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Proficiency of FPPI and objective numeracy in assessing breast cancer risk estimation☆

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ABSTRACT

Two studies examined the effectiveness of the Fuzzy Processing Preference Index, (FPPI) an individual differences measure of base rate neglect/respect, and an objective numeracy scale in predicting subjective probabilities of the likelihood of breast cancer, BRCA mutations, and the conditional probability of breast cancer given BRCA mutations in medical risk scenarios. FPPI and objective numeracy independently predicted estimate accuracy for breast cancer and genetic mutation risk. Surprisingly, objective numeracy positively correlated with overestimating conditional probabilities across the board, as well as BRCA mutations and breast cancer risk for high-risk scenarios. FPPI was strongest in predictions for high-risk scenarios, but did not predict conditional probability estimates. FPPI uniquely predicts risk estimation accuracy controlling for objective numeracy suggesting the two measures assess distinct cognitive processes. We conclude that FPPI and other numeracy measures may be profitably used together, and FPPI appears better than traditional numeracy measures in some medical decision-making contexts.

1. Introduction

Subjective probability plays a vital role in our everyday decision making process (Kahneman & Tversky, 1974). Many choices we make, conclusions we reach, and actions we take are influenced by how likely we think an event might be. For instance, a woman who believes she has a high probability of developing breast cancer may be more likely to seek more frequent mammograms, and a woman who believes she is likely to carry a mutation in the BRCA1 or BRCA2 genes may be more likely to undergo genetic testing. Yet communicating numerical risk is challenging for health care providers (Brust-Renck, Royer, & Reyna, 2013). The goal of this research is to investigate factors that contribute to more accurate estimates of probabilities involving breast cancer risk.

One of the most pertinent ways in which subjective probability estimation impacts our everyday lives is when we estimate risk (Kahneman & Tversky, 1979; Weber, 1994). Assessing how dangerous a situation is or weighing the pros and cons of a choice can have life-altering consequences, particularly when the person making the decision is not well-informed. This is especially true in medical decision making where inadequate information or an inability to understand that information could lead to potentially fatal decisions (Gigerenzer & Edwards, 2003; Reyna, Nelson, Han, & Pignone, in press). Digital technologies can provide people with an estimate of their personal risk of medical illness. For instance the Breast Cancer Risk Assessment Tool on the National Cancer Institute's (NCI) website is an interactive tool based on the Gail Model which estimates an individual's risk of invasive breast cancer (Breast Cancer Risk Assessment Tool., 2015). This is a valuable resource, but people often fail to understand what that risk means in practical terms. Such tools are often best used in concert with medical advice or tools that help the patient understand what the bottom-line meaning of the risk is.

The importance of accurately estimating risk in a medical context is aptly demonstrated by the difficulties people encounter when assessing breast cancer risk. Breast cancer is a serious issue that affects many people today. The National Cancer Institute estimates that approximately 1 in 8 women will develop breast cancer at some point during their lives (Breast Cancer Risk in American Women, 2014), and in just the past year 40,000 women and 430 men have died from breast cancer in the United States alone (Breast Cancer, 2014). Due to recent medical advances and the availability of the internet, a lot of information about breast cancer is widely available to the public, though it is typically not presented in a format understandable to most people (Brust-

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Renck et al., 2013). Despite the benefits that information about breast cancer might bring to everyday people, many people lack the ability to fully understand the information they are given. For instance, understanding their own risk for breast cancer often involves complicated processes such as interpreting base-rates, joint-probabilities (Wolfe & Reyna, 2010a, 2010b), or conditional probabilities (Wolfe, Fisher and Reyna, 2012; Wolfe, Fisher, Reyna and Hu, 2012) as well as comparing risks and understanding fractions, percentages, decimals, and frequencies (Reyna, Nelson, Han, & Dieckmann, 2009). Thus, the ability to understand numerical information and relationships between numbers is key in estimating medical risk.

Recent research on individual differences in judgment and decision making (Reyna et al., 2009) suggests that some people are better able than others to interpret the numerical information necessary to estimate their risk of breast cancer. The probability judgments these people make often have better correspondence to objective values (or best estimates of those values) and coherence (internal consistency) than judgments of people who are less numerate. Identifying these people and understanding what gives them this advantage has immediate implications for improving how medical information is presented, and how we can help people make informed choices about risk (Nelson, Reyna, Fagerlin, Lipkus, & Peters, 2008; Reyna & Farley, 2006).

Our ability to understand and use numerical information is known as numeracy (Ancker & Kaufman, 2007; Nelson et al., 2008). Although numeracy plays an important role in estimating medical risk, national surveys estimate that about half of the population of the United States has no more than a rudimentary ability to deal with quantitative information (Reyna & Brainerd, 2007). In the medical world, patients with low numeracy are especially prone to framing and formatting effects (Peters, Dieckmann, Dixon, Hibbard, & Mertz, 2007; Peters, Hart, & Fraenkel, 2011), and overestimating their own risk of cancer (Schwartz, Woloshin, Black, & Welch, 1997; Davids, Schapira, McAuliffe, & Nattinger, 2004). This high perception of cancer risk can then, in turn, lead to higher screening rates which may be generally beneficial so long as false positives are understood and managed appropriately (Champion, 1991; McCaul, Branstetter, Schroeder, & Glasgow, 1996; Jirojwong & MacLennan, 2003; Nelson, Huffman, Fu, & Harris, 2005). Additionally, incorrect beliefs about cancer risk can in turn lead to damaging behaviors such as worse self-care (Reyna et al., 2009; Wolf, Gazmararian, & Baker, 2005). Thus, it is critical for both a person's physical and emotional wellbeing to understand how to accurately estimate individual cancer risk.

Aside from the standard numerical pitfalls in risk assessment, there are often even more complicated numerical relationships involved in medical decision making. For example, understanding conditional probabilities, such as the chance of getting breast cancer given a genetic BRCA mutation, can further complicate the decision making process. Research has shown that even individuals with high levels of numeracy can struggle with these types of difficult concepts (Portnoy, Roter, & Erby, 2010; Peters, McCaul, Stefanek, & Nelson, 2006; Reyna et al., 2009; Wolfe, 1995; Wolfe, Fisher, Reyna, & Hu, 2012; Wolfe, Fisher and Reyna, 2012). These difficulties further emphasize the need to help patients understand complicated information given to them in order to make informed medical choices.

Numeracy has historically been defined and measured in several different ways. However it has been argued that numeracy scales have been developed without adequate theoretical grounding (Liberali, Reyna, Furlan, Stein, & Pardo, 2012; Reyna & Brust-Renck, 2014). When measuring numeracy in relation to how it predicts medical risk assessment, the expanded numeracy scale (Greene, Peters, Mertz, & Hibbard, 2008; Hibbard, Peters, Dixon, & Tusler, 2007; Peters et al., 2007) presents a good example of a numeracy scale that is both valid and reliable. This scale was originally adapted from the numeracy scale created by Lipkus, Samsa, and Rimer (2001), and performance on this scale has been linked to better comprehension of treatment options, hospital choices, and other health-related decisions (Peters et al., 2007). It is important to differentiate measures of numeracy like this with measures of education and intelligence. Although these variables have been shown to be related (e.g., Reyna & Brainerd, 2007), research assessing numeracy in highly educated individuals still found significant deficits in numerical decision making (Lipkus et al., 2001; Woloshin, Schwartz, Moncur, Gabriel, & Tosteson, 2000), suggesting numeracy is a unique factor in accurate medical decision making.

A more recent measure of one aspect of numeracy is the fuzzy processing preference index (FPPI; Wolfe & Fisher, 2013). The FPPI measures an individual's ability to integrate quantitative base-rates and qualitative verbal information in order to estimate subjective probabilities. Wolfe and Fisher (2013) demonstrated that those participants who tended to incorporate quantitative base-rates into their judgments were more accurate in their probability estimations. Data from both laboratory experiments and web-based studies indicate that the FPPI has good psychometric properties, with Cronbach's Alpha ranging between .91 and .96 in several experiments, indicating reliability, and validity suggested by significant correlations with “Rule Based” Process Dissociation Procedure scores; the number of conjunction fallacies in joint probability estimation; and logic index scores on syllogistic reasoning tasks (Wolfe & Fisher, 2013).

Development of the FPPI was guided by fuzzy trace theory (FTT), a dual-processing theory of judgment and decision making (Reyna, 2008; Reyna, 2012; Wilhelms & Reyna, 2013). A central tenet of FTT is that when we process information we simultaneously encode multiple traces of that information along a continuum ranging from broad, meaning-based gist traces, to detailed but superficial verbatim traces (Reyna, 2008). According to FTT people have a fuzzy processing preference in that they prefer to reason with the simplest gist representation of the information possible (Wolfe, 1995; Brainerd & Reyna, 2001; Reyna, 2012). Interestingly, research has shown that instead of an inferior system, gist processing is in many ways adaptive and a prototype of mature, expert reasoning (Reyna & Casillas, 2009; Reyna & Farley, 2006; Reyna, 1996; Reyna & Lloyd, 2006). Critically, FTT claims that successful judgment and decision making depend on forming an appropriate understanding of the gist of the information and knowing what verbatim details are important to incorporate (Reyna, 2008).

When assessing the quality of probability judgments there are two different components that contribute to the value of the judgment: correspondence and coherence. Correspondence refers to the empirical accuracy of the judgment made in relation to objective probabilities, which can be further broken down into measures of accuracy (Yates, Lee, Shinotsuka, Patalano, & Sieck, 1998) and calibration (Keren, 1991). Coherence refers to internal consistency among judgments made by the same individual and logical fallacies rather than empirical accuracy (Hammond, 2000; Wolfe, Fisher, & Reyna, 2012). Much of our previous research has focused on coherence (Fisher & Wolfe, 2011; Wolfe, Fisher, & Reyna, 2012; Wolfe, Fisher, Reyna, & Hu, 2012; Wolfe & Reyna, 2010a, 2010b) and the present work assesses probability estimation accuracy – the correspondence between subjective and objective probabilities of breast cancer risk.

The present research was embedded in two larger studies aimed at developing and testing an Intelligent Tutoring System (ITS) designed to educate people on breast cancer and genetic risk. This particular study, however, focused on the relation between different individual difference measures of numeracy and participants' ability to estimate risk. We looked at the predictive power of both an objective numeracy scale and FPPI on accuracy in assessing the risk of breast cancer, genetic mutation, and the conditional probability of breast cancer given a mutation in 12 scenarios vetted by a medical expert. In order to measure our dependent variables, participants interacted with an ITS called BRCA Gist or one of two control conditions (see Wolfe, Reyna, Brust-Renck, et al., 2014; Wolfe, Reyna, Widmer, et al., 2014 for a review of these conditions and their effectiveness).

Our first hypothesis was that high levels of objective numeracy would predict more accurate probability estimates, but that high FPPI