, for a review). Indeed, empirical studies dealing with Memorisation and reading comprehension tasks have shown a causal link between monitoring output and decisions regarding allocation of study time (Metcalfe & Finn, 2008; Thiede, Anderson, & Therriault, 2003).

**Meta-Memory and Meta-Reasoning**

Thus far, metacognitive research has focused primarily on four types of judgments: Ease of Learning, which is elicited before studying; Judgment of Learning, elicited after studying but before testing; Feeling of Knowing, which predicts the likelihood that one will retrieve or recognize answers to knowledge questions; and confidence that a provided answer to a knowledge question is correct (see Bjork et al., 2013, for a review). Because the examined tasks are based on memory storage and retrieval, the metacognitive domain is often referred to as *Meta-Memory*.

Recently, Ackerman and Thompson (2015, in press) offered a *Meta-Reasoning* framework. This framework has been designed to promote delving into reasoning processes by using insights gained from meta-memory research. It provides a conceptual basis and methodologies for discovering sources of biases in reasoning processes (e.g., certainty in wrong answers), non-optimal decisions regarding effort regulation (stopping too quickly or investing much effort with little benefit), overgeneralization of knowledge (e.g., belief bias), etc.

Ackerman and Thompson (2015) considered four meta-reasoning judgments. The first two meta-reasoning judgments go beyond the meta-memory realm: Judgment of Solvability, which reflects one's first impression as to whether a problem is solvable, and Feeling of Rightness, which reflects the likelihood that the first solution that comes to mind is correct (see Thompson, 2009). The other two judgments, which are relevant in both domains, are intermediate and final confidence judgments. They reflect the chance of a considered answer to be correct either during the thinking process or after choosing the answer to be provided, respectively. In recent years, scholars have suggested additional judgments for the context of reasoning (e.g., Feeling of Error while solving reasoning problems, see Cruz, Arango-Muñoz, & Volz, 2016). The present study introduces yet another judgment: final Judgment of Solvability, which reflects the likelihood that a problem is solvable even though the respondent could not produce a solution. While research regarding all meta-reasoning judgments is nascent, the two most studied so far are Feeling of Rightness and final confidence. For instance, Feeling of Rightness is accounted as the bridge between the quick, autonomous, Type 1 and the deliberate, effortful, Type 2 processes in reasoning processes (e.g., Thompson, Prowse Turner, & Pennycook, 2011). Collecting confidence ratings allowed researchers to discover that participants are aware to conditions of conflict or error (e.g., Aczel, Szollosi, & Bago, 2016; De Neys, Rossi, & Houdé, 2013).

Beyond comparison of judgments across conditions, a central question in meta-memory research is the puzzle of how people monitor their knowledge. That is, how does a person infer the likelihood that she will later recall a particular memorised item, or that her answer to a knowledge question is correct? This question is central in meta-memory research and almost neglected in meta-reasoning research. According to the cue utilization approach (Koriat, 1997), metacognitive judgments are inferential in nature and based on heuristic cues that are generally predictive of performance (see Rhodes, 2016, for a review). For instance, processing fluency is one's subjective feeling of ease or difficulty while memorising or answering a question. Operationalized by response time, it was found to be a dominant cue for meta-memory judgments (e.g., Kelley & Lindsay, 1993; Koriat, Ma'ayan, & Nussinson, 2006; Undorf & Erdfelder, 2015).

**Cue utilization and cue validity**

A useful methodology for demonstrating that a cue underlies a judgment is to demonstrate that the judgment may deviate from actual performance with fluctuations in the examined cue. In the metacognitive literature, the term *cue utilization* stands for the association between the examined heuristic cue and the relevant judgment, and *cue validity* stands for the association between the cue and actual performance (Koriat, 1997). For example, Kelley and Lindsay (1993) primed participants with correct and wrong answers to some of the questions that appeared later in a general knowledge task. Priming was hypothesized to make retrieval of a potential answer more fluent regardless of its accuracy. Indeed, questions with primed answers were answered more quickly and were accompanied by higher confidence than those with unprimed answers. Notably, this effect was dissociated from success rates. Moreover, participants could not resist the priming effect despite explicit warnings that it would bias them. The findings affirmed that confidence is based on fluency, above and beyond the natural association between ease of processing and actual chance for success. Previous attempts to expose shared bases for several judgments have been done across memory-related tasks (Dougherty, Scheck, Nelson, & Narens, 2005; Leonesio & Nelson, 1990). However, processing fluency, operationalized by answering time, was also found to underlie Feeling of Rightness and final confidence judgments in reasoning tasks (Ackerman & Zalmanov, 2012; Koriat et al., 2006; Thompson et al., 2013). Thus, processing fluency is an example of a shared cue for meta-reasoning and meta-memory judgments.

In the present study we aim to expose an additional shared cue. Consistent commonalities, as just described, would suggest that when considering bases of meta-reasoning judgments, for having unique added value researchers better focus on cues which were not considered before in memory contexts. Distinctive patterns, in contrast, motivate further research into the particulars of cues utilized in each domain in isolation and in comparison across domains, for exposing factors affecting cue utilization, in addition to cues not considered before.

A pioneering indication for distinctive cue utilization patterns across domains was provided by Ackerman (2014), who compared time-judgment relationships between problem solving and memorising. In line with the findings regarding fluency described above, she found in both tasks an overall pattern of a negative correlation between response time and judgments. However, she also found different patterns of results after dividing the items into comparable difficulty (success rate) levels. As shown in Figure 1, after division by difficulty, the time-judgment correlation weakened dramatically in Memorisation (panel A), but remained strong in problem solving (panel B). These different patterns suggest that delving into the particular pattern in each task is required for understanding the mechanisms behind cue utilization in general and those unique for each cue-task combination.

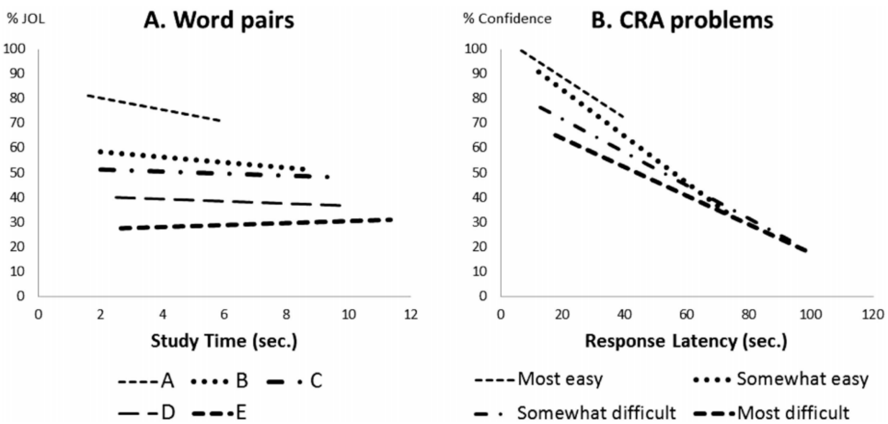


*Figure 1.* Comparison between memorising word pairs and solving Compound Remote Associate (CRA) problems in the association between response time and metacognitive judgments, in division into parallel difficulty levels. Adapted from Ackerman (2014, Figure 3).

Although the evidence provided by Ackerman (2014) clearly pointed to great potential in studying meta-reasoning to extend metacognitive research, the comparison she used was problematic in two respects. First, as can be seen in Figure 1, the two tasks differed in their x-axis range. It takes much more time to solve Compound Remote Associate (CRA) problems than to memorise word pairs. This fact may present a problem when the examined heuristic cue is response time, as a proxy for fluency. That is, it is possible that time is utilized differently as a cue for brief tasks than for tasks which take longer to perform, regardless of the object-level and meta-level differences between problem solving and memorising. Second, although the author made sure to balance the two tasks for difficulty (based on success rates), the presented words differed between the tasks. It is possible that each word set led to utilization of different cues (e.g., word familiarity), and that these differences contributed to the differing time-judgment patterns.

Notably, Ackerman's comparison was focused on judgments which take place at the end of processing the item, after the decision to stop investing effort in it. However, as mentioned above, there are metacognitive judgments which take place before starting the required processing itself (e.g., Reder & Ritter, 1992; Vernon & Usher, 2003). In addition, previous studies in Memorisation and reasoning, which compared several judgments elicited during the same task, revealed that judgments become more accurate as the processing progresses (Dougherty et al., 2005; Leonesio & Nelson, 1990; Siedlecka, Paulewicz, & Wierzchoń, 2016). Thus, initial judgments deserve a thorough comparison across tasks in addition to Judgment of Learning and confidence, which are provided after performing the task (see Thomas, Lee, & Hughes, 2016, for a review).

The aim of the present study was to expose shared and distinctive cue utilization in meta-reasoning and meta-memory initial and final judgments. We see this study as a starting point for motivating further meta-reasoning research addressing the numerous gaps in this nascent domain and for taking advantage of mutual fertilization across domains. Towards this aim, we used the same set of words in both a reasoning and a Memorisation task. This novel method allowed us to focus on comparing cue utilization processes across task types with a common heuristic cue associated with the exact same semantic association net for the words used as the common stimuli. This methodology allows controlling for many alternative explanations (e.g., differences in words' frequency in the language). Discovering biases in meta-reasoning in general, and in particular those that stem from the associative net associated with the used words, has a potential to shed new light on reasoning research with other verbal tasks such as conditional inference, syllogistic reasoning, logic problems, etc.

**Subjective Accessibility as a heuristic cue**

Accessibility was first suggested to underlie Feeling of Knowing . Traditionally, the Feeling of Knowing judgment relates to situations in which a person attempts to answer a knowledge question, but fails. The respondent is then asked to assess the chance that she will be able to retrieve the target information in the future or identify it in a multiple-choice test (Hart, 1965). Koriat (1993, 1995) defined accessibility as reflecting the amount of associations activated when encountering a question, rather than the quality or relevance of these associations. Accessibility and Feeling of Knowing are positively correlated: The more information comes to mind, the stronger the Feeling of Knowing. Because having a large pool of relevant associations indeed promotes retrieval, accessibility is a reliable cue for this task (see Koriat, 2008).

Koriat and his colleagues used a norming study to generate a measure of accessibility. In this study (e.g., Koriat & Levy-Sadot, 2001), they asked participants to produce associations in 40 seconds for each question (see De Neys, Schaeken, & D'Ydewalle, 2003 for a similar generation norming study in the context of conditional reasoning). Since we were interested in initial judgments in addition to final ones, we used subjective accessibility (sAccessibility)—the number of associations people can quickly assess as existing for each word—rather than the actual associations that may be found when producing an exhaustive associations list or when looking in a dictionary. We hypothesized that sAccessibility influences judgments before engaging in the task as well as after the decision to stop investing effort in it. Thus, we examined its utilization as a cue for initial and final judgments and its validity in predicting performance in both reasoning and Memorisation tasks, when both tasks included the same stimulus words. Although accessibility is generally considered a reliable cue (Koriat, 2008), previous research has shown that associations to stimuli which are not directly related to the task at hand may undermine people's memory and mislead metacognitive judgments upwards (e.g., Eakin, 2005). In reasoning, although the effect of accessibility or sAccessibility has not been directly examined so far, it is likely to have a mixed contribution as well. Specifically, although relevant associations may support problem solving efforts, irrelevant ones may interfere with the solving process (Gupta, Jang, Mednick, & Huber, 2012; Wiley, 1998).

In many cases, researchers use carefully chosen stimuli for demonstrating utilization of heuristic cues. In particular, this was the case when examining cue utilization of accessibility for Feeling of Knowing (e.g., consensually correct or wrong, Koriat, 1995; for a similar approach see also Judgment of Answerability, Allwood, Karlsson, & Buratti, 2016) and when examining the beliefs in reasoning tasks (e.g., Stupple, Ball, & Ellis, 2013). For the purpose of the present study, this was not required, as we expected a random selection of stimuli to provide enough sAccessibility variability, which is desirable for generalizability.

The tasks we chose were hypothesized to yield different cue validity when presented the very same words for problem solving and for Memorisation, as detailed below. This allowed us to examine whether cue utilization reliably reflects the difference in cue validity between the tasks, or shows over-generalization which biases the relevant metacognitive judgments. If such dissociation between cue utilization and cue validity is also found for sAccessibility, as previously found with familiarity and fluency (see below), the study has potential to highlight biases in metacognitive judgments that have been unrecognized thus far.

**Overview of the study**

We used CRA problems (Bowden & Jung-Beeman, 2003) for the reasoning task. These problems consist of three words, each of which is associated with a fourth word so as to form a compound word or two-word phrase. For instance, the triad PINE, CRAB, SAUCE has the solution word APPLE, producing PINEAPPLE, CRABAPPLE, and APPLESAUCE.[1] This task particularly fits the purpose of the present study, because while the solutions of CRA problems tend to be well-known words, these may be crowded out during the solving process by others which more readily come to mind (see Storm & Hickman, 2015; Wiley, 1998). For this reason, the CRA task requires well-established knowledge of the language, but also involves holistic and creative thinking, as the solution phrases are often not those which readily come to mind when considering each word in isolation. We therefore hypothesized that this task falls into the group of reasoning tasks for which sAccessibility predicts success with a negative correlation--the more associations the harder is the problem to solve.

It may be noted that the combination of systematic and creative processing required for solving the CRA problems is shared with many daily tasks. In an analogy, the task resembles the problem solving process faced by a chef considering what to cook with a given cupboard of ingredients. In this case, accessibility reflects the number of recipes the chef knows for each item in the cupboard, rather than how the ingredients relate to each other. Similarly, an experienced architect designing a bridge has many associations for each set of possible materials, design options, ground conditions, etc. The architect integrates this vast knowledge to find the combination that addresses the requirements of the current task. Indeed, CRA tasks have been used for research in various work-related contexts (e.g., Miron-Spektor, Efrat-Treister, Rafaeli, & Schwarz-Cohen, 2011; Probst, Stewart, Gruys, & Tierney, 2007).

The CRA problems were used in Experiment 1 and Experiment 2. In Experiment 1, we used regular CRA problems and a set of unsolvable CRA problems. Unsolvable

[1] CRA problems are a subset of the remote associates test (RAT; Mednick, 1962). The distinguishing feature of CRA problems is that the solution word is not merely associated with each cue word, as is the case in RAT problems, but forms a compound word or two-word phrase with each one.

triads can be easily constructed by generating random word triads (see Topolinski & Strack, 2009; Undorf & Zander, in press). In the first phase of Experiment 1, participants judged the solvability of each triad and then, in the second phase, attempted to solve it. In this experiment, sAccessibility was examined as a cue for three judgments: initial Judgment of Solvability was collected in the first phase, while final Judgment of Solvability and confidence were collected in the second phase. To control for possible carryover effects between the two phases of Experiment 1, in Experiment 2 we used a straightforward CRA solving task with one phase including solving of the solvable problems used in Experiment 1 and confidence ratings.

The fact that CRA problems consist of word triads allowed us to use the same stimuli for a Memorisation task in a manner highly similar to Memorisation of paired associates, which is the dominant task in meta-memory studies (e.g., Metcalfe & Finn, 2008; Undorf & Erdfelder, 2015). In Experiment 3, participants memorised the word triads used as CRA problems in Experiment 1 and Experiment 2. In the first phase, they provided Ease of Learning judgments and in the second phase, after studying, they provided a Judgment of Learning. These judgments collected in the two phases were parallel to the meta-reasoning judgments collected in Experiment 1.

## Experiment 1

In Experiment 1 we focused on meta-reasoning judgments collected before and after solving CRA problems. Our hypothesis was that the level of sAccessibility of a CRA triad is derived from the sAccessibility of each word in isolation[2]. Thus, we used a norming study to determine the sAccessibility of each word that appeared in

[2] Although sAccessibility of the entire triad as a whole could potentially be examined, we chose to focus on sAccessibility at the component level, representing real-life situations as the examples described above.

our CRA pool (see the Method section below). The sAccessibility of each triad was defined as the mean rating across the three words.[3]

Experiment 1 had two phases. In Phase A, the participants saw each word triad, either a solvable CRA problem or an unsolvable random collection of three words. Their task was to provide an initial Judgment of Solvability (iJOS) in terms of Yes or No. Based on Topolinski and Strack (2009), we allowed two seconds for the iJOS. It should be noted that the selected problems did not include very easy items, as success rates were 20% to 80% in all problems. In Ackerman (2014), participants invested 18 seconds on average in solving the easiest CRA problem in the set used here, meaning that a two-second limit should not allow actual solving, but only a first impression.

Recent studies have found iJOS regarding various problem types to be affected by the concreteness of a problem's components (i.e., concrete vs. abstract terms; Markovits, Thompson, & Brisson, 2015), pronounceability (Topolinski, Bakhtiari, & Erle, 2016), processing fluency, and affect (Topolinski & Strack, 2009). We hypothesized that sAccessibility would also be utilized as a cue for iJOS, with a positive correlation. In order to examine its unique contribution, we dissociated sAccessibility and solvability by using unsolvable problems matched in sAccessibility to solvable problems (see the Method section below). This way, sAccessibility was necessarily non-predictive of solvability. Thus, any association found between sAccessibility and JOS would suggest a misguided utilization of the former. For the sake of completeness, we asked half of the participants to rate the general solvability of each problem (general iJOS), and the other half to rate their own personal ability to solve the problem (personal iJOS). We expected

[3] Two additional sAccessibility calculations were examined: by word location (accessibility of the first, second, and third word) and by maximum and minimum accessibility in each problem. Mean accessibility showed the strongest predictive power, although the trends were highly similar with all calculation options.

sAccessibility to affect both iJOS types, but were interested to explore whether one would be more susceptible to stimulus-related cues than the other.

To further stress the unique contribution of sAccessibility and examine its generalization across the two domains, we controlled for two cues, word familiarity and fluency. Both cues have been shown to affect other metacognitive judgments, and are potential alternative cues in our paradigm. Regarding word familiarity, Koriat and Levy-Sadot (2001) carefully designed materials which allowed dissociating accessibility and familiarity as bases for Feeling of Knowing. Jönsson and Lindström (2010) found Ease of Learning judgments to rely on frequency of a word in the language, such that participants expected more-frequent—and therefore presumably more-familiar—words to be easier to learn. Word familiarity was operationalized as word frequency in the present study as well.[4] As expected, the mean word frequency for each CRA problem was indeed correlated with its sAccessibility, $r(30) = .38$, $p = .04$, meaning that we had to control for frequency in order to expose the unique contribution of sAccessibility to the judgments we examined. Regarding fluency, as mentioned above, previous studies have shown a consistent negative correlation between response time and various metacognitive judgments (e.g., Thompson, Prowse Turner, et al., 2011; Undorf & Erdfelder, 2015), including confidence in CRA solutions (Ackerman, 2014; Ackerman & Zalmanov, 2012). In the present study, we also operationalized fluency as response time and controlled for it when examining the association between sAccessibility and judgments.

In Phase B, the participants attempted to solve each problem. If they could provide a solution, they rated their confidence (0-100%). Confidence in answers to knowledge questions was found to be based in part on familiarity (e.g., Shaw &

[4] Frequency data were collected by MILA (Knowledge Center for Processing Hebrew), http://mila.cs.technion.ac.il/eng/index.html (Itai & Wintner, 2008). Three words were missing from this collection and were assigned frequencies of zero.

McClure, 1996) and fluency (response time; e.g., Ackerman & Koriat, 2011; Kelley & Lindsay, 1993). Both cues were also found to be associated with confidence in problem solutions (Ackerman & Zalmanov, 2012; Markovits et al., 2015).

In order to generate our hypothesis regarding sAccessibility association with confidence, we consulted the decision making literature. In this literature, it is well-established that people are more confident in choices selected from among fewer options compared with more options (e.g., Iyengar & Lepper, 2000). Thus, we hypothesized that confidence would reflect the greater difficulty of solving problems when participants attempt to consider many potential answers, resulting in a negative sAccessibility-confidence correlation.

Very similar to accessibility as defined by Koriat (1993), Eakin and Hertzog (2012) examined the effects of the associative set size of the cue words when memorising paired associates for a free recall test. Under some conditions they found opposite effects to those of Koriat's—lower recall and feeling of knowing for cues with the larger set size than for those with the smaller set size. Notably, their procedure involved instructing the participants to attempt to form an image of the two words to be memorised. We raise the option that high accessibility hindered participants' generation of a specific image, similarly to the expected hindering effect of considering many possible phrases for each word in a CRA triad on the chance of success and on confidence. If supported, our study may help explaining these seemingly contradicting results to those of Koriat's.

If the participants could not come up with a solution, they provided the new judgment we introduce in this study, final Judgment of Solvability (fJOS)—a rating of the chance (0-100%) that the problem was solvable, even though they could not find the solution. Notably, as the participant already gave up on solving the problem at this point, in this case we only asked about general solvability—the chance that the three words have a common association rather than being a random collection of words. Comparing iJOS and fJOS is parallel to the discrimination in meta-memory between initial and final Feeling of Knowing, provided after a quick glance or after a sincere attempt to answer a question, respectively (Koriat, 1993; Reder & Ritter, 1992). We are aware of only one study which compared initial to final JOS in the context of reasoning. Payne and Duggan (2011) asked participants to provide a JOS every 15 seconds while attempting to solve a set of problems that varied in problem size (i.e., the number of possible states in the problem). The participants were informed in advance about the proportion of problems that were solvable (25% or 75%). Interestingly, only information regarding the proportion of solvable problems affected participants' initial JOS, but as problem solving continued, an effect of problem size emerged as well. That is, the iJOS was based mainly on information that was available before approaching the problem, related to the task as a whole, while later judgments were affected by the specific solving process. Thus, studying the cue utilization for both iJOS and fJOS is certainly called for.

We hypothesized that when participants could not produce a solution even after an exhaustive search, they would utilize sAccessibility as an indication of whether a problem was generally solvable, as is the case with Feeling of Knowing (Koriat, 1993). This was expected to result in a positive correlation between sAccessibility and fJOS. We controlled for familiarity and fluency for the judgments collected in Phase B, as done in Phase A.

In sum, in this experiment we examined cue validity and cue utilization of sAccessibility for iJOS, fJOS, and confidence when facing CRA problems. We operationalized sAccessibility as the perceived number of associations for each word. In Phase A, we manipulated sAccessibility to be non-predictive of actual solvability, but nevertheless expected iJOS to be affected by sAccessibility with a positive correlation, generating a bias. As for fJOS in Phase B, this study was exploratory, so we did not know whether people tend to give up more or less on highly accessible problems, but we expected them to base fJOS on sAccessibility with a positive correlation, regardless of its actual validity as predictor of solvability. When participants provide a solution in Phase B, we expected a negative correlation between sAccessibility and solution accuracy for the solvable problems, as explained above, and of course, no correlation when all answers to unsolvable problems are necessarily wrong. We expected confidence to reflect this pattern reliably for the solvable problems, but did not know what to expect regarding the confidence in solutions provided for unsolvable problems.

## Method

### *Participants*

Fifty-two undergraduate students who reported being native Hebrew speakers participated in the experiment for course credit (36% female). They were randomly assigned to the General-iJOS ($N = 27$) or Personal-iJOS ($N = 25$) condition.

### *Materials*

The thirty CRA problems used by Ackerman (2014; Experiments 2-4) were used. Success rates in these problems were in the range of 20%-80%. A norming study with a different sample drawn from the same population ($N = 29$) was first conducted to provide the sAccessibility of the triads. Participants in the norming study were given an intermixed list of the ninety words. For each word, they estimated the number of two-word phrases in the language. The sAccessibility ratings were normalized within participants into a -1 to 1 range. The sAccessibility of each word triad was defined as the mean rating across the three words in the triad. Mean sAccessibility across triads was 0 ($SD = 0.30$).

The thirty problems were divided into two sets balanced in accessibility, with *t*s < 1 for the difference of each set from zero accessibility. The sets were also balanced for difficulty based on success rates in Ackerman (2014) with a sample from the same population. For each participant, one set served for the solvable problems, and the words in the second set were used to create random triads used as the unsolvable problems. The role of the two sets was counterbalanced across participants.

*Procedure*

The experiment was conducted in a small computer lab in groups of up to eight participants, all in the same experimental condition. At the opening of the session, participants were given instructions and examples. The instructions included an explicit statement that half of the problems were solvable and the other half unsolvable.

In Phase A, participants were presented with the word triads, one at a time. For each triad, they were asked to provide an iJOS as quickly as possible, relying on their gut feeling. The General-iJOS group was asked to indicate whether they thought the problem was solvable (yes/no) and the Personal-iJOS group indicated whether they thought they would be able to solve that problem (yes/no). If they did not respond within two seconds, the triad disappeared and the message "Too slow" appeared. These problems were removed from the analyses. This phase began with four practice trials, though only the first two problems were explicitly identified as such. The third and fourth were also not included in the analysis, but participants were not informed of this. This was done in order to eliminate outliers stemming from participants' familiarizing themselves with the task.

In Phase B, the same problems were presented again for solving. Pressing a Start button on an empty screen brought up a word triad, with a designated space below the three words for the answer. Participants could enter a solution word or give up on solving by clicking a button marked "I don't have a solution." At that point, they pressed a Continue button to move on. There was no time limit for this phase. Response time was measured from when participants pressed Start to when they pressed Continue. For participants who had answered "I don't have a solution," pressing the Continue button exposed the fJOS question "How sure are you that the problem is solvable?" and a horizontal scale with anchors labeled "Sure it is unsolvable" (0%) and "Sure it is solvable" (100%). Participants provided their judgment by dragging an arrow along the scale. For participants who had provided a solution, pressing the Continue button brought up a similar scale for confidence ratings, with its anchors labeled “Definitely incorrect” (0%) and “Definitely correct” (100%). Pressing a button marked Next then cleared the screen for the following problem.

**Results and discussion**

Two participants who provided only "yes" or only "no" iJOS responses were replaced, as were three participants with fewer than 25 responses within the two-second time limit. The remaining participants provided, on average, 28 valid iJOS responses (i.e., responses within the time limit; $SD = 1.5$). The valid responses were provided well before the two-second limit ($M = 1.34$ sec., $SD = 0.24$), $t(51) = 19.2$, $p < .0001$, Cohen’s $d = 2.67$.

All items with too-slow responses to the iJOS question (106 items, 7% of the total) were removed from the analyses. Interestingly, these responses were equally divided between solvable (51%) and unsolvable (49%) problems, and their mean sAccessibility was 0.008 ($SD = 0.33$; $t < 1$ for the difference from zero).

In Phase B, participants responded "I don't have a solution" for 54% of the triads. Of the problems where a solution word was provided, 48% were correct.

*General-iJOS versus Personal-iJOS*

As a first step, we looked for differences between those asked about the general solvability of the problems, the General-iJOS group, and those asked about their own ability to solve them, the Personal-iJOS group. No differences were found in response times or accuracy across both phases, or in the frequency with which participants used the no-solution button in Phase B. In Phase A, participants in the general-iJOS group were marginally more likely to judge a given problem as solvable ($M$ = .61, $SD$ = .08) compared with the personal-iJOS group ($M$ = .56, $SD$ = .11), $t(50) = 1.71$, $p$ = .09, $d$ = .48. However, both groups judged more problems to be solvable than the actual rate of solvable problems (.50), both $p$s $\leq .01$. Because of the similarity between the groups and because no other differences or interactive effects were found in the following analyses, we report the results combined across the two groups.

*Discrimination between solvable and unsolvable problems*

In Phase A, the frequency with which participants responded "yes" to the iJOS question did not differ between the solvable (51%) and unsolvable problems (49%), $\chi^2$(chi-*square)* < 1. However, examining response time for iJOS in a two-way within-participant Analysis of Variance (ANOVA) of iJOS (yes/no) × Solvability (yes/no) revealed a main effect of iJOS, $F(1, 51) = 17.80$, $MSE = 0.1$, $p < .0001$, $\eta_p^2 = .26$, such that "yes" responses were provided faster than "no" responses. There was also a main effect of solvability, $F(1, 51) = 6.16$, $MSE = 0.1$, $p = .016$, $\eta_p^2 = .11$, such that responses for solvable problems took longer than for unsolvable problems. This finding differs from previous findings with coherence judgments (e.g., Topolinski & Strack, 2009). However, there was also an interactive effect, $F(1, 51) = 4.28$, $MSE$ = 0.1, $p = .044$, $\eta_p^2 = .08$. A one-way ANOVA comparing the four conditions revealed that all the effects stemmed from slower "no" responses for solvable problems ($M$ = 1.4 sec., $SD$ = .27), while the three other conditions were equivalent ($M$s = 1.31-1.35

sec.), all *p*s $< .005$. Thus, although there was discrimination between solvable and unsolvable problems in response times, this was not reflected in participants' iJOSs.

In Phase B, the participants provided solutions for 59% ($SD = 17.7$) of the solvable problems and only 29% ($SD = 16.8$) of the unsolvable problems, $t(51) = 10.53$, $p < .0001$, $d = 1.38$. Thus, they seem to differentiate between solvable and unsolvable triads. However, when they gave up, their fJOSs did not differ between the solvable and unsolvable problems, $t < 1$. All fJOSs were fairly low ($M = 36.0\%$, $SD = 14.4$) regardless of the problems' actual solvability, $t < 1$.

Solutions were provided more quickly and accompanied by higher confidence for solvable than for unsolvable problems, both *p*s $< .0001$. More important, however, was to test whether confidence reliably discriminated between correct solutions, wrong solutions to solvable problems, and solutions provided for unsolvable problems (which were, of course, all wrong). Ackerman and Zalmanov (2012) found that confidence judgments reliably discriminated between correct and wrong solutions above and beyond the misleading effects of fluency. In the present study as well, resolution (the mean within-participant Gamma correlation between the confidence judgment and performance) for provided solutions was high ($M = .82$, $SD = .31$, $t(50) = 18.84$, $p < .0001$, $d = 2.64$). Looking deeper, a within-participant post-hoc test using one-way ANOVA revealed that confidence was much higher for the correct solutions ($M = 91.0$, $SD = 8.7$) than for wrong solutions to solvable problems ($M = 57.1$, $SD = 18.0$), $p < .0001$, while the latter did not differ significantly from confidence in solutions to unsolvable problems ($M = 62.2$, $SD = 20.0$), $p = .11$. Thus, confidence discrimination between solvable and unsolvable problems in Phase B stemmed only from participants' high confidence in correct solutions.

So far, the results suggest that until and unless participants found the correct solution to a problem, their judgments were fairly arbitrary. That holds for iJOS in

Phase A, before participants had an opportunity to work on the problems, and for fJOS and confidence when they failed to find the correct solution in Phase B. Next, we examined sAccessibility as a potential heuristic cue for these judgments. Findings which show predictable patterns in these judgments should convince us that the judgments were in fact not arbitrary.

*Cue validity*

Before examining whether participants used the sAccessibility cue in making their judgments, we sought to determine the cue's validity—that is, the extent to which the cue predicts the actual solvability of a problem and the correctness of provided solutions. We used a mixed hierarchical logistic regression (Proc Glimmix macro of SAS© 9.3) to examine the predictive value of sAccessibility (a continuous variable) for solvability (a dichotomous variable). As a basis for iJOS the analysis included all problems, while as a basis for fJOS the analysis included problems which the participants gave up solving in Phase B. As a basis for analyzing confidence later on, the dependent variable in the logistic regression was the accuracy (a dichotomous variable) of the provided solutions in Phase B.

The dashed lines in Figure 2 represent cue validity. As we intended by counterbalancing the problem sets across participants, sAccessibility did not predict solvability, $t < 1$ (see Figure 2A). There was no association between sAccessibility and solvability among the problems given up, $t < 1$ (36% overall chance of being solvable; see Figure 2B). This finding is important in its own right, because it does not stem from the manipulation, but sheds light on participants' decisions to give up solving. At the same time, the accuracy of solutions provided for solvable problems was, as predicted, associated with sAccessibility with a negative slope, *Exp(b)* = -1.07, $t(405.6) = 3.53$, $p = .0005$. That is, participants had more difficulty solving high-sAccessibility problems than those with lower sAccessibility. For the unsolvable problems, of course, all responses were wrong, regardless of sAccessibility (see Figure 2C).

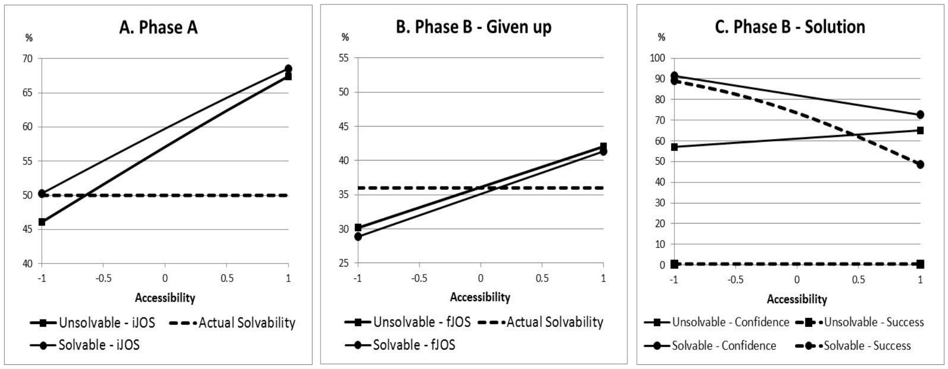


*Figure 2.* Experiment 1 – Reasoning. Cue validity (dashed lines) and cue utilization (full lines) of perceived accessibility for initial Judgment of Solvability (iJOS, Panel A), final Judgment of Solvability after giving up a solving attempt (fJOS, Panel B), and confidence in provided solutions (Panel C). Solvable and unsolvable problems are compared where relevant.

*Cue utilization*

A logistic regression examining the predictive value of sAccessibility for iJOS revealed a significant positive slope, *Exp(b)* = 0.42, $t(1410) = 2.39$, $p = .017$. Comparing the slopes of solvable and unsolvable problems revealed no interactive effect, $t < 1$. See Figure 2A.

In an analysis controlling for word frequency, a proxy for familiarity, and response time, a proxy for fluency, as potential alternative cues for iJOS, sAccessibility did not lose its predictive value, *Exp(b)* = 0.54, $t(1408) = 2.75$, $p = .006$. Thus, the greater the sAccessibility of the words in a given problem, the more likely participants were to consider the problem solvable, above and beyond the effects of familiarity and fluency.

For fJOS (a continuous variable), a linear regression (Proc Mixed macro of SAS© 9.3) revealed a positive slope as well, $b = 6.17$, $t(769) = 2.34$, $p = .020$. Solvability also had no effect on the fJOS slope, $t < 1$. See Figure 2B. When controlling for frequency and response time, the predictive value of sAccessibility became insignificant, $b = 4.24$, $t(770) = 1.47$, $p = .142$, suggesting on a combination of the three cues, and/or other cues, that underlie fJOS.

In a linear regression for confidence, the overall pattern was of a negative slope, $b = -7.51$, $t(607) = 2.47$, $p = .014$. Separating out the solvable from the unsolvable problems revealed an unexpected difference between the two, $b = 13.37$, $t(615) = 2.05$, $p = .040$, such that the entire effect came from the solvable problems, $b = -9.41$, $t(562) = 2.95$, $p = .003$, while for unsolvable problems the slope was insignificant, $t < 1$. Notably, in this case the direction of the slope for cue utilization matched that for cue validity (see Figure 2C). However, controlling for word frequency and response time for the solvable problems cancelled out the effect of sAccessibility, $t < 1$. Thus, like for fJOS, although sAccessibility was correlated with confidence overall, it was not a unique predictor of it for either solvable or unsolvable problems.

For considering why sAccessibility had unique contribution for iJOS, but not for fJOS and confidence, we did additional analyses. The association between sAccessibility and familiarity was constant across the two phases. Response time, in contrast, differed between the phases—it was the iJOS time in the first phase and solving time or time to giving up in the second phase. Correlating sAccessibility and response time revealed that in the first phase, the mean within-participant Pearson correlation did not differ from zero ($M = -.04$, $SD = .19$), $t(51) = 1.66$, $p = .10$, $d = 0.23$. In the second phase, the correlations of sAccessibility with solving times ($M = .14$, $SD = .33$) and with giving up times ($M = .18$, $SD = .22$) were significantly positive, $t(51) = 2.95$, $p = .005$, $d = 0.41$ and $t(51) = 5.95$, $p < .0001$, $d = 0.84$, respectively, with a significant difference between the former and the latter two, $F(2, 102) = 10.52$, $MSE = 0.71$, $p < .0001$, $\eta_p^2 = .17$, which did not differ significantly, $p = .42$. These findings may suggest that considering the potential solutions associates response time and sAccessibility, while speeded response does not allow this association. The association between the two cues then conceals the contribution of sAccessibility to fJOS and confidence, while for iJOS its contribution can be exposed.

In sum, assessing solvability is clearly not trivial. Participants could not discriminate between solvable and unsolvable problems unless and until they engaged in the task and found the correct solution. The sAccessibility was a unique predictor only for iJOS, while for fJOS and confidence both familiarity, operationalized by word frequency, and fluency, operationalized by response time, shared variance with it.

## Experiment 2

In Experiment 1, sAccessibility was positively correlated with iJOS and fJOS, in line with previous findings with Feeling of Knowing. For confidence, in contrast, sAccessibility showed a negative correlation for the solvable problems and no association for the unsolvable ones. As far as we know, the only previous similar findings involved memorising with imagery (e.g., Eakin & Hertzog, 2012).

Notably, Experiment 1 included several unique procedural characteristics that might underlie this finding. First, confidence ratings were provided in a second phase, after encountering the problems in the initial block used to collect the iJOS, and this might have affected cue utilization. Second, confidence analyses were relevant only in cases where participants provided solutions (less than half the items altogether). Such a procedure might affect confidence values relative to tasks for which confidence is collected for all items, regardless of their difficulty. It also reduces the power of the analyses relative to those based on confidence provided for more items.

To address these concerns, we report here on reanalysis of data from an experiment reported by Ackerman (2014; Experiment 2), which employed the same solvable problems used in Experiment 1. A control group in that experiment rated confidence with no manipulation and after only one encounter with each problem. The manipulation group underwent a within-participant manipulation of incentive, where each problem was marked by one or five stars to indicate its importance (though these marks carried no monetary value). In that experiment, the negative response time-confidence correlation was affected by the incentive manipulation: lengthy responses were accompanied by higher confidence for the 5-star problems than for the 1-star problems, while for the quick responses there was no effect of the incentive.

For the purpose of the present analysis, the incentive manipulation was similar to the solvability manipulation in Experiment 1 in that participants were required to pay attention to another aspect of each problem while attempting to solve it, and both factors similarly varied between two halves of the problems. Thus, having the control group and the manipulation group allowed verifying the robustness of the confidence pattern found in Experiment 1 with and without another within-participant manipulation and with variations in time-confidence correlations.

**Method**

*Participants*

Sixty participants drawn from the same population as in Experiment 1 participated in the experiment (28% females). They were randomly allocated at a rate of 1:2 to the Control group ($N = 20$) and Incentive group ($N = 40$).

*Materials*

The CRA problems used for Experiment 1 were used in this experiment.

*Procedure*

The experimental setting was the same as in Experiment 1. For the Control group, the instruction booklet detailed the procedure, explained what represented a valid solution, and illustrated the procedure using two problems. The answering procedure was identical to Phase B in Experiment 1. However, in this experiment the participants had to enter solutions and rate their confidence for all problems.

The procedure for the Incentive group differed from that for the Control group in that half the problems were preceded by one star and half by five stars. The stars appeared on the screen two seconds before the problem. The meaning of the point values was explained in the instructions and demonstrated by the first two problems.

**Results and discussion**

In this experiment, there was no reason to exclude any participant. Comparing the two groups in response time, confidence, and success rates revealed no significant differences, all $p$s $\geq .15$. The analyses reported below also revealed no differences between the groups. Thus, the data were collapsed across both groups.

*Discrimination between solvable and unsolvable problems*

Resolution was almost perfect ($M = .91$, $SD = .10$). Confidence in correct solutions was high ($M = 91\%$, $SD = 17.1$) and in wrong solutions was low ($M = 37\%$, $SD = 32.3$).

*Cue validity*

The sAccessibility was a strong predictor of solution accuracy, with a negative association between them, $Exp(b) = -.42$, $t(1720) = 2.75$, $p = .006$. This is in line with the pattern of confidence in solvable solutions in Experiment 1.

*Cue utilization*

The sAccessibility was negatively associated with confidence, $b = -5.43$, $t(1722) = 2.04$, $p = .042$. As in Experiment 1, this effect was eliminated when word frequency and response time were included in the analysis, $t < 1$. As in Experiment 1, sAccessibility and response time were weakly but still positively correlated ($M = .07$, $SD = .16$), $t(59) = 3.47$, $p = .001$, $d = 0.44$.

In sum, in a straightforward procedure and regardless of the presence of the within-participant incentive manipulation, this experiment replicated the entire pattern of results for confidence in solutions provided for solvable problems found in Experiment 1.

## Experiment 3

In order to expose shared and distinct mechanisms underlying meta-reasoning and meta-memory, in Experiment 3 we followed the procedure employed in Experiment 1 as closely as possible while using a Memorisation task. We used the same stimuli employed for the reasoning task in the previous experiments, and collected Ease of Learning judgment (EOL) and Judgment of Learning (JOL) in a way designed to parallel the elicitation of iJOS, fJOS, and confidence.

EOL, like iJOS, is elicited at the start of the learning process. As explained above, iJOS might refer to general solvability of the problem or to personal ability to solve the problem. In contrast, EOL necessarily predicts personal ability to recall the stimulus at a later test, because for young and healthy adults, any item in isolation can be memorised if enough effort is invested. Relative to other meta-memory judgments and despite the early studies dealing with this judgment (e.g., Leonesio & Nelson, 1990; Underwood, 1966), little is known about cues that underlie EOL. The few studies that have examined bases for EOL in the context of word Memorisation have found it to be affected by a priori beliefs about item difficulty (see Dunlosky & Tauber, 2014; Koriat, 1997). Jönsson and Lindström (2010) found it to be affected by word length, frequency in the language, and concreteness. Thus, beyond the comparison between EOL and iJOS, in the present study we add sAccessibility to the list of potential heuristic cues utilized for EOL.

JOL is probably the most studied metacognitive judgment in the Memorisation literature. It reflects the expected chance to recall in a later test and is typically collected immediately after the decision to stop studying. Several bases have been identified for JOL, including beliefs about memory (e.g., Mueller, Dunlosky, Tauber, & Rhodes, 2014), domain familiarity (e.g., Shanks & Serra, 2014), perceptual fluency (e.g., sound loudness, Rhodes & Castel, 2009), processing fluency (e.g., study time; Undorf & Erdfelder, 2015), subjective effort (e.g., Koriat, Nussinson, & Ackerman, 2014), and memory of performance in a past test (Finn & Metcalfe, 2008). Regarding word frequency, Benjamin (2003) found this to be a reliable predictor of JOL, though the results of Jönsson and Lindström (2010) were inconclusive. Thus, although many bases for JOL have been identified, sAccessibility has not yet been examined.

In most JOL studies, including those cited above, Memorisation tasks involve word pairs (e.g., Sock – Kite). In the test, the first word is used as a trigger for the second word, which is the target to be recalled. Recently, Undorf and Zander (in press) asked participants in four experiments to judge quickly (1.8s) the ease of recognizing word triads which were solvable and unsolvable CRA triads. In all experiments they found the judgments to be higher for solvable than for unsolvable triads. The authors concluded from their set of experiments that judgments' sensitivity to solvability does not depend on awareness to triads' solvability. Notably though, the participants were not asked to memorise the triads.

For the present experiment, given that we employed as our stimuli the word triads used in the previous experiments, we had to decide which word(s) to use as triggers and which as targets, and, in particular, whether to make the test easier (using two triggers and one target) or more challenging (using one trigger and two targets). In the present study, success rates for the solvable problems were 43% (*SD* = 16.5) and 47% (*SD* = 16.1) in Experiment 1 and Experiment 2 respectively, while success rates in paired associates studies are often higher. In addition, previous research has found that perceived item difficulty affects cue utilization for JOL (Ackerman, 2014). Similarly, Ackerman, Leiser, and Shpigelman (2013) found that people's Judgments of Comprehension of solution explanations—a judgment similar to JOL—were led astray by a manipulation involving illustrations only for the items perceived as more difficult. Hence, in order to make the reasoning and Memorisation tasks as similar as possible in terms of difficulty, we challenged the participants in the present experiment with one trigger word and two target words.

We predicted that, as found for Feeling of Knowing, sAccessibility would show reliable cue utilization, in line with cue validity. That is, we expected sAccessibility to be positively correlated with EOL, JOL, and actual recall. This prediction was based on a generalization of the traditional definition of accessibility (Koriat, 1993), despite the fact that in the present study we used sAccessibility. In order to verify the unique predictive value of sAccessibility, we controlled for word frequency and response time, which are relevant in this experiment as in the previous ones.

In sum, the main purpose of Experiment 3 was to mirror meta-reasoning processes using their meta-memory parallels, for examining the shared and distinct patterns of cue utilization across the domains. Moreover, as explained above, this experiment also addresses open questions regarding mechanisms underlying meta-memory judgments.

**Method**

*Participants*

Twenty-six undergraduate students were drawn from the same population as in the previous experiments (39% female).

*Materials*

The word triads were the same as in the previous experiments.

*Procedure*

The experimental setting was as in the previous experiments. At the opening of the session, participants read instructions regarding the Memorisation task. The procedure consisted of three phases. In Phase A, the EOL phase, participants were presented with the word triads one at a time, and were asked to decide as quickly as possible whether they would be able to recall both other words when given the first word (yes / no). Judgments not provided within two seconds generated the message “Too slow.” These problems were removed from the analyses.

In Phase B, the same triads were presented again, and participants studied them in a self-paced manner. When done studying a triad they pressed the Continue button, which revealed a horizontal scale for JOL (0%-100%). Pressing the Next button then cleared the screen for the following word triad. There was no time limit for this phase, but study times were documented.

In Phase C, the recall phase, the first word of each triad was presented, along with a space for participants to type the second and third words. They could respond "I don't remember" by clicking a designated button below the entry space. As above, this phase was self-paced with no time limit.

**Results and discussion**

As in Experiment 1, we replaced six participants who provided only "yes" or "no" EOL judgments to all the triads in Phase A or had fewer than 25 valid responses (i.e., responses within the two-second limit). Within the final sample, respondents failed to provide a valid EOL in 63 cases (8%). The mean sAccessibility of triads with too-slow responses was 0.03 ($SD$ = 0.33; $t < 1$ for the difference from zero), similar to the overall mean of zero. Recall success in these triads was 37%—virtually the same as for the other triads. On average, the included participants had 28 valid responses ($SD$ = 1.6) and rated their EOL much quicker than the time limit ($M$ = 1.42 sec., $SD$ = 0.14), $t(25) = 52.3$, $p < .0001$, $d = 10.2$.

In Phase C, participants provided answers, rather than responding "I don't remember," for 50% ($SD$ = 20.3) of the solicited words (two words per triad). Given that, in this experiment, the initial judgment (EOL) was equivalent to a prediction of successful recall, we accounted wrong answers and "I don't remember" responses together as unsuccessful recall attempts. Thus there were three potential success levels per triad: no words successfully recalled, one word successfully recalled (50% recall), and both words successfully recalled (100% recall). The overall successful recall rate was 37% ($SD$ = 23.9).

*Discrimination between recalled and unrecalled words*

In Phase A, the frequency of "yes" EOL judgments was 50%, although there were no objective features preventing any triad from being memorised. "No" EOL judgments were used more than "yes" judgments for no-recall triads (66% and 45% for "no" and "yes," respectively), while for recalled triads the pattern was reversed (20% and 37%, respectively).[5] Thus, EOL predicted recall quite reliably, $\chi^2(2) = 33.51$, $p < .0001$. Notably, though, the "yes" rate was higher for no-recall triads than for triads where recall was successful. Response time for EOL was not associated with success rates, $F(2, 42) = 1.65$, $MSE = 9923.4$, $p = .20$, $\eta_p^2 = .07$. Thus, in contrast with our findings for iJOS, EOL showed reliable discrimination and no response time variation.

In Phase B, JOLs reliably reflected the three recall levels, $F(2, 42) = 18.48$, $MSE = 118.4$, $p < .0001$, $\eta_p^2 = .47$, with significant differences among them, all $p$s ≤ .04 ($M_{\text{no recall}}$ = 39%, $SD$ = 2.8; $M_{\text{50\% recall}}$ = 47%, $SD$ = 4.2; $M_{\text{100\% recall}}$ = 59%, $SD$ = 4.1).

[5] For 50%-recall triads (i.e., those where respondents recalled one of the two words), the differentiation was weak (14% and 18% for "no" and "yes," respectively).

There was no difference in study time between the recall levels, $F < 1$. In Phase C, there were differences in recall time, $F(2, 42) = 6.95$, $MSE = 36.8$, $p = .002$, $\eta_p^2 = .25$. Response times were longer for both the no-recall ($M = 15.2$ sec., $SD = 6.7$) and 50%-recall triads ($M = 18.0$ sec., $SD = 8.9$) than for those where recall was 100% ($M = 11.2$ sec., $SD = 3.4$), both $ps \leq .02$, with no difference between the no-recall and 50%-recall triads, $p = .16$. Notably, the 100% recall data necessarily included typing two words, which took longer than pressing the "I don't remember" button, but nevertheless the responses were quicker than in the cases with lower rates of successful recall. This result suggests that the participants made an effort to recall the target words when they could not do so immediately.

With respect to resolution, we wanted to compare resolution for the JOLs in this experiment with resolution for confidence in Experiment 1, on the grounds that the difference between the predictive nature of JOL and postdictive nature of confidence may generate differences in cue utilization (Benjamin, 2003). Resolution calculation by Gamma correlation examining JOL as a predictor of the three levels of accuracy (0, 50, 100%) yielded mean correlation of .42 ($SD = .29$) which was significantly larger than zero, $t(25) = 7.37$, $p < .0001$, $d = 1.42$. An analysis with accuracy as a dichotomy was also done for comparing JOL resolution with the confidence resolution found in the previous experiments. A resolution calculation accounting both 50% and 100% success as correct and no recall as wrong revealed similar results ($M = .45$, $SD = .31$, $t(25) = 7.44$, $p < .0001$, $d = 1.46$). Thus, although JOL resolution was weaker than confidence resolution, it showed good discrimination. This finding suggests that participants could reliably predict their recall in Phase C despite the time lag between the judgment and performance. The question of interest is whether sAccessibility contributed to JOLs even though the number of phrases associated with each word was not directly relevant to the Memorisation task.

*Cue validity*

In order to conduct cue validity analyses using logistic regressions, as done in the previous experiments, we followed the approach taken for resolution and accounted triads with either one or two successfully recalled words as correct, and no recall as wrong. As expected, in contrast with the effect of sAccessibility on problem solving success, the slope for predicting recall by sAccessibility was positive, *Exp(b)* = 0.74, *t*(714) = 2.70, *p* = .007. The dashed line in Figure 3 represents the same results data, enabling a comparison between EOL and JOL as predictors of recall.

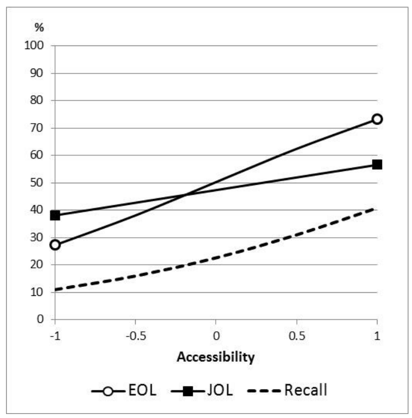


*Figure 3.* Experiment 3 – Memorisation. Cue validity (dashed lines) and cue utilization (full lines) of perceived accessibility for Ease of Learning (EOL) judgment and Judgment of Learning (JOL).

*Cue utilization*

As hypothesized, sAccessibility predicted EOL and JOL with positive slopes, in line with its cue validity, *Exp(b)* = 0.94, *t*(687.4) = 3.66, *p* = .0003 and *b* = 10.91, *t*(690) = 3.62, *p* = .0003, respectively (see Figure 3). Including word frequency and response time in the regressions did not eliminate the predictive power of sAccessibility for either EOL or JOL, *Exp(b)* = 0.82, *t*(683.9) = 2.97, *p* = .003, and *b* = 11.10, *t*(688) = 3.41, *p* = .0007, respectively. The sAccessibility was not significantly correlated with EOL time (*M* = -.02, *SD* = .23), *t < 1*, or study time (*M* =

.06, *SD* = .23), *t*(25) = 1.27, *p* = .22, *d* = 0.25. This finding is in line with those of the previous experiments, suggesting that when there is no point (or time) for considering the alternative potential solutions, sAccessibility and response time are not correlated and sAccessibility has a unique contribution.

In sum, unlike iJOS and fJOS, both memory-related judgments collected in Experiment 3—the first solicited after a quick glance at each triad (EOL) and the second after self-paced study (JOL)—reflected good discrimination. The sAccessibility predicted EOL, JOL, and recall success. It had unique predictive value for both judgments and was utilized reliably by participants.

## General Discussion

We had two aims in this study: first, to explore to what extent, and in which manner, reasoning processes rely on shared metacognitive cues with meta-memory; second, to develop a reliable methodology for testing this question, which could then provide a useful tool for future work along similar lines. For these purposes, we used the same stimuli for two entirely different reasoning and memorising tasks and examined sAccessibility as a cue that could be utilized in both. This novel approach allowed controlling for alternative cues (e.g., familiarity) and comparing the metacognitive processes on common grounds (e.g., reading time) despite the inherent differences between the tasks in the required cognitive processing and time on task. The cue we chose has not been examined before regarding any of the judgments we collected.

### Utilization of sAccessibility as a cue for judgments

The sAccessibility was associated with all the judgments we collected: iJOS, fJOS, and confidence in a reasoning task (Experiment 1 and Experiment 2), and EOL and JOL in a Memorisation task (Experiment 3), except for confidence in solutions provided for unsolvable problems. Notably, sAccessibility had a unique contribution to predictive judgments in both reasoning and Memorisation, namely iJOS, EOL, and JOL, while alternative cues shared variance with it for postdictive judgments, namely, fJOS and confidence. Dougherty et al. (2005) found that participants utilized the heuristic cue of study time differently when forming JOL and confidence ratings for memory tasks and that confidence ratings were more reliable than JOL. The present study generalizes both these findings. Notably, though, in our study the predictive judgments could be compared across the two task domains, but both postdictive judgments related to reasoning tasks only. It is thus yet open to consider whether postdictive reasoning judgments are more reliable than memory judgments (e.g., confidence in answers to knowledge questions).

As reported above, for the predictive judgments sAccessibility and response time were not correlated, while for the postdictive judgments, they were correlated, though weakly. We suggest that the contribution of sAccessibility was concealed by response time when there was both time and relevance to come up with potential associations. If we had examined only the reasoning task, we would have suggested that allowing time for producing associations is a requirement for allowing correlation between the two cues. The comparison with the memory task suggests that time is not enough, but relevance to the task is required as well. These findings may inform research about the ubiquitous cue of fluency (Unkelbach & Greifeneder, 2013) regarding conditions that allow other cues to be exposed, which is relevant across domains. For instance, in the reasoning domain, this was the case regarding both the quick initial Feeling of Rightness and final confidence (e.g., Thompson, Prowse Turner, et al., 2011).

An additional consideration regarding the cases of unique contribution of sAccessibility to judgments is a methodological one. We used two different types of judgment scales, binary (yes/no) for the initial judgments and continuous (0-100%)

for the final judgments. Zawadzka and Higham (2015) showed that using a binary scale in and of itself seems to improve JOL accuracy relative to a continuous scale. This differentiation potentially suggests that sAccessibility plays a stronger role in binary judgments than in continuous judgments. However, sAccessibility was a unique predictor of the continuous JOL in addition to the binary judgments. Thus, this differentiation is not a clear cut. Additional research is needed for examining whether these differences among the judgments are generalizable across domains, tasks, and methodologies.

The robust predictive value of sAccessibility generalizes previous findings on its utilization for Feeling of Knowing when facing knowledge questions (Eakin, 2005; Koriat, 1993, 1995). Koriat (1993) emphasized that accessibility takes effect regardless of the associations' relevance to the sought answer. In our study, sAccessibility was relevant for the CRA task, but absolutely irrelevant for rote Memorisation of the words themselves. Nevertheless, this cue made a unique contribution to EOL and JOL, above and beyond two other cues often considered in the literature, familiarity and fluency. Thus, our findings underscore that sAccessibility can affect judgments even when its utilization is not rational. In Koriat's terms, this finding suggests that the use of sAccessibility as a cue is experience-based, grounded in sheer subjective feeling, rather than theory-based, grounded in analytic inferences (see Koriat, 2008, for a review). Of course, direct examinations of such inferences as well as of other potentially confounding cues are warranted.

The present study highlights the distinction between confidence in provided solutions and all other judgments in terms of cue utilization. The sAccessibility was associated with iJOS, fJOS, EOL, and JOL with positive correlations, while confidence correlation was negative for solvable and nil for unsolvable problems. Of course, these findings may suggest on dominance of cues that we did not consider. However, focusing on sAccessibility, our findings potentially suggest on malleability of the cue utilization process itself in the course of performing the task. First, they highlight the need for investigating the heuristic bases for the various meta-reasoning judgments in detail, as is already well-established regarding meta-memory judgments (e.g., Jönsson & Lindström, 2010; Souchay & Isingrini, 2012). Second, our findings raise the possibility that a cue is utilized differently under distinct conditions. For instance, as mentioned above, we offer a potential explanation for the negative associations between accessibility and Feeling of Knowing found by Eakin and Hertzog (2012), unlike Koriat's (1993) findings. By our explanation, higher accessibility (larger set size) should correlate negatively with feeling of knowing when imagery is required during the memorising task, but not without directing the participant explicitly to this strategy. More generally, such malleability of cue utilization across conditions and tasks is rarely addressed in the metacognitive literature and calls for future research to shed more light on factors affecting the extent of utilization of each considered cue.

**Reliability of judgments: Cue validity versus cue utilization**

As expected, we found sAccessibility to predict performance with a negative association in the reasoning task and a positive association in the Memorisation task we used. This design provided the opportunity for examining the extent of correspondence between cue validity and cue utilization. Looking solely on the high cue validity of sAccessibility for memory judgments (Figure 3), one might conclude that meta-memory judgments are generally more reliable than meta-reasoning judgments. However, this is probably not the case. In particular, resolution was better for confidence in solutions than for JOLs when memorising.

Many metacognitive studies highlight persistent cue utilization despite differences in cue validity between conditions (e.g., Yue, Castel, & Bjork, 2013; Zimmerman & Kelley, 2010). For the reasoning domain, the present study demonstrates a dissociation between cue utilization and cue validity—a methodology rarely applied in this domain (but see Ackerman & Zalmanov, 2012). While sAccessibility was associated with both judgments of success (confidence, EOL, and JOL) and judgments of solvability (iJOS and fJOS), only for the former it was reliably predictive of actual performance, while in the latter cases, it was misleading. It thus seems likely that utilization of sAccessibility as a cue for judgments of solvability reflects overgeneralization from judgments regarding expected success in the task.

Interestingly, previous studies have found judgments to be particularly prone to bias when participants are forced to judge quickly (e.g., Benjamin, 2005). Here we found a shared bias for both the pressured iJOS and when there was no time constraint for providing fJOS. Thus, the predictive value of sAccessibility for these judgments was independent of the time frame.

In real life having a lot of knowledge relevant to a reasoning task is often desirable, because it provides the reasoner with solution alternatives and strategies to be considered, increasing the probability of success (see Butler & Winne, 1995; e.g., Holyoak, 1990; Thibodeau & Boroditsky, 2013). In the examples given earlier, a chef who knows a lot of recipes for individual ingredients will have a larger pool of possible recipes to draw from when considering what to cook with the contents of a given cupboard, and the same for an architect tasked with designing a bridge. Moreover, a robust finding in the metacognitive literature is that people who are more knowledgeable in a domain are also better at assessing their knowledge than those who are less knowledgeable (Dunning, Johnson, Ehrlinger, & Kruger, 2003; Kleitman

& Moscrop, 2010). However, a well-established source of bias in the reasoning literature is generated by associatively related knowledge that is not relevant to the particular task at hand (see Evans, 2002; Thompson, Newstead, & Morley, 2011, for reviews about the belief bias). In the present study, in which high sAccessibility was based on perceiving having many associations for the presented words, it was not in fact associated with solvability (Figure 2A and Figure 2B). Nevertheless, we found that iJOS and fJOS were associated with sAccessibility, and for iJOS, it even had a unique explanatory value. This may be because problem solving requires an ability both to retrieve relevant knowledge and to ignore or suppress irrelevant information (Passolunghi & Siegel, 2001). Thus, we see that having a lot of related knowledge does not necessarily promote resistance to such biases (see also Fazio, Brashier, Payne, & Marsh, 2015).

Our study produced results inconsistent with previous findings regarding the reliability of judgments of solvability and JOL. Topolinski (2014) reviewed several studies in which people could distinguish between solvable and unsolvable RAT or CRA problems. In some studies participants were asked about the coherence of the triads, while in others the variables of interest were reading time or response time for a lexical decision (the existence of a non-word within a triad). In all these studies, the findings showed consistent discrimination between solvable and unsolvable problems, with higher judgments or quicker responses for the solvable problems than for the unsolvable ones. The authors explained these findings in terms of processing fluency stemming from semantic priming among the words. Similarly, Undorf and Zander (in press) found quick judgment of ease of recognition to differentiate between solvable and unsolvable triads. The present study shows a different pattern of results. First, iJOS, which is the most similar judgment to that collected in the previous studies, did not discriminate between solvable and unsolvable problems. The reliability of EOL judgments provided for the same stimuli in the same time frame rules out that the allotted time was too short for reading and discrimination to occur. Moreover, iJOS was clearly not arbitrary, as it was associated with sAccessibility. Second, while there was no difference in response time between solvable and unsolvable problems for "yes" iJOS responses, participants took longer to settle on a "no" response for solvable problems than for unsolvable ones. A possible account for the difference is provided by our finding of equivalence between general solvability and personal solvability judgments. It is possible that our participants inferred from the instructions that they would be tasked with attempting to solve all the problems in the following experimental phase even when asked about general solvability. By this account, both groups treated the iJOS as a personal prediction of performance, and this affected their judgment and/or mental load differently than in Topolinski's studies. This explanation is in line with the lack of discrimination found in Payne and Duggan's (2011) study, mentioned above. It is also in line with the findings by Topolinski and Strack (2008) that awareness to the semantic structure of the triads impaired discriminability. Indeed, in our study the discrimination between solvable and unsolvable problems found in Phase B stemmed only from the problems for which the participants found the correct solutions. When participants failed to find the correct solution, there was no discrimination for either fJOS or confidence. In some studies reviewed by Topolinski, participants were asked to report when they had found a solution, and these trials were discarded. This finding suggests that unlike in the present study, in the reviewed studies at least some problems were solvable in the allotted time. Thus, it is possible that participants solved some problems without acknowledging that they had done so, and that this underlies the found discrimination. This issue also necessitates further investigation.

**Conclusion**

In this study we used the sAccessibility cue to demonstrate shared and distinct cue utilization between meta-reasoning and meta-memory. Indeed, we found that the pattern of cue utilization found before for accessibility with Feeling of Knowing when answering knowledge questions (e.g., Koriat, 1993, 1995) generalizes to the similar cue of sAccessibility in other meta-memory judgments, EOL and JOL. The meta-memory literature is vast, while meta-reasoning research is in its infancy. The natural step for meta-reasoning research is to draw on analogous processes in the extant literature. What the current work shows, however, is that such steps should be taken with caution, in a systematic way. In particular, sAccessibility was misleading for judgments of solvability, and reliable for the other judgments. Thus, we conclude that studying metacognitive processes from a meta-reasoning perspective provides a sight-hole into unknown aspects of reasoning, and vice versa (see Ackerman & Thompson, 2015, in press). We call future studies to elaborate on metacognitive research questions by examining comparisons across domains based on principles known in one domain, but not in the others.

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