Cognitive Psychology 96 (2017) 54–84

Contents lists available at ScienceDirect

Cognitive Psychology

journal homepage: www.elsevier.com/locate/cogpsych

Diagnostic causal reasoning with verbal information ☆

Björn Meder [a,*,1], Ralf Mayrhofer [b,1]

[a] Max Planck Institute for Human Development, Center for Adaptive Behavior and Cognition, Lentzeallee 94, 14195 Berlin, Germany
[b] Department of Psychology, University of Göttingen, Gosslerstraβe 14, 37075 Göttingen, Germany

ARTICLE INFO

Article history:
Accepted 25 May 2017
Available online 15 June 2017

Keywords:
Diagnostic reasoning
Causal reasoning
Bayesian models
Order effects
Verbal uncertainty expressions
Verbal reasoning

ABSTRACT

In diagnostic causal reasoning, the goal is to infer the probability of causes from one or multiple observed effects. Typically, studies investigating such tasks provide subjects with precise quantitative information regarding the strength of the relations between causes and effects or sample data from which the relevant quantities can be learned. By contrast, we sought to examine people's inferences when causal information is communicated through qualitative, rather vague verbal expressions (e.g., "*X* occasionally causes *A*"). We conducted three experiments using a sequential diagnostic inference task, where multiple pieces of evidence were obtained one after the other. Quantitative predictions of different probabilistic models were derived using the numerical equivalents of the verbal terms, taken from an unrelated study with different subjects. We present a novel Bayesian model that allows for incorporating the temporal weighting of information in sequential diagnostic reasoning, which can be used to model both primacy and recency effects. On the basis of 19,848 judgments from 292 subjects, we found a remarkably close correspondence between the diagnostic inferences made by subjects who received only verbal information and those of a matched control group to whom information was presented numerically. Whether information was conveyed through verbal terms or numerical estimates, diagnostic judgments closely resembled the posterior probabilities entailed by the causes' prior probabilities and the effects' likelihoods. We observed interindividual differences regarding the temporal weighting of evidence in sequential diagnostic reasoning. Our work provides pathways for investigating judgment and decision making with verbal information within a computational modeling framework.

1. Introduction

The present paper investigates diagnostic causal reasoning with verbal expressions. Natural language contains a plethora of verbal terms for expressing various kinds of uncertainty, such as "frequently," "rarely," "likely," and "probably." In many real-world situations, such linguistic terms are used to communicate probability or frequency information, despite (or because of) the apparent lack of precision. A doctor says that "disease *X* frequently causes symptom *A*," a friend remarks that he "lost weight because of exercising often," and the news states that "car accidents are almost never caused by bad weather

☆ Experiment 1 was presented at the 2013 Annual Meeting of the Cognitive Science Society (Meder & Mayrhofer, 2013); Behavioral data can be downloaded from https://osf.io/gc2nd/.

* Corresponding author.
E-mail addresses: meder@mpib-berlin.mpg.de (B. Meder), rmayrho@uni-goettingen.de (R. Mayrhofer).

[1] Björn Meder and Ralf Mayrhofer contributed equally to this research and share first authorship on this paper.

http://dx.doi.org/10.1016/j.cogpsych.2017.05.002
0010-0285/

alone." Oftentimes, people also need to make inferences and decisions based on such rather vague expressions, for instance, because precise quantitative information is not available or not communicated. One example are law suits, where the prosecution or the defense may present several pieces of evidence in a sequential fashion, such as eyewitness reports or forensic analyses. Each datum may speak for or against the defendant, and the sequential nature of the task requires keeping track of the relative plausibility of the hypotheses under consideration, given the evidence obtained so far. Similarly, a doctor may make diagnostic inferences based on a series of symptoms reported by a patient, such as a headache, dizziness, and vomiting. Knowing that a particular disease frequently causes these symptoms, whereas another disease rarely does, will increase the probability of the former, even though no precise numerical estimates may be available for quantifying the inference.

Although verbal uncertainty expressions are ubiquitous, they do not easily fit with computational models of cognition, which usually require numerical input. Most behavioral studies therefore provide subjects with precise quantitative information, which enables researchers to derive predictions from formal models. For instance, causal reasoning studies typically provide subjects with described numerical information, such as percentages or frequencies (e.g., Hayes, Hawkins, Newell, Pasqualino, & Rehder, 2014; Krynski & Tenenbaum, 2007; Rehder & Burnett, 2005) or sample data (e.g., Mayrhofer & Waldmann, 2015; Meder, Mayrhofer, & Waldmann, 2014; Rottman, 2016; Waldmann & Holyoak, 1992). In contrast, we investigated diagnostic causal inferences from effects to causes based on verbal terms and compared human judgments to those of a matched control group receiving precise numerical information. Our research was motivated by the rich literature on how people understand verbal frequency and probability expressions, and the numerical estimates they assign to different terms (for reviews, see Clark, 1990; Mosteller & Youtz, 1990; Teigen & Brun, 2003; Wallsten & Budescu, 1995). For the present studies, the mapping between words and numbers was provided by a study that elicited numerical estimates for several frequency terms (Bocklisch, Bocklisch, & Krems, 2012). This mapping provided the basis for our comparison of diagnostic reasoning with verbal versus numerical information. We also used the numerical equivalents to derive quantitative predictions from different probabilistic models of diagnostic reasoning.

We investigated three key issues. First, can people make sound diagnostic causal inferences with verbal information? Second, how do they perform relative to a matched control group in which subjects are provided with the corresponding numerical information? Third, what model accounts best for people's judgments in sequential diagnostic reasoning, that is, when inferences are based on multiple, sequentially observed pieces of evidence?

To address these questions, we conducted three experiments in which the subjects' task was to infer the probability of a binary cause (chemical *X* vs. chemical *Y*) from three sequentially observed effects (symptoms such as dizziness or headache). Subjects received either numerical information on the relevant quantities (e.g., the likelihoods of effects; e.g., "chemical *X* causes headache in 66% of cases") or only verbal information (e.g., "chemical *X* frequently causes headache"). Experiments 1 and 2 employed different verbal terms to convey the strength of the cause–effect relations, using a uniform prior over the two causes [i.e., $P(X) = P(Y) = 0.5$]. In Experiment 3, we additionally manipulated the prior probability of the two causes and conveyed base rate information through either verbal terms or numerical information.

We compared subjects' diagnostic judgments to different computational models whose predictions were derived from the numerical equivalents of the verbal expressions used (Bocklisch et al., 2012). The simplest model is based on standard Bayesian inference, which can be used to derive the posterior probabilities of the causes given the evidence available at each time step. This approach, however, is not sensitive to the potential temporal dynamics of belief updating (e.g., primacy or recency effects). We therefore developed a novel Bayesian model that allows for a differential weighting of earlier or more recent evidence. This model also enabled us to investigate interindividual differences regarding the temporal weighting of evidence in sequential diagnostic reasoning, both in the aggregate and on a subgroup level.

1.1. Mapping words to numbers

Several studies have investigated how people understand linguistic expressions of uncertainty, with research dating back to at least the 1940s and 1950s (Cliff, 1959; Lichtenstein & Newman, 1967; Simpson, 1944, 1963; Stone & Johnson, 1959; for reviews see Clark, 1990; Mosteller & Youtz, 1990; Teigen & Brun, 2003; Wallsten & Budescu, 1995). Typically, subjects are presented with different verbal frequency or probability terms (e.g., "frequently," "likely") and are asked to assign a numerical estimate to each expression (e.g., a percentage or frequency estimate). Key issues of interest include within-subject and between-subjects stability and variability in numerical estimates (e.g., Brun & Teigen, 1988; Budescu & Wallsten, 1985; Dhami & Wallsten, 2005; Simpson, 1963), influence of context and considered events (e.g., Harris & Corner, 2011; Wallsten, Fillenbaum, & Cox, 1986; Weber & Hilton, 1990), different elicitation methods (e.g., Hamm, 1991; Wallsten, Budescu, Rapoport, Zwick, & Forsyth, 1986; Wallsten, Budescu, & Zwick, 1993), and alternate ways of formally modeling the representation of verbal terms (e.g., Reagan, Mosteller, & Youtz, 1989; Wallsten, Budescu et al., 1986; Zadeh, 1975).

Although research shows that the perceived meaning can vary depending on context, elicitation method, or as a function of individual differences, the literature also indicates a relatively stable understanding of verbal uncertainty terms. For instance, Simpson (1963) compared the numerical estimates elicited for several frequency terms to an earlier study he conducted in 1944 with a different subject sample and found a remarkably close correspondence: "For only one word, *sometimes*, was the difference greater than five percentage points, and in over one-third of the terms the percentages are identical" (p. 149; his emphasis). Mosteller and Youtz (1990) analyzed 52 verbal expressions examined in 20 different studies and concluded that "the studies give similar, though not identical, results for the same expression when sampling and