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Numeracy, numeric attention, and number use in judgment and choice

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Abstract

People higher (vs. lower) in objective numeracy—the ability to use probabilistic and mathematical concepts—use numeric information more when making decisions. Specifically, they are more sensitive to numeric levels than the less numerate and use more numeric versus nonnumeric information. Greater attention to numbers may explain this effect, but little is known about objective numeracy's relation to numeric attention and possible subsequent effects on choice. Therefore, we investigated whether numeracy is related to greater attention to numbers and greater use of numbers in consumer judgments and choices. Crucially, we tested whether numeric attention mediated number use in choices. In three experiments, we provided participants with information about different consumer products (e.g., dishwasher). Participants received either numbers-only or both numbers and verbal information. In Study 1 ($N = 548$), participants were asked to rate product attractiveness. In Studies 2a and 2b ($N = 187$ and 399), participants instead chose between product pairs. Attention was recorded using Mouselab. Greater objective numeracy was not related to sensitivity to numbers, but it was related to using numeric (instead of verbal) information more when making choices. The association of numeracy and attention was inconsistent across studies, although a meta-analysis combining the studies revealed a weak but significant relation between numeracy and frequency of attending to numbers. This attention variable mediated the association of numeracy and number use in the more powered Study 2b (but not 2a). Our research highlights the potential of considering attention when studying numeracy and provides insights for designing decision aids.

KEYWORDS
attention, evaluative categories, Mouselab, number use, numeracy, process tracing

1 | INTRODUCTION

We often need to use numeric information to make good judgments and decisions. However, understanding, interpreting, and using numbers require objective numeracy—the ability to understand and use probabilistic and numerical concepts (Peters et al., 2006). Consistent with greater numeracy leading to better judgments and decisions, more numerate people tend to be healthier and wealthier than the less numerate, even after controlling for other cognitive abilities and demographic variables (Banks et al., 2011; Estrada-Mejia et al., 2016; Estrada-Mejia et al., 2020; Garcia-Retamero et al., 2015; J. P. Smith et al., 2010). In the present paper, we focus on understanding psychological processes underlying the effects of numeracy on judgment and choice.

Although recent research has demonstrated that attention to options affects choices (e.g., Krajbich et al., 2010; Krajbich & Rangel, 2011), relatively little research exists examining attention's role in the effects of numeracy on judgment and choice. In particular, no known research directly tests whether attention to numbers mediates the relation between objective numeracy and the use of numeric information. In three studies, we investigated whether those higher in numeracy use numbers more than the less numerate and pay more attention to numbers in judgments and decisions. Crucially, we analyze whether attention explains any association between numeracy and number use. Understanding how numeracy is related to attention is important for three reasons. First, it is interesting in its own right, as it can explain the processes connecting numeracy to better decision making. Second, it has practical implications for decisions made by consumers, patients, and stake holders; we need to know more about the pre-decisional processes which underlie superior decision making in those with higher numeracy. Third, this knowledge can be used to improve decision making of especially the less numerate people that are at risk of making less optimal decisions.

1.1 | Using numbers

People higher in objective numeracy use numeric information more in judgments and decisions than those lower in objective numeracy, both in terms of using numeric information when numeric and non-numeric information are available and being more sensitive to numeric information. For example, highly numerate patients judged the benefits of a cancer treatment as higher when its numeric survival statistics were higher than lower; the less numerate were relatively insensitive to these statistics (Lipkus et al., 2010). Less numerate people instead rely on nonnumeric, even sometimes irrelevant, information. For example, in numeric tasks, people lower in objective numeracy were more influenced by task-irrelevant affect than those higher in objective numeracy (Peters, 2012; Traczyk & Fulawka, 2016). Further, when people were asked to judge risks after being presented with numerical risks and anecdotal, narrative information (e.g., about individuals' experiences), more numerate people based their judgments more strongly on the numeric information, whereas judgments of the less numerate were more strongly affected by less reliable narrative information (Betsch et al., 2015; Dieckmann et al., 2009; Obrecht & Chesney, 2016). Finally, people higher (vs. lower) in objective numeracy were more sensitive to both outcomes and probabilities in risky choice (Pachur et al., 2018; Patalano et al., 2015). Although greater number use is generally beneficial, researchers also have designed tasks in which the highly numerate overuse numbers, making worse judgments as a consequence of unnecessary, irrelevant numeric operations (Kleber et al., 2013; Peters et al., 2006, 2019).

This greater number use by the highly numerate may be due to their ability to better evaluate the goodness or badness of numbers (Peters et al., 2009; Zikmund-Fisher, 2019). For instance, studies have shown that people higher (vs. lower) in numeracy were better at understanding numeric information provided by nutrition labels (Mulders et al., 2018; Rothman et al., 2006). However, to ease product comparisons, verbal and color labels often accompany numeric values and describe how good or bad the numeric information is. Examples include front-of-package nutrition labels with traffic-light colors for foods, Consumer Reports Ratings, and energy efficiency labels on nonfood products (e.g., the energy efficiency of a larger refrigerator consuming 150 kWh/year could be labeled as 'good' or 'A++'). Note that henceforth we use the term *labels* to refer specifically to verbal evaluations of numeric information. In one field study, adding traffic-light labels to menu descriptions helped less numerate people to reduce calorie consumption, whereas presenting only numbers reduced consumption for the highly numerate (VanEpps et al., 2016). Besides this study and Peters et al. (2009), little is known about how numeracy relates to number use when numbers are accompanied by verbal evaluative labels.

Evaluative categories can increase understanding of numerical information and allow more intuitive processing of information (Dieckmann et al., 2012; Liu et al., 2020; Peters et al., 2009). These labels could facilitate decisions especially among those lower in numeracy who struggle when only numeric information is available. For example, in one study, participants were asked to rate the attractiveness of a hospital after providing them with performance on three indicators, either using only numbers or both numbers and evaluative labels (Peters et al., 2009). In that study, providing evaluative labels led to an increased use of numeric information and a greater focus on more relevant attributes when judging attractiveness. In this case, the addition of evaluative labels helped more and less numerate people similarly (although it also led to less reliance on irrelevant current mood states among the less numerate). The labels' effect may have been similar for people varying in numeracy because although all numeric values used in their study ranged from 0 to 100, the health insurance and hospital attributes and their associated values were relatively unfamiliar, making it difficult to use the numbers without assistance.

In daily consumer judgments and choices, many numeric values (e.g., 150 kWh/year) are not easily interpreted due to a lack of prior knowledge, varying ranges, and unfamiliar units. Especially when numeric product information is presented in unfamiliar units, people are less sensitive to this information than when compared with standard units (Herberz et al., 2020; see also Study 1 of Peters et al., 2009). No known research has investigated whether evaluative labels increase the use of numeric information in judgments with such difficult-to-evaluate numeric values and whether any effect might differ by numeric skills. In Study 1, we examine whether evaluative labels would help those with lower numeric ability more than those with higher ability when the numbers are hard to evaluate because they vary in ranges and units between and within products, as typical in consumer judgment and choice. However, this hypothesis requires that, despite the difficulty of the values, people have at least some knowledge about the attributes.

Evaluative labels are intended to ease the interpretation of numbers, but they can also distort or conceal numeric values and differences. For example, when two similar values (e.g., 74% and 76%) slightly deviate from the category cutoff (75%), they might receive different evaluations (e.g., fair and good, respectively) and, thus, be judged quite differently. Conversely, numeric values that are further apart but in the same category may receive the same verbal rating and be judged similarly. In one example, participants were asked to choose between health-care plans that differed on two attributes. Although the options were about equally preferred when only numeric values were provided, in the condition with additional evaluative categories, the option that included an attribute in a 'better' category was preferred significantly more (Study 2, Peters et al., 2009). Thus, evaluative labels shifted choice proportions. However, this study could not test directly what information participants used and how this reliance depended on numeracy. Therefore, in the present Studies 2a and 2b, we investigated how objective numeracy related to which type of information people use for their decisions when numeric and verbal information is provided. Based on previous research, we expected that more numerate would rely more on numeric (vs. verbal) information in choice, whereas the less numerate would use nonnumeric, verbal information more.

1.2 | Numeracy and attention

Research on numeracy's effects on judgment and choice has focused primarily on behavioral outcome measures such as choices, with less focus on the processes underlying these effects. For instance, a growing body of research has demonstrated that attention to available options and attributes can partially explain choice behavior. Specifically, in value-based decisions, people tend to choose options at which they look longer (Krajbich et al., 2010; Krajbich & Rangel, 2011). In risky choices, they are also more sensitive to information to which they allocate more attention (Pachur et al., 2018). In addition, studies on risk communication have found that allocating more attention to the relevant parts of a risk communication can improve risk understanding (Garcia-Retamero & Cokely, 2017; Keller, 2011; Keller & Junghans, 2017). Thus, studying the role of attention in the effect of numeracy on the use of numbers appears to be a valuable avenue towards understanding how people make judgments and decisions.

Currently, limited empirical research exists on how numeracy relates to attention to numeric information (Peters, 2020). People who are more (vs. less) numerate deliberate longer in decisions involving numbers (Ghazal et al., 2014; Petrova et al., 2016) and are more inclined to work with numbers (e.g., by comparing them; Peters et al., 2019). Further, more (vs. less) objectively numerate people sample more numerical information in experience-based risky choices (Ashby, 2017; Lejarraga, 2010; Traczyk et al., 2018). Together, these findings suggest that people higher in objective numeracy might also attend more to numerical information. In fact, in one study, among participants choosing between risky options, those higher (vs. lower) in objective numeracy looked more often and longer at payoff amounts (in dollars) and probabilities (Jasper et al., 2017). In contrast, in another risky choice study, no association existed between numeracy and attention to outcomes and probabilities (Pachur et al., 2018). These studies examined attention in the domain of risky choice and provided numerical information only. Thus, it is unclear what result may hold in consumer decision making with certainty and that includes numbers with and without evaluative labels as well as other types of information such as pictures. Because to date little empirical knowledge exists on the association of numeracy and attention to numbers, the goal of the present research is to gain further insights into the role numeric attention plays in judgment and choice.

1.3 | The mediating role of attention

Any numeracy-related allocation of attention, in turn, may affect information use and, thus, choices. For example, more attention to information increases its use in choices between risky gambles (Pachur et al., 2018). In their Study 1, Pachur et al. (2018) found that the more attention participants allocated to outcomes and probabilities, the more sensitive they were to outcomes and probabilities, respectively. In Study 2, they demonstrated the causal effect of attention on sensitivity to probabilities and outcomes by manipulating attention experimentally (see also Armel et al., 2008). Other studies have shown similar effects. For example, in eye-tracking studies, participants first rated the value of food items or attributes and then made choices. The more people looked at an option or attribute before deciding, the more its rated value related to choice (Fisher & Rangel, 2020; Krajbich et al., 2010; Krajbich & Rangel, 2011; S. M. Smith & Krajbich, 2019). Taken together, the research suggests that the more people focus attention on information, the more they will use it to judge and decide.

Thus, if objective numeracy is associated with attention to numbers and attention, in turn, is associated with a stronger use of information, attention may play a crucial role in explaining numeracy's relation to the use of numbers. Therefore, we examine in an exploratory analysis whether attention to numbers mediates the relation between objective numeracy and use of numbers. Greater objective numeracy may lead to more use of numbers at least partly through greater attention to numbers, a novel empirical test.

Hence, pinpointing the role of attention to numbers in the effects on numeracy on judgment and choice may contribute to our understanding of why more numerate people make better health and financial decisions than less numerate ones. Further, these insights may help scientists and practitioners to develop decision aids that assist people, and perhaps especially the less numerate, to make better decisions in medical, financial, and consumer-product domains.

1.4 | Current research and hypotheses

We conducted three studies in which we provided only numeric information or both numeric and verbal information about products. In Study 1, participants rated the attractiveness of products based on provided information. In Studies 2a and 2b, participants provided with pairs of products were asked which one they preferred. All studies were approved by the Institutional Review Board of The Ohio State University.

In all studies, we measured attention using Mouselab methodology (Payne et al., 1993). In it, all pieces of information were initially hidden behind labeled boxes and participants could open a box by moving the mouse cursor over it. As soon as the cursor left the box, the information was hidden again. Thus, participants could acquire only one piece of information at a time. This methodology allowed us to track how often participants acquired different types of information (i.e., number of acquisitions) and how much time they spent looking at them (i.e., attention time). Accordingly, we examined both the number of acquisitions of and time attended to numeric information. Mouselab has been widely and successfully used to measure attention in judgments and decisions (for an overview, see Willemsen & Johnson, 2019).

In all three studies, we further tested whether numeracy's effects appeared due to objective abilities or subjective numeracy (confidence in numeric skills combined with preference for numbers). Although subjective numeracy correlates with objective numeracy (e.g., Fagerlin et al., 2007; average $r = .45$, Peters, 2020), more recent research demonstrates that these constructs have unique effects in judgment and choice when both constructs were measured and analyzed simultaneously (Nelson et al., 2013; Peters & Bjalkebring, 2015). The few studies on numeracy and attention have employed only one of the measures, making it hard to disentangle which construct is responsible for effects. Therefore, in the present studies, we measured both objective and subjective numeracy. Further, we assessed an intelligence proxy in Studies 2a and 2b to rule out the possibility that general cognitive abilities drove the effects of numeracy.

Our studies aimed to test five core hypotheses. First, we hypothesized that objective numeracy would be positively associated with use of numeric information (H1). Specifically, in Study 1 we expected that the more (vs. less) numerate would be more sensitive to numeric information. In Studies 2a and 2b, we expected that the more (vs. less) numerate would rely on numeric (vs. verbal) information when making decisions, a different operationalization of number use. Second, we hypothesized that objective numeracy would moderate the effect of adding evaluative labels on information use. In particular, we expected that evaluative labels would increase number use more among people with lower (vs. higher) objective numeracy (H2). Third, higher objective numeracy scores would be associated with attending to numeric information more often (H3a) and longer (H3b) in absolute terms. Finally, we tested whether the relation of objective numeracy with greater number use would be mediated by greater attention to numeric information (H4). In this paper, we focus on absolute measures of attention because our hypotheses concerning this construct were most supported by previous research. We also tested other, preregistered hypotheses that had somewhat less support in the literature. These results are summarized at the end of the result sections and described in detail in the supporting information. Data and scripts for all studies can be found at OSF (https://osf.io/s4mke), and the used stimulus materials are provided in the supporting information (Section S4).

2 | STUDY 1

Study 1 aimed to investigate whether objective numeracy, when controlling for subjective numeracy, was related to the use of numbers in terms of sensitivity to numbers when only numeric information was available. Further, we tested whether adding evaluative labels would attenuate this effect and thus help the less numerate use numeric information more. For this purpose, participants received either numeric information only or both numeric and verbal information about products before being asked to rate product attractiveness. Attention was assessed using MouselabWEB. Study 1 was exploratory as it was not preregistered.

2.1 | Method

2.1.1 | Design

Participants were asked to rate the attractiveness of 16 consumer-products. We manipulated between participants whether products were described using only numeric information or numeric information plus evaluative categories. To study information use, we varied one attribute value at the trial level within participants in the eight target trials. In these trials, the value of the first attribute varied randomly across three levels in each trial. The values for the second and third attribute (their order was randomized) were the same for all participants. In the eight filler trials, the product information did not vary across participants. In sum, condition, attribute value, objective numeracy, and subjective numeracy were independent variables. Attractiveness ratings and attention variables served as dependent variables. We implemented Mouselab using MouselabWEB (Version 1.00beta; Willemsen & Johnson, 2008).

2.1.2 | Procedure

After providing informed consent, participants completed a brief unrelated numerical task. Subsequently, participants were randomly assigned to one of the two experimental conditions and completed its 16 trials in randomized order. Afterwards, participants filled out the subjective numeracy questionnaire, other measures not reported here, and an objective numeracy scale. Finally, participants reported demographic variables and were debriefed. Unrelated tasks and measures not reported here are described in the supporting information (Section S2).

2.1.3 | Judgment task

In each trial, participants were presented information about a consumer product (primarily electronic devices, e.g., a washing machine) and were asked to rate the product's attractiveness (‘Based on the information above, how attractive is this product to you’? on a 7-point scale from 0 = ‘not at all attractive’ to 6 = ‘extremely attractive’). For each product, a picture of a typical model was displayed; below it, information about three product attributes (e.g., energy efficiency; see Figure 1) was available. In the *numbers-only* condition, numeric values were provided for each attribute. The numeric values were specific to the attributes and varied across units, ranging from fairly interpretable ratings (e.g., ‘4 out of 5 stars’) to technical details (e.g., ‘400 kWh/year’). In the *numbers-and-labels* condition, verbal labels were also available that evaluated the numeric value (e.g., ‘400 kWh/year’ was ‘fair’ and ‘4 out of 5 stars’ was ‘good’) and resembled those provided by product-comparison and product-rating homepages such as Consumer Reports. Participants did not receive prior information on the products, attributes, or value ranges, although we provided the general range of evaluative categories and explanations of the less familiar attributes.

On each trial, each piece of product information (including the picture) was hidden behind boxes and could be opened by hovering the mouse cursor over the box. At the bottom of the trial page, participants were asked to answer the attractiveness question.

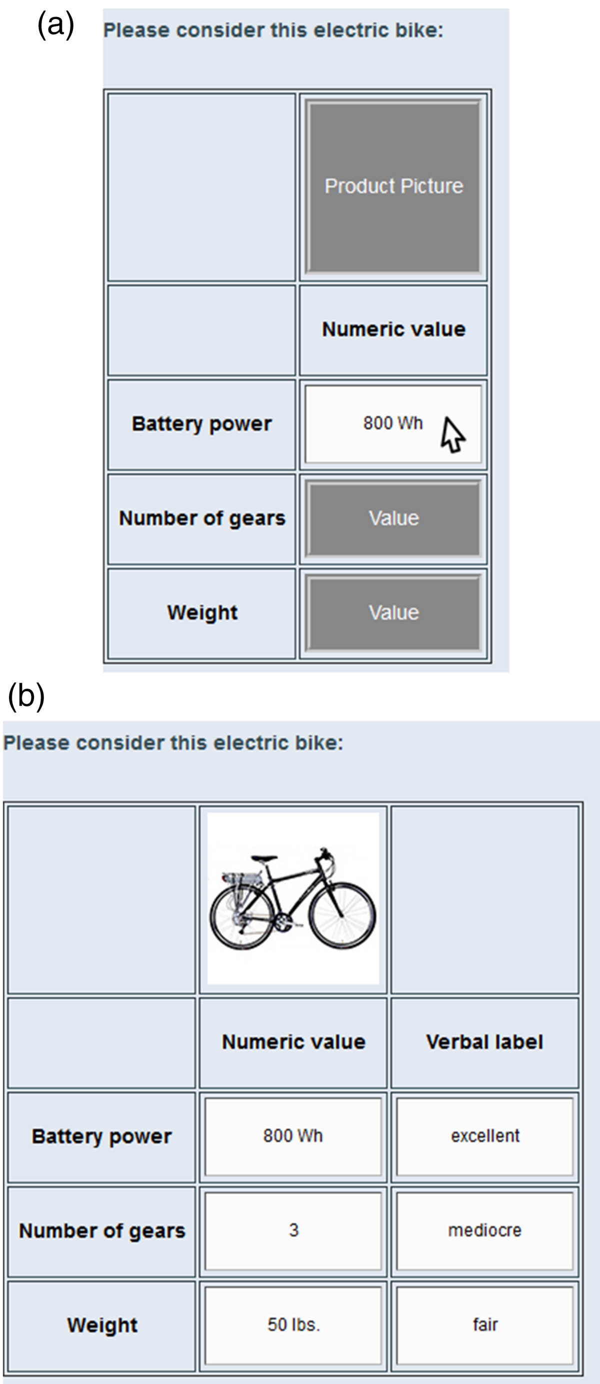

FIGURE 1 Study 1: Example (a) of the numbers-only condition, with one opened box as in the experiment, and (b) of the numbers-and-labels condition with all boxes opened to display all possible values

2.1.4 | Stimuli

Based on thorough online research, we selected a range of relevant attributes for each product. In a pretest with 50 participants, we tested these attributes for their importance when evaluating the product. For each product, we chose the attribute rated most important as the first attribute (i.e., the varied attribute) and the two less important ones as second and third attributes (i.e., fixed attributes). For each of the three attributes, based on further online research, we carefully selected a numerical value corresponding to each of the five verbal label values (i.e., ‘bad’, ‘mediocre’, ‘fair’, ‘good’, and ‘excellent’). For the variable attribute, the three levels were selected from the ‘bad’, ‘fair’, and ‘excellent’ levels, including respective numeric values. The numeric values and verbal labels for the second and third attributes as well as all attributes of the filler trials were selected from the three intermediate levels (i.e., ‘mediocre’, ‘fair’, or ‘good’) to avoid effects of extreme values.

2.1.5 | Measures

Objective numeracy

We assessed objective numeracy using four items from a modified version of the nonadaptive Berlin Numeracy Test (BNT; Cokely et al., 2012) and the easier three-item numeracy scale by Schwartz et al. (1997). This combined seven-item scale has been recommended for use in studies with general populations such as MTurk samples and has good discriminability (Cokely et al., 2012). The scale consisted of numerical tasks with varying difficulty (e.g., ‘On a bingo game show, the chance of winning an LED TV is 1 in 1,000. What percent of people on that bingo game show would win the LED TV on average’?). Missing responses were considered incorrect. The objective numeracy score represents the sum of correct answers.

Subjective numeracy

We also assessed subjective numeracy (Fagerlin et al., 2007). The scale consists of eight items which ask participants to rate their ability to perform mathematical tasks (e.g., 'How good are you at working with percentages'?) and their preference for numeric information (e.g., 'How often do you find numerical information to be useful'?) on a 6-point scale. The internal consistency of the scale was good (Cronbach's $\alpha = .85$). The subjective numeracy score represents the mean rating across all items.

2.1.6 | Sample

Participants were recruited via Amazon Mechanical Turk (MTurk) and received $1.50 for completing the study. In total, 603 participants took part in our study. Four participants with duplicate IP addresses were excluded from data analysis. Data of 15 participants were removed due to errors in data recording. Finally, we excluded 36 participants who made unreasonably quick responses (≤5 min for the whole study) and/or who looked at only one or no boxes in at least 3 out of the 16 trials. In the remaining sample ($N = 548$), the mean age was 39.8 years (range: 18–77; $SD = 12.3$), 49% were female, and 55% had at least a college degree.

2.2 | Results

For all analyses, we used the data of the eight target trials only; results were similar when all trials were used. In line with standard practice, we considered information as acquired when the box was opened for at least 200 ms (Willemsen & Johnson, 2019). When participants opened only one or no boxes on a trial, that trial's data were excluded (2.14% of trials). Descriptive results for individual measures and attention variables can be found in Table 1. No significant differences existed in objective numeracy or subjective numeracy scores between the two conditions.

TABLE 1 Means (and standard deviations) of numeracy measures and attention variables (Study 1)

Variable	Numbers-only ($n = 258$)	Numbers-and-labels ($n = 290$)
Objective numeracy	3.59 (1.64)	3.43 (1.68)
Subjective numeracy	4.32 (0.76)	4.24 (0.71)
Acquisitions	4.01 (1.04)	3.08 (1.61)
Time (seconds)	4.71 (2.31)	2.57 (1.89)

Note: Time = mean time attended to numeric information per trial. Acquisitions = mean number of acquisitions of numeric information per trial.

2.2.1 | Use of numeric information

To test H1 (that people higher in objective numeracy would use numbers more—be more sensitive to numeric levels—than those lower in objective numeracy) and H2 (that adding evaluative labels would help less numerate people use information more than it helped the highly numerate), we conducted a linear mixed-effects model with random intercepts for participants and trials. Attractiveness rating served as outcome variable. Predictors were level of attribute value (coded as $-1 =$ low value; $0 =$ medium value; $+1 =$ high value), objective numeracy, subjective numeracy (both mean-centered), condition (dummy coded as $0 =$ numbers-only, $1 =$ numbers-and-labels), and their interactions.[1] The results demonstrated that participants in general used the attribute level to determine attractiveness (see Figure 2). The higher the attribute level, the higher participants rated attractiveness when only numbers were provided ($b = 0.63$, $p < .001$); however, participants used this attribute level information more strongly when evaluative labels were also provided (value level × condition interaction: $b = 0.35$, $p < .001$). If objective numeracy was related to the use of numbers, numeracy should moderate the relation of value level and attractiveness rating. However, inconsistent with H1, more and less objectively numerate participants did not differ in how much they used information in the numbers-only condition, as indicated by a nonsignificant interaction of objective numeracy and value level ($b = 0.01$, $p = .695$). Further, if providing evaluative labels improves number use in more and less numerate people differently, attractiveness ratings should be predicted by a three-way interaction of objective numeracy, condition, and value level. However, inconsistent with H2, providing evaluative labels did not affect how more and less numerate people use the information for their attractiveness ratings (three-way interaction: $b = 0.00$, $p = .994$). In sum, objective numeracy was not related to the use of numbers and adding labels increased the use of the numeric information in attractiveness judgments for all participants, independently of numeracy. Hence, neither H1 nor H2 were supported in this study.

2.2.2 | Attention

H3a and H3b stated that people higher (vs. lower) in objective numeracy would attend more often and longer to numeric information, respectively. To analyze these hypotheses, we conducted two linear mixed-effects models with random intercepts for participants and trials. Outcome variables were the number of times boxes containing numeric information were opened and the total time these boxes were opened on each trial. Objective numeracy, subjective numeracy (both mean-centered), condition (dummy-coded), and their interactions were included as predictors.[2] Participants generally allocated less attention to numeric information when labels were available than when only numbers were provided (number of acquisitions: $b = -0.92$, $p < .001$; time: $b = -2.02$, $p < .001$). In line with H3a and H3b, more (vs. less) objectively numerate people looked more often ($b = 0.15$, $p = .010$) and longer ($b = 0.26$, $p = .003$) at numeric

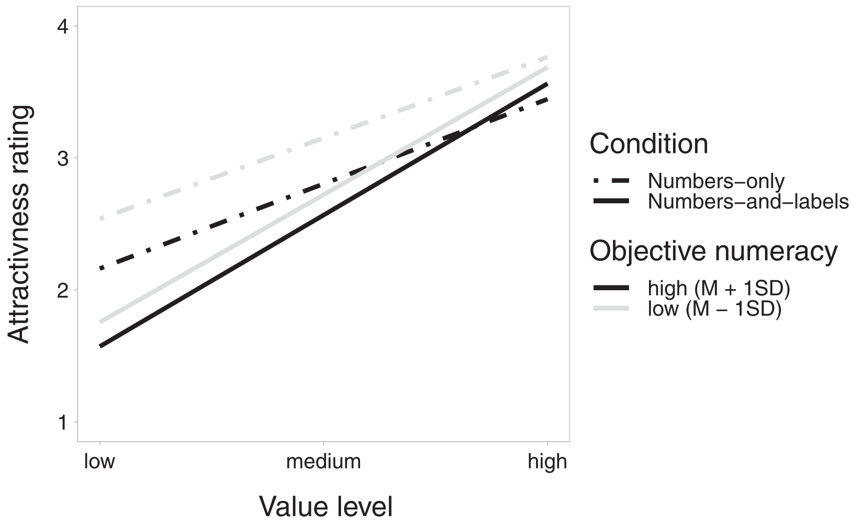

FIGURE 2 Predicted attractiveness ratings as a function of condition and objective numeracy (subjective numeracy is set at the mean). Participants used attribute value levels to determine attractiveness but more so when labels were added. Objective numeracy did not moderate this effect

information. The association of objective numeracy and attention did not differ between conditions, as indicated by nonsignificant interactions of objective numeracy and condition (interaction results—number of acquisitions: $b = 0.01$, $p = .871$; time: $b = -0.22$, $p = .070$). To corroborate the finding that objective numeracy's relation to numeric attention was independent of condition, we ran the same models without condition as a predictor as an exploratory analysis. The results for objective numeracy were the same in these models. No effects emerged of subjective numeracy. In sum, we found that objective numeracy was related, as expected, to attention to numbers (H3a and H3b).

For consistency with the preregistered hypotheses of Studies 2a and 2b, we also examined whether objective numeracy is related to numeric information relative to all types of information attended to. Detailed results can be found in the supporting information. In sum, there was no association of objective numeracy and relative attention to numeric information.

2.3 | Discussion

In Study 1, participants were provided with information about products and were asked to rate their attractiveness while we measured attention using a process tracing method. We examined how attractiveness ratings depended on provided information. Regardless of objective numeracy, people's judgments were more value sensitive when evaluative labels also were provided than when only numeric information was provided (though they used numbers to some extent in both conditions). Surprisingly, objective numeracy did not relate to information use in terms of sensitivity to numbers in the numbers-only condition nor did it moderate the effect of adding labels. These findings demonstrate the general usefulness of evaluative labels, but they did not support our hypothesis that labels would help the less numerate more. Additionally, we found that people higher (vs. lower) in objective numeracy attended more often and longer to numeric information. We found no effect of subjective numeracy on attention to numbers.

Because the numeric and verbal labels always coincided when both information types were present, we were unable to identify which one was relied upon in judgments. Therefore, in Studies 2a and 2b, we aimed to disentangle the information type used by participants.

3 | STUDIES 2A AND 2B

Study 1's evaluative labels were designed to aid the interpretation of the respective numbers. Hence, it was impossible to disentangle whether people used the numbers or the evaluative labels to rate product attractiveness when both information types were available. To test whether people relied on numeric values or verbal labels in their decisions, in the following studies, we used a choice task in which numeric and verbal information conflicted in half of the target trials.

In the preregistered Studies 2a and 2b, participants were provided with numeric information or both numeric and verbal information on pairs of products and were asked to choose the one they preferred. We again measured attention using Mouselab. Because we wanted to replicate Study 2a with more power, Study 2b was a direct replication of Study 2a with a larger sample, and we report their results simultaneously. Finally, we assessed a proxy for intelligence to rule out the possibility that our results could be attributed to general cognitive abilities rather than objective numeracy. All hypotheses (except for the mediation hypothesis) of Studies 2a and 2b were preregistered (https://osf.io/u4p2y and https://osf.io/avqyh, respectively; see supporting information Section S5, for an overview of hypotheses in the preregistration). The preregistrations are identical except for one hypothesis regarding the choice processes which was stated as exploratory for Study 2a and as a hypothesis for Study 2b.

3.1 | Methods

3.1.1 | Design

Participants were asked to choose between two products based on provided information. We manipulated between participants whether only numeric information was provided or both numeric and verbal information were provided. Numeric and verbal labels varied across the 20 trials. There were 12 target and 8 filler trials. In the target trials, numeric and verbal information varied so that in half of the trials, both types of information favored the same option, whereas in the other half the numeric information favored a different product than the verbal information. Therefore, condition (numbers-only vs. numbers-and-labels), values, objective numeracy, and subjective numeracy were independent variables. Choices and attention variables served as dependent variables. We implemented Mouselab using lab.js (Version 19.01.2000; Henninger et al., 2021). We decided to use lab.js instead of MouselabWEB because lab.js is a generic online experiment builder which provides high flexibility when designing Mouselab screens and makes it easy to integrate Mouselab into an overall study flow.

3.1.2 | Procedure

Participants on MTurk first were pretested on several objective and subjective measures of ability (i.e., objective numeracy, intelligence, and subjective numeracy) and socio-demographic variables approximately 1 year (Study 2a) and 5 weeks (Study 2b) before completing the study. All pretested participants (Study 2a: $N = 999$; Study 2b: $N = 941$) were invited to participate in the current studies. Pretested participants who participated in the main studies were slightly younger than those who did not participate; otherwise, these subsamples were relatively similar in demographic variables and cognitive abilities (for details, see supporting information Section S3 and Tables S1 and S2). In the study itself, participants first were instructed about the task; they then chose between 20 pairs of products. Finally, participants were asked to rate how good or bad it feels for them if a product is rated with a particular numeric or verbal rating (e.g., 75 points or ‘good’) and then continued with an unrelated study, both of which are not reported here.

3.1.3 | Decision task

In each of the 20 trials, participants were provided with two models of the same product and asked to choose the one they preferred (see Figure 3). These consumer products were labeled generically (e.g., ‘TV A’ and ‘TV B’). Instead of product attribute values as in Study 1, for each product, we provided three reviewer ratings (‘Reviewer 1’ etc.). In the numbers-only condition, these ratings ranged from 0 to 100, with 100 being the best. In the numbers-and-labels condition, participants also were provided with verbal ratings describing each numeric rating (e.g., ‘fair’). The range of numeric and verbal ratings was explained to the participants in the instruction. No product pictures were shown. Again, participants opened the boxes using their mouse cursor to see information. Product side (left vs. right) and order of ratings within a product were randomized at the trial level.

3.1.4 | Stimuli

Stimulus materials were designed to enable identifying which information type was used in making a choice. Across trials, each verbal rating always referred to the same range of numerical values (e.g., ratings ranging from 71 to 85 points were always described as ‘good’), so numeric and verbal ratings were positively correlated across stimuli throughout the studies. Reviewer ratings of the 12 target trials were constructed so that in half of target trials, no dominant option existed. In other words, the mean numeric rating was higher for one option, while the ‘mean’ verbal rating was higher for the other option. The mean of the verbal ratings was determined by assigning a number to each rating (i.e., fair = 1, good = 2, excellent = 3) and computing the mean of these numbers. The conflicting trials were constructed using sensible numeric values which deviated strongly despite the same evaluative category or using similar numeric values that led to their placement in different categories. For example, in Figure 3b, the mean numeric rating for Smartwatch B was higher than that for Smartwatch A, but A's mean label rating was higher than B's. This seemingly nonintuitive difference is possible because the numeric value of A's 67 point ‘fair’ rating is considerably higher than B's 53 point ‘fair’ rating, but it is only slightly lower than B's 71 point ‘good’ rating. In the other half of the target trials, both types of information favored the same product creating a dominant option. Although the latter half of the target trials could not directly test whether numeric or verbal information was used for the decision, we included them in the statistical analyses and controlled for numeric and verbal superiority. Thereby, we could identify the unique effect of each type of superiority on choice. Further, in four of the eight filler trials, there was one obviously dominant option, while in the other four filler trials, both products received comparable numeric and verbal ratings.

3.1.5 | Measures

Cognitive ability measures were assessed approximately 1 year (Study 2a) and 5 weeks (Study 2b) before experiment completion, thus minimizing the possibility of bias from the cognitive tests driving people to look more at the numbers.

Objective numeracy

We assessed objective numeracy using a modified version of the same seven-item measure used in Study 1 (Cokely et al., 2012).

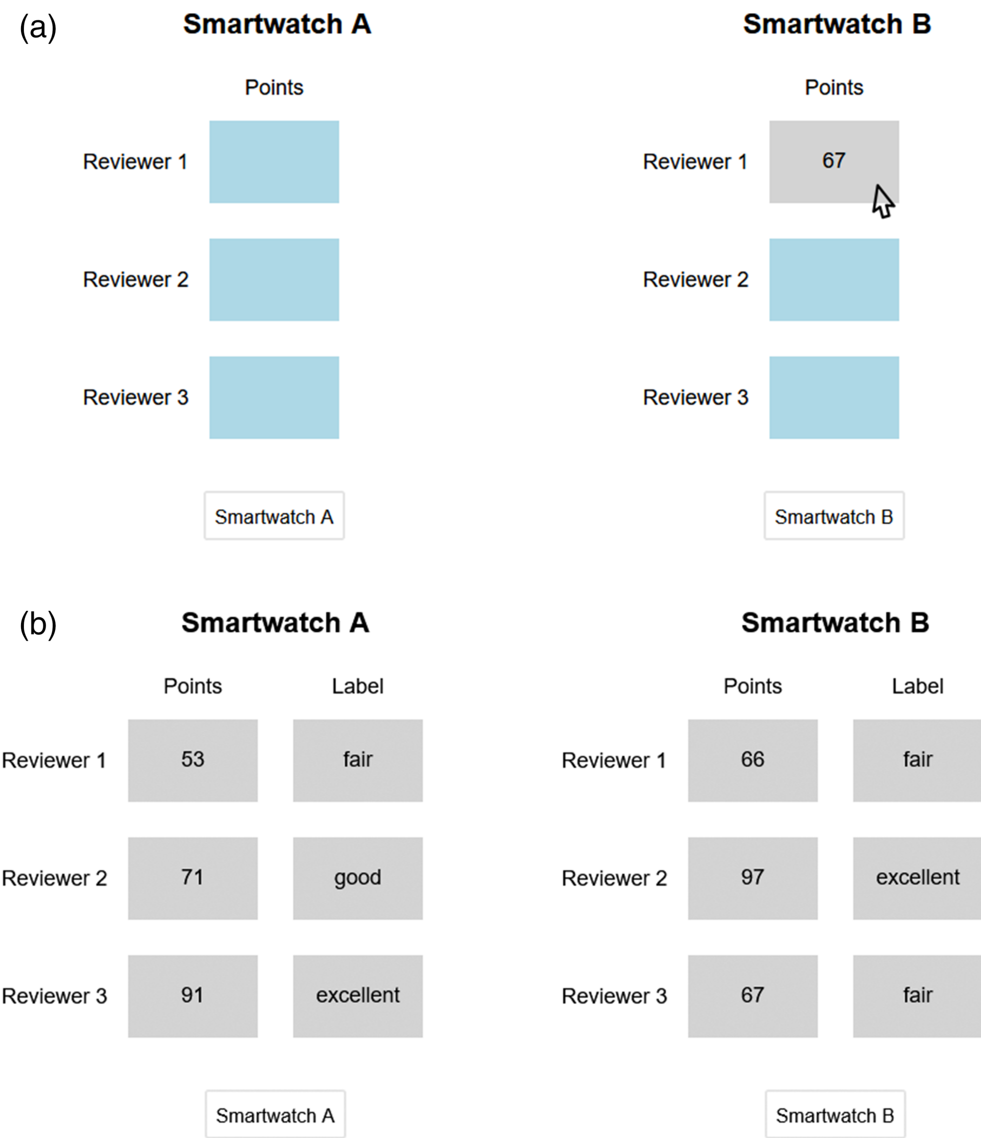

FIGURE 3 Studies 2a and 2b: Examples of (a) the numbers-only-condition, with one opened box mirroring what participants saw in the experiment, and (b) the numbers-and-labels condition with all boxes opened to display all possible values (participants could only open one box at a time)

Subjective numeracy

We assessed subjective numeracy using the same measure as in Study 1. The internal consistency of the scale was good (Cronbach's $\alpha = .88$ and .86 in Study 2a and 2b, respectively).

Intelligence

We assessed a nonnumeric proxy of fluid intelligence using a 10-item Raven's matrices reasoning test (modified from Raven's Progressive Matrices, Dørum, 2008; Raven, 2000). Participants were repeatedly asked to choose a missing shape which completes a pattern in a 3×3 grid of shapes. The intelligence score represents the sum of correct answers.

3.1.6 | Sample

Participants in both studies were recruited from MTurk and received $1.00 for completing the study.

In Study 2a, we aimed at 200 participants (i.e., 100 per condition) and collected data from 196 participants. As preregistered, participants who failed the attention check (i.e., chose the inferior option in two or more of the obvious trials; one participant), responded too fast to have responded conscientiously (i.e., ≤60 s for all 20 trials; six participants), and looked at no or very little information (i.e., opened fewer than two boxes in three or more of the 20 total trials; three participants) were excluded from data analysis. The other preregistered exclusion criteria led to no further exclusions. In the remaining sample ($N = 187$), at the time of the pretest, mean age was 41.6 years (range: 22–69; $SD = 11.8$), 45% were female, and 47% had a 4-year college degree or more.

In Study 2b, we aimed at 400 participants (i.e., 200 per condition) and collected data from 414 participants. Participants who failed the attention check (one participant), responded too fast (ten participants), and looked at no or very little information (four participants) were excluded from data analysis, with no further exclusions. In the remaining sample ($N = 399$), mean age was 41.0 years (range: 20–79;

SD = 12.6), 51% were female, and 52% had a 4-year college degree or more.

3.2 | Results

By using ratings ranging from 0 to 100, the numeric information in the current studies was designed to be interpreted more intuitively than in Study 1 which used numeric values and units which mostly required prior knowledge. Because pretests supported this presumption through shorter times per acquisition than in Study 1, we preregistered that we would consider a box as 'opened' if it was opened for at least 100 ms. When participants opened only one box or no boxes, we excluded data for that trial (Study 2a: 0.02% of trials; Study 2b: 0.01%). Descriptive results for Studies 2a and 2b can be found in Table 2. Participants did not significantly differ on any measure by condition or the two studies.

3.2.1 | Use of numeric information

To test H1 (that people higher in objective numeracy use numeric information rather than verbal information more than those lower in objective numeracy), we tested whether participants chose the product favored by the numeric rating or the verbal rating. For this purpose, we conducted a logistic mixed-effects model with random intercepts for participants and trials. We analyzed the 12 target trials of the numbers-and-labels condition only ($n = 92$ and 197 in Studies 2a and 2b, respectively) because only in this condition was it possible to examine the use of numeric vs. verbal information. The outcome variable was choice for Product A (i.e., the left product), while the predictors were numeric superiority, label superiority (both dummy coded as 1 = Product A and 0 = Product B), objective numeracy, subjective numeracy (both mean-centered), and their two-way interactions with numeric and label superiority (a total of four interaction terms). Intelligence (mean-centered) was included as a covariate.[3]

In Study 2a, people higher (vs. lower) in objective numeracy used the numeric rating more as indicated by a positive interaction of objective numeracy and numeric superiority (interaction: $b = 0.24$, $p = .027$). In addition, people who subjectively perceived themselves to be more (vs. less) numerate used numerical information more (interaction $b = 0.57$, $p = .008$).

In the replication Study 2b, people higher (vs. lower) in objective numeracy used the numeric ratings more (interaction: $b = 0.28$, $p = .001$). No main effects existed of subjective numeracy or intelligence and no other interaction effects emerged as significant.

3.2.2 | Attention

H3a and H3b stated that people higher (vs. lower) in objective numeracy attend more often and longer to numeric information, respectively. To test this, we conducted two linear mixed-effects models with random intercepts for participants and trials. The number of acquisitions of numeric information and the time numeric boxes were opened on each trial served as outcome variables, while objective numeracy, subjective numeracy (both mean-centered), condition (dummy coded as 0 = numbers-only, 1 = numbers-and-labels), and their interactions were included as predictors; intelligence (mean-centered) was a covariate.[4] As preregistered, we tested the hypotheses using the data of both conditions and both target and filler trials for two reasons. First, whereas the number use analysis could only be performed in the numbers-and-labels conditions, we could assess attention in both conditions. Second, we assume that the relation of numeracy and attention is not limited to the target trials, so we included all trials to increase statistical power and the generalizability of the findings. Results were similar when analyzing subsets of trials with target trials only or conflicting trials only.

In Study 2a, people tended to attend more often to numeric information ($b = -0.86$, $p = .057$) but not longer to it ($b = -0.66$, $p = .107$) in the numbers-only condition compared with the numbers-and-labels condition.[5] Objective numeracy did not predict either attention variable as a simple effect nor in interaction with condition. No significant effects emerged of subjective numeracy or intelligence.

In Study 2b, people attended more often ($b = -1.01$, $p = .002$) and longer ($b = -0.64$, $p = .015$) to numeric information in the numbers-only condition than the numbers-and-labels condition. People higher (vs. lower) in objective numeracy attended more often to numeric information ($b = 0.29$, $p = .030$) but not longer to it ($b = 0.11$, $p = .320$).[6] These associations did not differ between

TABLE 2 Means (and standard deviations) of numeracy measures, intelligence, and attention variables (Studies 2a and 2b)

	Study 2a		Study 2b	
Variable	Numbers-only ($n = 96$)	Numbers-and-labels ($n = 91$)	Numbers-only ($n = 202$)	Numbers-and-labels ($n = 197$)
Objective numeracy	3.26 (1.68)	2.99 (1.75)	3.36 (1.77)	3.34 (1.66)
Subjective numeracy	4.78 (0.82)	4.72 (0.91)	4.70 (0.84)	4.76 (0.78)
Intelligence	5.54 (1.54)	5.49 (1.77)	5.82 (2.04)	5.53 (1.64)
Acquisitions	8.10 (2.38)	7.23 (3.43)	8.30 (2.53)	4.43 (2.18)
Time (sec)	4.05 (2.57)	3.40 (2.67)	4.07 (2.60)	2.06 (1.29)

Note: Time = mean time attended to numeric information per trial. Acquisitions = mean number of acquisitions of numeric information per trial.

conditions, as indicated by nonsignificant interactions of objective numeracy and condition (number of acquisitions: $b = 0.13$, $p = .486$; time: $b = 0.17$, $p = .278$). Again, we exploratorily ran the same models without condition as a predictor to corroborate the finding that objective numeracy's relation to numeric attention was independent of condition. The results for objective numeracy were the same in these models. In sum, H3a was not supported in Study 2a, but it was supported in the more powered Study 2b. However, H3b was not supported in either study.

3.2.3 | Attention as a mediator

To test H5 (that the association of objective numeracy and use of numeric information would be mediated by attention to numeric information), we conducted a multilevel structural equation model with random intercepts for participants using a Bayesian estimator in Mplus (Version 8.4; Muthén & Muthén, 2019). In Bayesian parameter estimation, an association is considered credible when the 95% highest density interval (HDI; i.e., the interval that spans 95% of the distribution) of the posterior distribution does not include 0. This analysis was exploratory as it was not part of the preregistrations. Objective numeracy, subjective numeracy, their interaction, and intelligence were the predictors and choice of Product A was the outcome variable. The number of numeric acquisitions and numeric attention time in each trial were included as mediators. We analyzed the data of the numbers-and-labels condition only because number (vs. label) use could only be examined in this condition. By including both attention variables as mediators, we could examine which type of attention mediates the effect of objective numeracy on number use. As in H1's analysis, the effects on choice were set to interact with the numeric superiority of product A, so that an effect on number use was reflected by a significant interaction of the attention or objective numeracy and numeric superiority. The effects on product choice were controlled for by superiority with regard to labels to identify the unique reliance on numbers and labels in both trials with conflicting and trials with congruent information. Multilevel modeling with Mplus enables analysis of within- and between-participant variance simultaneously. The results on the between-participant level reflect how participants varying in numeracy and numeric attention relate to their use of numbers. The within-participant level results indicate how within each participant, attending more strongly to numeric information in a trial is associated to the use of numeric information in that trial. The mediation model and results for the between-participant level of Study 2b are illustrated in Figure 4.

In Study 2a, the associations of objective numeracy and the two attention variables were not significant. Therefore, we did not conduct the mediation analysis for Study 2a.

In Study 2b, the model shows that the more objectively numerate attend to numeric information more often and longer. In turn, the more often people attend to numeric information, the more often they choose the product which is in line with numeric ratings. Accordingly, the indirect effect of objective numeracy on choices via number of acquisitions was credible (posterior mean: 0.05 [95% HDI: 0.00–0.13]). However, the indirect effect via attention time was not credible (−0.01 [−0.07–0.04]). In this model with mediators included, the direct effect of objective numeracy on choice was not credible, indicating that attention fully mediated this association. In addition, within participants, on trials with a greater number of numeric acquisitions, numbers were used more in choice (0.14 [0.09–0.18]).

We also conducted the mediation analysis with pooled data from Studies 2a and 2b, controlling for study and found that the pattern found in Study 2b held also in the pooled data set: There was a positive association of objective numeracy with number of acquisitions (posterior mean: 0.31 [95%HDI: 0.02–0.60]) and attention time (0.21 [0.02–0.40]). The indirect effect via number of acquisitions only slightly missed the credibility threshold (0.03 [−0.00–0.08]).

In sum, the mediation results of Study 2b, but not 2a, suggest that more (vs. less) numerate people may use numeric information more

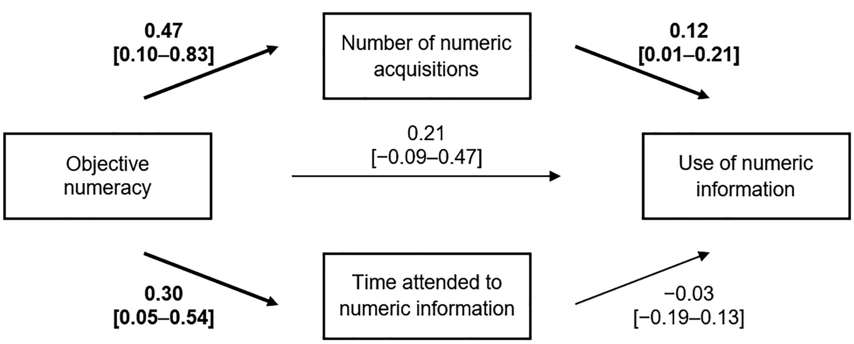

FIGURE 4 Graphical illustration and participant-level results of the mediation models for Study 2b. Values attached to the paths represent means of the estimated posterior distribution [95%HDI]. Credible associations are printed in boldface. The effect on use of numeric information represents the interaction effect of objective numeracy or the attention variable and Option A being the numerically superior option on the choice for Option A (see analysis for H1 for more details). For consistency with prior analyses of the direct effects, subjective numeracy, the objective numeracy × subjective numeracy interaction, and intelligence are included in the models as predictors but are not shown for clarity (none of these predictors were significant)

strongly and perhaps because they attend more often, but not longer, to numeric information.

3.2.4 | An exploratory meta-analysis of the association of numeracy and attention

To examine whether the association of numeracy and attention is reliable when considering the three studies simultaneously, we conducted a meta-analysis using the data of all studies. For this purpose, we conducted a three-level mixed-effects model with trials nested in participants and participants nested in studies (analog to the analysis for H3a/H3b but with an added third level and random intercepts for participants only). We standardized all continuous predictor and outcome variables at the level of the studies. Overall, a significant association existed of objective numeracy with number of numeric acquisitions ($\beta = .10$, $p < .001$) but not with attention time ($\beta = .04$, $p = .112$).

3.2.5 | Analyses of further preregistered hypotheses

We had preregistered further hypotheses which we describe and test in detail in the supporting information (Section S1). In particular, we first tested whether people higher (vs. lower) in objective numeracy attended more often and longer to numeric information in proportion to overall acquisitions but found no association of numeracy and relative attention in either study. Further, we tested whether people higher (vs. lower) in objective numeracy made more comparisons between numeric information (i.e., switched between two numeric boxes) in proportion to all comparisons. We found no significant associations of numeric comparisons and numeracy in either study. Finally, we tested whether objective numeracy would be negatively related to use of heuristic processing (preregistered as hypothesis in Study 2b only). In particular, people lower in numeracy could base their choices more on ordinal comparison of numeric information, whereas those higher in numeracy could calculate means of the numeric values. In sum and consistent with hypothesis, objective numeracy was positively related to choosing options with higher mean values (Studies 2a and 2b), whereas choosing options in line with the heuristic was negatively related to objective numeracy in Study 2a. In Study 2b, there was a significant interaction of objective and numeracy, with the heuristic being used less by people high in both objective numeracy and subjective numeracy and by people low in both measures.

3.3 | Discussion

In Studies 2a and 2b, participants were asked to choose between pairs of products given provided information. In one combined condition, participants were presented numeric and verbal information which coincided in some trials but conflicted in other trials. In the other condition, participants received numeric information only. This design allowed us to examine which type of information people rely on when making decisions and whether the association of numeracy and information use is mediated by attention to numbers.

Results from the numbers-and-labels condition demonstrated that people who were more objectively numerate used numbers more in choices than the less numerate. Further, the more objectively numerate people were, the more often they attended to numeric information in Study 2b, but not Study 2a. We found no significant association between objective numeracy and the time people attended to numeric information. Finally and most importantly, in Study 2b (but not Study 2a), the association of objective numeracy and number use was mediated by the frequency people attended to numbers.

4 | GENERAL DISCUSSION

The ability to work with numbers has been shown to affect decisions and life outcomes across a wide range of domains (Peters, 2020). Despite a growing interest in predecisional attention, relatively little research has investigated the role of attention in the effects of numeracy on judgment and choice. Based on previous research, we argued that higher objective numeracy would be associated with both a stronger use of numeric information (both in terms of number sensitivity and use of numeric vs. nonnumeric information) and attention to numeric information. Crucially, we tested whether attention to numbers would explain, at least in part, why objective numeracy relates to a greater use of numeric information. We tested our hypotheses in three studies with one judgment task and one decision task. In all studies, participants received varying information about one product or a pair of products. For each one, they were provided either numeric information only or both numeric and verbal information. Then, they were asked to rate the attractiveness of the product or to choose the one they preferred. We used Mouselab to assess attention to numeric information in all studies.

In line with previous findings, our results demonstrated that people higher in objective numeracy used numeric information rather than verbal information more than the less numerate in Studies 2a and 2b. In Study 1, however, we found no relation of objective numeracy with sensitivity to numbers. We further demonstrated a beneficial effect of evaluative labels on the use of information (over numbers-only) that helped the more and less numerate similarly. Our hypotheses regarding attention to numbers received mixed support. We found an association of objective numeracy with number of numeric acquisitions in two of the studies and with attention time in only one. A meta-analysis across all studies revealed a small but significant association of numeracy and numeric acquisitions. When we conducted a mediation analysis of Study 2b, attention in terms of more acquisitions of numeric information mediated the association of objective numeracy with number use; however, longer time spent acquiring numeric information was not a credible mediator, and in Study 2a, there was no credible mediation. These results suggest that numeric attention (in terms of number of numeric acquisitions) may play a critical role in explaining why people higher in objective numeracy use numeric information more than those lower in objective numeracy.

4.1 | Numeracy and number use

Previous research has indicated that more numerate people are more sensitive to numeric information and that they use numeric versus nonnumeric information more than the less numerate when different types of information are available (Betsch et al., 2015; Lipkus et al., 2010; Peters et al., 2009). Study 1 results, however, were not in line with the findings on number sensitivity; instead, more and less numerate people similarly used numeric information in their attractiveness ratings. A possible explanation for this discrepancy is that, compared with stimuli in previous studies, the numeric values and units used in Study 1, which varied strongly across ranges and units and often required some prior knowledge, simply were very difficult to interpret, even for the highly numerate. In addition, the association of objective numeracy and number sensitivity has not been completely consistent in prior research. For example, in the numbers-only condition of Peters et al. (2009), numeracy was only related to number sensitivity for one out of three numeric attributes.

However, in Studies 2a and 2b with choices between two alternatives, people higher (vs. lower) used numeric information more strongly than verbal information. This finding is in line with studies showing that objective numeracy is related to the use of numeric information when different types of information are available (e.g., narrative reports, mood; Betsch et al., 2015; Peters et al., 2009; Traczyk & Fulawka, 2016).

When comparing the results of Study 1 with those of Studies 2a and 2b, methodological differences must be acknowledged. First, because in Studies 2a and 2b, numeric values used a common range from 0 to 100, the finding suggests that objective numeracy may be more strongly related to the use of numeric information when numeric information is easier to interpret. Second, numeracy might relate to number use differently in judgments and decisions. Because choices require comparison processes which more (vs. less) numerate people are more inclined to perform (e.g., Peters et al., 2019), numeracy could have a stronger impact on number use in choices than in judgments. Third, in Studies 2a and 2b, we provided reviewer ratings instead of product attribute values as in Study 1. Perhaps, reviewer ratings imply a more subjective or at least preprocessed evaluation of product attributes than the objective product attributes themselves. This difference, in turn, could result in different ratings of usefulness or reliability and thus different processing of information depending on numeracy.

4.2 | Evaluative labels

Although more and less numerate participants used numeric information similarly when only numeric information (and a picture) were available, they did so, too, when evaluative labels were added. Possibly, Study 1's numeric information was rather difficult to incorporate in an attractiveness judgment so that people varying in objective numeracy could not use numeric information appropriately and relied mostly on the evaluative labels (e.g., 'bad', 'fair', and 'excellent') when they were provided. However, people did rely on the numeric information when it was the only meaningful information available. Although the findings did not support our hypothesis that evaluative labels would help especially the less numerate to use information more, one other study has also found only main effects of evaluative labels on information use without moderation by objective numeracy (Dieckmann et al., 2012). Together and consistent with Hsee's evaluability principle (Hsee, 1996; Hsee et al., 1999), these findings suggest that numbers without a comparison might be hard to interpret and use for people both lower and higher in numeracy. Further, the results speak to the benefit of evaluative labels in consumer choices for all consumers (but not to their greater benefit for less numerate consumers as compared with the more numerate).

4.3 | Numeracy and attention

Our findings regarding the association of objective numeracy and attention were rather mixed. People higher (vs. lower) in objective numeracy looked more often at numeric information in two of the three studies and looked longer at numeric information in only one of the studies. Furthermore, when conducting a meta-analysis across all studies, we found a small but significant association of numeracy and the number of numeric acquisitions. This inconsistency may be in line with prior research on risky choices that presented only numeric information; one study found reliable associations of numeracy and attention (Jasper et al., 2017), whereas another study detected no significant correlations (Pachur et al., 2018). However, our findings extend these findings to the consumer domain and to judgments and choices alike and show that they are not dependent on whether only numeric or both numeric and verbal information are available. Finally, we ruled out subjective numeracy and intelligence as likely drivers of the associations. Previous studies combined with our results suggest that there exists an association of numeracy and attention, but that the correlation is relatively small. Moreover, some factors may exist that we did not vary but that systematically moderated the relation of numeracy and numeric attention (e.g., personal relevance of information, ease of interpretation, or the task domain). Because little research exists on the association of numeracy and numeric attention, future research should investigate the robustness of the association and moderating factors.

4.4 | Attention as a mediator

Perhaps most importantly, our research demonstrates that the relation of objective numeracy with greater use of numeric information could be at least partially attributed to attentional processes. In Study 2b, with greater numeracy, participants attended more to numbers, which in turn led to greater number use. This finding is in line with previous research showing that the more people attend to information, the more sensitive they are to it and the more they use it (e.g., Fisher & Rangel, 2020; Pachur et al., 2018). However, in Study 2a, we found neither a direct association of numeracy and number use nor a mediation of attention to numbers, so the mediation results, too, were somewhat mixed.

Although different proposals exist concerning why the more numerate use numbers more than less numerate (e.g., Peters, 2020), to the best of our knowledge, the present studies are the first to empirically test the relation of numeracy and decision making, with a focus on the mediating role of attention to numbers. One study showed that attention allocation to the task-relevant parts of a graph displaying medical information could partially explain the association of objective numeracy and graph comprehension (Keller & Junghans, 2017). Although that study had a different focus than our studies, it underlines our conclusion that attention could play an important role in the effects of numeracy.

Our analysis and study design are correlational and thus we cannot draw conclusions about causal effects. Although objective numeracy is considered a relatively stable trait (Chesney et al., 2015), attention to numbers could be considered a relatively stable trait as well. It is possible that participants were better at answering the objective numeracy questions *because* they attended more strongly to the numbers, and thus, the causal link might be reversed compared with our argumentation. Our study was not designed to test the causal relation of numeracy and numeric attention so that we can only draw conclusions about the statistical association between them. Concerning the link between attention and number use, although our study could only examine associations, prior studies did establish a causal effect of attention on number use by experimentally manipulating attention to pieces of information (Armel et al., 2008; Pachur et al., 2018).

Although the relation of objective numeracy and number use was not completely consistent in the present paper, we believe nonetheless that exploring the role of attention in numeracy research reflects an important future avenue for research. First, previous numeracy research has often focused on the outcomes of judgments and decisions (but see Cokely & Kelley, 2009). Paying more attention to the processes which underly the effect of numeracy on outcomes may provide further insights into the reasons for numeracy influencing judgment and decision making. Second, as the less numerate tends to make less beneficial choices across different domains (Garcia-Retamero et al., 2019; Peters, 2020), decision aids have been developed to support the less numerate, in particular, in making better decisions. For instance, graphical representations of risk information improve understanding for the less numerate (Garcia-Retamero & Cokely, 2017). Previous research has already shown that graphical (vs. numerical) representation of risks improves risk comprehension in surgeons by increasing the time they spent deliberating (Garcia-Retamero et al., 2016). If decision aids could be developed which would draw attention to relevant numeric information, this change could help the less numerate use numeric information more. Further research should study whether understanding and number use could be improved by using decision aids which specifically direct attention to important information.

4.5 | Conclusions

In conclusion, numeracy may facilitate good decision making in a variety of ways (e.g., faster calculations and more accurate calculations). Our research highlights the potential of considering attention to numbers when studying the effects of numeracy in basic and applied research. Previous research on numeracy has often focused on decision outcomes, but research like the present studies can help to understand the processes which underlie these effects and to explain why more and less numerate people differ in making judgments and decisions. Furthermore, our research provides a basis for decision aids which require patients and consumers to use numbers in decisions. By directing attention to numbers, they could be encouraged to use numbers more. In sum, our research demonstrates that it is important to consider which information people are paying attention to in order to improve the decisions of both more and less numerate people.

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ENDNOTES

[1] To provide a formal description of the models, we also state the R codes for all models for use with the lme4 package (variable names may differ in actual uploaded R code): `lmer(attractiveness ~ AttributeValue * ObjNum * SubjNum * condition + + (1 | participantID) + (1 | trialID), data = dataset)`

[2] R code: `lmer(number of numeric boxes [or attentiontime] ~ ObjNum * SubjNum * condition + (1 | participantID) + (1 | trialID), data = dataset)`

[3] R code: `glmer(ChoiceOptionA ~ (NumSup + VerbSup) * ObjNum * SubjNum + intelligence + (1 | participantID) + (1 | trialID), family = binomial, data = dataset)`

[4] R code: `lmer(number of boxes [or attentiontime] ~ ObjNum * SubjNum * condition + intelligence + (1 | participantID) + (1 | trialID), data = dataset)`

[5] When excluding all acquisitions that were extremely long (i.e., longer than the mean + 3 SD), the results were similar.

[6] When excluding all acquisitions that were extremely long (i.e., longer than the mean + 3 SD), the association of objective numeracy with numeric acquisitions was similar, but the association with attention time was significant and in the hypothesized direction ($b = 0.14$, $p = .027$).

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