Tracking memory processes during ambiguous symptom processing in sequential diagnostic reasoning

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Keywords: eye movements; process tracing; memory indexing; diagnostic reasoning; belief updating

In sequential diagnostic reasoning multiple pieces of information have to be combined to find a best explanation for observed symptoms (e.g., Johnson & Krems, 2001). Tracking memory processes involved in reasoning proves difficult because they proceed without accompanying actions towards the environment. However, this is important in order to build and test cognitive models (Schulte-Mecklenbeck, Kühberger, & Ranyard, 2011). Memory indexing is a novel method to study the time course of information processing in memory during reasoning and decision making (Jahn & Braatz, 2014; Renkewitz & Jahn, 2012) by recording eye movements. The basic principle underlying memory indexing is that people look at an emptied spatial location when retrieving information that has been associated with the spatial location during encoding (e.g., Richardson & Spivey, 2000). We use memory indexing to reveal memory dynamics in sequential diagnostic reasoning in order to test process assumptions derived from cognitive models on reasoning and belief updating.

We study sequences of symptoms, for which more than one diagnosis is possible. Reasoners strive for a coherent interpretation of symptoms (Kostopoulou, Russo, Keenan, Delaney, & Douiri, 2012). When two diagnoses compete, coherence can be achieved by *biased interpretation of symptoms* that increases the belief in one hypothesis while decreasing the belief in alternatives (Holyoak & Simon, 1999; Mehlhorn & Jahn, 2009). Maximizing coherence often favors the initially leading hypothesis. But it can strengthen an alternative when stronger evidence for an alternative hypothesis has accumulated. Then, a *hypothesis change* takes place.

In this study, we test process assumptions of coherence maximization, i.e. biased symptom processing towards the leading hypothesis or hypothesis change, by applying memory indexing and presenting participants with ambiguous symptom sequences, for which coherence maximization over the course of symptom processing can favor one or the other diagnosis. The biases in symptom processing preventing or inducing a hypothesis change should be revealed by participants' gaze behavior.

Method

The study consisted of a learning phase and a subsequent reasoning phase. During the learning phase, participants acquired the knowledge needed for the reasoning phase. The reasoning task was to determine the most likely cause of a patient's symptoms. The patients were workers in a chemical plant that produces four chemicals and each worker was affected by exactly one of those chemicals (Mehlhorn, Taatgen, Lebiere, & Krems, 2011).

Participants

Thirty-two students (21 female, M_{age} = 22.4, range: 19-39 years) from Technische Universität Chemnitz participated in the study.

Apparatus and Material

An SMI RED remote eye tracker sampled data of the right eye at 120 Hz in a laboratory setting.

Four chemicals were assigned to screen quadrants (Fig. 1). Each quadrant enclosed three rectangular frames, which contained

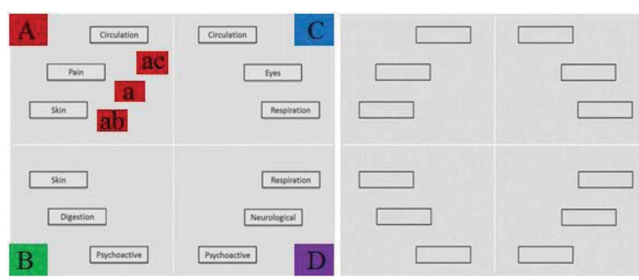

Figure 1: Left: Spatial arrangement of chemicals (A, B, C, D) and symptom classes (e.g., a, ac, ab) as presented during learning. Right: Emptied spatial arrangement during the reasoning phase.

three symptom classes that the respective chemical could cause. For example, the chemical at the top left caused symptoms from the symptom classes circulation, pain, and skin. One symptom class was unique (pain for the top left chemical, denoted with single small letters, e.g., a) and two symptom classes were shared with other chemicals (denoted with two small letters, e.g., ab).

Procedure

In the learning phase, participants first learned how symptoms were assigned to symptom classes and second how symptom classes related to chemicals. Associations between symptom classes and chemicals were established by presenting symptom classes in rectangular frames in the screen quadrants that each represented one chemical (Fig. 1, left side). During reasoning, symptoms were presented auditorily while participants only saw the emptied rectangular frames (Fig. 1, right side). Eye movements were recorded throughout the reasoning phase. The diagnostic decision was collected at the end of the reasoning trial.

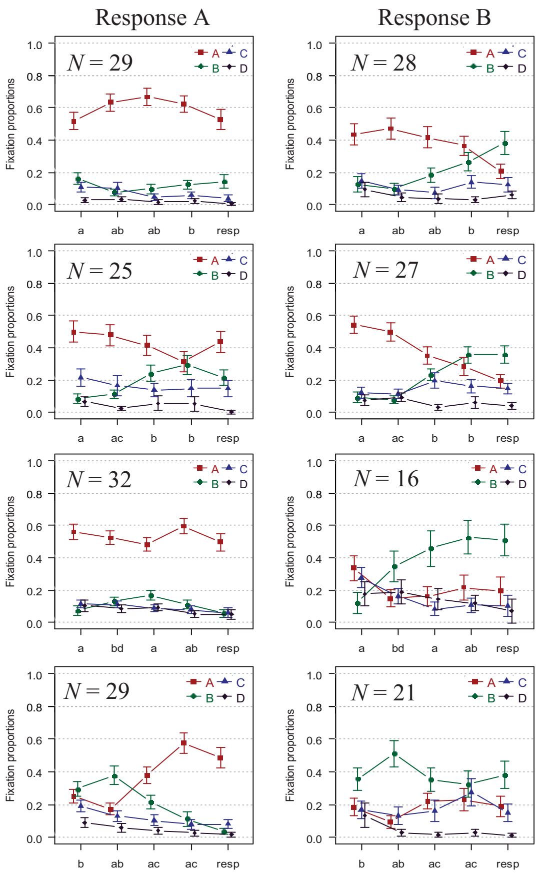

Figure 2: Mean proportion of fixation times in each interval that fell upon the A-, B-, C-, or D-quadrants for four ambiguous symptom sequences and A- and B-responses. Error bars represent standard errors.

Results and Discussion

For the analyses of eye movements, four areas of interest (AOIs) were defined corresponding to the four quadrants representing the four chemicals. The AOIs were denoted A, B, C, and D according to the four chemical roles. Each trial was divided in five time intervals defined by the onsets of each of the four symptom presentations and the response interval. For each of the five intervals and each AOI, we computed the proportion of total fixation time in the four AOIs separately for each symptom sequence, each participant, and by diagnostic response.

Fig. 2 shows plots of mean fixation proportions of four exemplary symptom sequences. There are separate plots for trials with A-, and B-responses. The sequences in Fig. 2 are ordered from top to bottom according to the number of consecutive symptoms that supported the A-hypothesis from the beginning of the sequence onward.

Fixation proportions after the *first symptom presentation* reflected which hypothesis was supported. During *subsequent symptom intervals* fixation proportions increased towards the most likely hypothesis given the subjective interpretation of symptoms in the symptom sequence. After strong evidence for an alternative hypothesis had accumulated, fixation proportions revealed a hypothesis change for B-responses in sequences starting with an a-symptom and for A-responses in the sequence starting with a B-symptom. Fixation proportions during the *response interval* reflected which hypothesis was chosen.

Eye movements as revealed by applying memory indexing to the study of sequential diagnostic reasoning of ambiguous symptom sequences reflect the reasoners' tendency to strive for coherence in interpreting new information. Studying eye movement behavior will inform existing computational models on reasoning and decision making and enhance the understanding even of memory-based reasoning processes.

Acknowledgments

This research was supported by German Research Foundation (DFG) grants KR 1057/17-1 and JA 1761/7-1. The authors would like to thank Ricarda Fröde and Claudia Dietzel for their help in conducting the experiment.

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