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Effort Regulation in Meta-reasoning: Monitoring and Control

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Abstract: Meta-reasoning is an intricate cognitive function that oversees and modulates advanced intellectual activities like reasoning and solving problems, employing continuous self-assessment to navigate complexities. Although this monitoring is somewhat vague, it often harnesses heuristic cues to render judgements and drive decisions. These heuristics, while efficient, vary greatly and can lead to different decision-making paths. The effort regulation in meta-reasoning, as articulated by the Diminishing Criterion Model(DCM), is influenced by a decline in confidence levels, coupled with a decrease in available time which, together, can precipitate a cessation in cognitive engagement. Consequently, compelling avenues for further research include a thorough examination of the dynamics of heuristic cues and an enhancement of reasoning abilities through improved meta-reasoning techniques. Additionally, it is crucial to investigate the specific the neural mechanism of meta-reasoning. Future studies in these areas are expected to refine our comprehension of heuristic reliance and the metacognitive effort.

1. Introduction

According to researchers at Cornell University, we make 226.7 decisions a day when it comes to food alone[1]. Given the large number of choices we have to make every day, why do we selectively think deeply about some of our decisions? The reason may lie in metacognition. Metacognition is often defined as "the perception of cognition"[2]. Since the introduction of the concept of metacognition, research has focused mainly on the areas of memory, comprehension[3,4] and learning[5], while little is known about the mechanisms of metacognition in complex processes such as reasoning and problem solving. Therefore, based on the meta-memory model constructed by Nelson the concept of meta-reasoning is proposed and a meta-reasoning framework is constructed. The framework describes the process of metacognitive monitoring and control of reasoning, problem solving and decision-making tasks[6].

In order to explain how reasoners monitor and control their own reasoning activities, this paper examines accuracy as well as heuristic cues in meta-reasoning monitoring in terms of the generalities involved in the meta-reasoning framework, and examines stopping rules for effortful regulation in meta-reasoning control. It concludes with a discussion of key directions for future research.

2. The Framework of Meta-reasoning

Meta-reasoning refers to the process of monitoring and controlling complex cognitive activities such as reasoning and problem solving. Ackerman and Thompson (2017) were the first to describe the relationship between monitoring and controlling meta-reasoning based on the meta-memory model proposed by Nelson et al. The meta-reasoning framework is shown in the Figure 1. It retains the basic framework proposed by Nelson et al.[4], and also reflects the object level reasoning process, which is unique to reasoning; and the meta level reasoning process, which is shown in the right two columns, where the reasoner needs to monitor, evaluate and control the object reasoning process. In the right column, the meta level reasoning process needs to monitor, evaluate and control the object reasoning process.

Depending on the direction of information flow, the meta-reasoning process is divided into two sub-processes: meta-reasoning monitoring and meta-reasoning control. The assessment of the likelihood of task completion at the beginning or at the end of the task, which means the initial judgement of solvability (iJOS) and the final judgement of solvability (fJOS). In contrast, the assessment of the acquired solution is represented by the feeling of rightness (FOR) and the feeling of error (FOE), which explains when the reasoner will have an intuitive response and when he or she will think further. Judgement of learning (JOL) in the meta-memory domain measures an estimate of the extent to which a particular task is learned, which in turn influences subsequent learning choices[7,8]. Intermediate confidence will continue to influence one's task performance during the course of the task. Taken together, this plays an important role in explaining the so-called "reasoning bias"[9,10], and this is essentially a metacognitive phenomenon: when the strength of the reasoner's FOR is strong enough to indicate that no rethinking is required, or when the strength of the FOR is weak but strong enough to reach the reasoner's current desired goal, or when time constraints make it necessary to abandon more difficult tasks in iJOS, or when more time and effort need to be invested, then the reasoner will terminate processing prematurely[11].

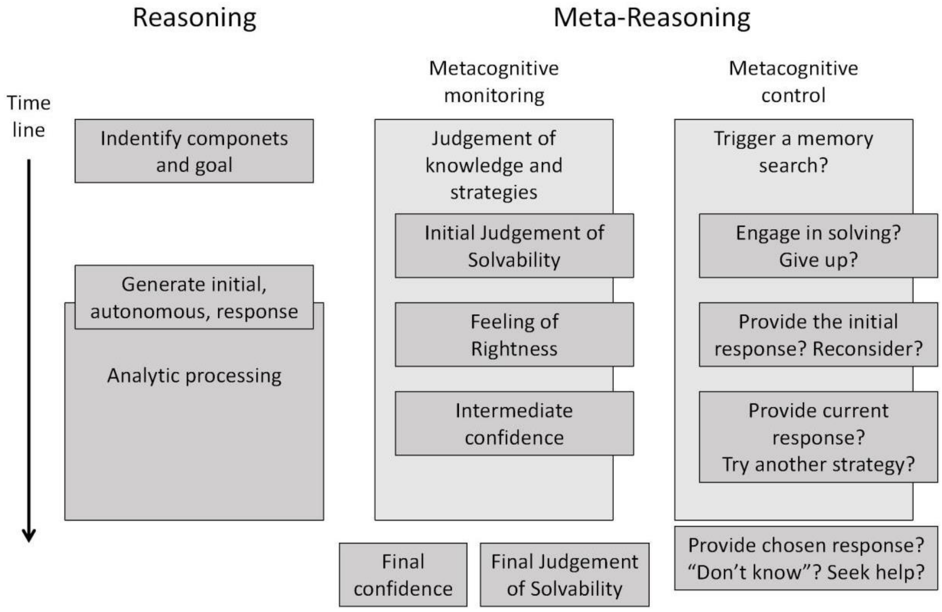

Figure 1: The framework of meta-reasoning[6]

3. Meta-reasoning Monitoring and Control

3.1 Accuracy of Meta-reasoning Monitoring: Confidence Judgements

As mentioned earlier, accurate meta-reasoning monitoring is essential for effective learning and general cognitive performance, and this confidence judgement underpins the adoption of different control behaviours, for instance, whether to continue or stop putting in effort based on the information provided by the monitoring, whether to ask for help or to provide answers[12]. Current research on self-confidence, however, focuses on the relationship between confidence judgements and actual performance in order to understand how accurately individuals monitor their own activities, which can be measured by two indicators: resolution and calibration. In previous research, discriminative ability has been measured by the correlation between confidence levels within the reasoner and answer accuracy. High correlations between confidence levels and accuracy have been found in a variety of tasks ranging from perceptual domains to problem solving, with strong discriminative ability[13,14].

Research in the areas of meta-memory and meta-comprehension has demonstrated that confidence judgements are metacognitive judgements based on heuristic cues, whereby people are unable to "read" the quality of cognitive processing directly, and instead make confidence judgements based on information gained from the task, the environment, or their own subjective experience[15,16]. Thus, the accuracy of confidence judgements depends on the value of heuristic cues[17]. In recent years some scholars have begun to investigate the heuristic cues of metacognitive monitoring in reasoning, problem solving and decision making within a meta-reasoning framework, and while most of the principles are common across a variety of domains, some of the heuristic cues can have a different impact on confidence judgements[18]. From the breadth of the metacognitive literature, heuristic cues can be categorised into three levels: self-perception, task characteristics and transient experience[19,20].

Self-perception refers to an individual's assessment of his or her own traits, abilities, or knowledge, which can be either an overall assessment or an assessment of a particular task or domain[21], specifically including cognitive needs, thought patterns, cultural background, etc. Task characteristics are information about what influences overall task performance, and cues at this level are often underestimated or overlooked[22,23]. The researcher did not reflect differences in confidence judgements through the interaction of two task features in the problem solving task: time frame and medium (done on screen versus paper)[22,24]. Transient experience as a cue at the item level is currently a major line of research involving metacognitive judgements, and a prominent heuristic cue in the field of meta-memory and meta-reasoning is answer fluency, the speed at which an initial answer is produced[25]. Unlike perceived fluency (difficulty of reading questions) [26], processing fluency reliably predicts FOR with final confidence judgements, and the effect of answer fluency on reasoning is independent of the effect of perceived fluency[27].

3.2 Meta-reasoning Control: Effort Regulation

When does monitoring the effort made based on meta-reasoning stop? What are the stopping rules that guide effort regulation? A regular finding is that people invest more time in learning difficult items[28]. This discovery led to the creation of the Discrepancy Reduction Model[3]. The model assumes that people will set a goal level based on their motivation in a given situation, a desirable level of knowledge that will satisfy their learning, and invest time in a goal-driven manner until their metacognitive judgement of knowledge reaches this preset goal[25,29]. Meta-reasoning research has shown that when people think about potential answer options, the time invested in finding a solution increases as the difficulty of the problem increases, according to the difference reduction model[8]. These models also predict that as the amount of effort invested in a particular task item increases, the confidence level rises until it reaches or exceeds the solver's pre-determined confidence target[30,31]. However, the model does not explain why some of the reasoners' confidence levels did not rise as they invested more time, which could be because a person lacked the knowledge needed to solve the problem, or simply because no acceptable solution came to mind[32]. After a long period of reflection, judgements are often made with less confidence, leading to an inverse relationship between time and confidence[25].

To explain the reasons for the above phenomenon, Koriat et al. suggest that this inverse relationship is the result of a bottom-up fluency-driven process, according to which reasoners tend to make metacognitive judgements corresponding to the effort required for each item[33]. The diminishing criterion model (DCM), on the other hand, offers a new interpretation of the relationship between time and confidence levels, emphasizing top-down effort regulation[34]. According to the model, the reasoner will abide by a stopping rule consisting of two top-down criteria, firstly the confidence criterion, which is similar to a pre-determined goal in a discrepancy reduction model, but the DCM argues that the confidence criterion is not static but decreases with time invested[10,35]. The second stopping rule is a mental time limit, reflecting the length of time the reasoner believes is reasonable to process each task, and if no solution comes to mind within that time, the reasoner will offer the best solution they can think of, even if that solution has a lower level of confidence than initially expected[11]. As a result, for items with the lowest or moderately low confidence levels, response times will peak within the time constraints[36].

4. Conclusion

In summary, meta-reasoning, as a new field distinguished from creative metacognition, is based on metamemory monitoring and control, which measures the accuracy of meta-reasoning monitoring by two indicators, namely, discriminative ability and calibration, and makes confidence judgements based on three-level heuristic cues of self-perception, task characteristics, and transient experience; and constructs the stopping rules for effort regulation, i.e., the confidence criterion and the time constraint, based on DCM. However, there are still the following issues that need to be further explored for the field of meta-reasoning.

First, heuristic cues for different confidence judgements are further explored. Although the three levels of heuristic cues explain the common basis for confidence judgements, which level of heuristic cues are more significantly influenced by a particular confidence judgement? Which cues are unique? Most of the current researchers have studied heuristic cues for iJOS and FOR judgements. A non-verbal Raven-based reasoning matrix examined heuristic cues that are unique in iJOS - nameability, the ease with which graphs can be recoded into verbal representations[37].

Second, how to improve reasoning by improving meta-reasoning processes. Confidence judgements and subsequent effort regulation are not very precise, and according to research in the field of education, learner feedback on the accuracy of confidence both improves test scores and reduces overconfidence[38]. There is now preliminary evidence that the reasoning monitoring process can be improved, for instance, Prowse et al. reduced overconfidence by training university students to solve trinomial reasoning problems, but did not improve the ability to discriminate between right and wrong reasoning answers[39].

Finally, the neural mechanisms of metacognitive reasoning need to be further investigated. Recently, anatomical, functional and neuropsychological evidence suggests that the anterior parietal network is consistently involved in metacognitive processes and activates brain regions located in the posterior medial prefrontal, ventral medial prefrontal and bilaterally prefrontal areas. Therefore, whether metacognitive monitoring and control at different stages in the domains of problem solving, reasoning and decision making is different from the domains of memory, perception and learning still needs to be thoroughly investigated.

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