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Risk ladder, table, or bulleted list? Identifying formats that effectively communicate personalized risk and risk reduction information for multiple diseases

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Abstract

Background: Personalized medicine may increase the amount of probabilistic information patients encounter. Little guidance exists about communicating risk for multiple diseases simultaneously or about communicating how changes in risk factors affect risk (hereafter “risk reduction”).

Purpose: Determine how to communicate personalized risk and risk reduction information for up to five diseases associated with insufficient physical activity in a way laypeople can understand and that increases intentions.

Methods: We recruited 500 participants with <150 weekly minutes of physical activity from community settings. Participants completed risk assessments for diabetes, heart disease, stroke, colon cancer, and breast cancer (women only) on a smartphone. Then, they were randomly assigned to view personalized risk and risk reduction information organized as a bulleted list, a simplified table, or a specialized vertical bar graph (“risk ladder”). Last, they completed a questionnaire assessing outcomes. Personalized risk and risk reduction information were presented as categories (e.g., “very low”). Our analytic sample (N=372) included 41.3% individuals from underrepresented racial/ethnic backgrounds, 15.9% vocational-technical training or less, 84.7% women, 43.8% age 50–64, and 71.8% who were overweight/obese.

Results: ANCOVAs with *post-hoc* comparisons showed the risk ladder elicited higher gist comprehension than the bulleted list (p=0.01). There were no significant main effects on verbatim comprehension or physical activity intentions, and no moderation by sex, race/ethnicity, education,

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Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent: Informed consent was obtained from all individual participants included in the study.

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numeracy, or graph literacy, p>.05. Sequential mediation analyses revealed a small beneficial indirect effect of risk ladder *versus* list on intentions through gist comprehension and then through perceived risk (*b*IndirectEffect=0.02, 95% CI: 0.00, 0.04).

Conclusion: Risk ladders can communicate the gist meaning of multiple pieces of risk information to individuals from many socio-demographic backgrounds and with varying levels of facility with numbers and graphs.

Introduction

Much personalized risk communication research focuses on communicating the risk of a single disease (1–4) or on communicating the risks and benefits of medical treatments (5–7). Devising communication formats that help people understand not only how a risk factor might affect their risk of several diseases, but also the extent to which changing that behavior might reduce risk, could help laypeople understand the importance of engaging in that behavior for their future overall health.

Risk Communication Formats

Hundreds of studies have investigated how to communicate health risk information in ways that the public can understand and use effectively when making health and medical decisions (for reviews, see (8–14)). According to fuzzy trace theory, health messages that allow users to extract the “gist” or bottom-line meaning of information are more effective in promoting behavior change than messages that only foster “verbatim” knowledge (e.g., recalling exactly which risk category or probability was provided) (15). The current risk communication literature recommends supplementing risk probabilities with well-designed visual displays (10, 13) that allow for the extraction of “gist,” such as bar graphs (10, 13, 16–19). Bar graphs have perceptual cues that help people draw comparisons between risks and promote understanding of proportions, magnitudes, and differences in magnitude (8, 10, 14, 20–22). Icon arrays, which are collections of symbols that are shaded in different ways to indicate event probabilities, can also help people navigate complex medical treatment decisions (5, 19, 23–25). However, they may not always be practical solutions; their size and structure may make it difficult for users to draw comparisons among more than two health problems.

Risk ladders are specialized vertical bar graphs in which several risk estimates or categories are placed vertically according to their absolute risk, such that higher placement on a ladder indicates higher risk (26) (Figure 1). Risk perceptions are affected by location on the ladder; people perceive risks as being higher when they are located higher on the ladder (26). They can also be structured to show how risk varies under different conditions. For example, one study used risk ladders to compare the risk of lung cancer conferred by two behaviors: cigarette smoking and radon exposure (26). Other work has demonstrated that risk ladders can be an effective way of communicating risk information to individuals with limited numeracy (27), in part by helping people draw comparisons between risks (28). However, scant research has used risk ladders to communicate information about multiple hazards within the same domain (e.g., chronic diseases) and also across different behavioral conditions. None has presented personalized risk information.

Tables, with their ability to organize information in clearly-labelled columns and rows, are another way of showing complex risk-benefit information. Although some studies have found tables to have limited effectiveness in communicating risk information (16, 17, 29), others have found that they can be as helpful as icon arrays for communicating multiple benefits and harms (30). Tables can vary in complexity; specialized tables called Drug Facts Boxes provide a structure for showing numeric estimates of the frequency of several potential side effects and benefits of medications compared to placebo (6, 31–33). Research suggests that such a structure may improve comprehension of the information compared to standard alphanumeric text. However, no published research has examined whether risk ladders or tables that are simpler than Drug Facts Boxes elicit higher information comprehension or behavior change motivation.

Long-Term Goal and Conceptual Framework

We developed a personalized risk assessment tool that provides personalized risk information for up to five diseases associated with insufficient physical activity: heart disease, stroke, diabetes, colon cancer, and breast cancer (women only) (34, 35). It also provides personalized risk information of the same diseases if people obtain at least 3 hours of activity weekly (34). Finally, it uses a risk communication format that adheres to current risk communication guidelines and can be understood by people with varying levels of numeracy.

Our conceptual framework was an adapted form of the Health Action Process Approach (HAPA) (35, 36). This study focuses on the motivation phase of HAPA, which asserts that higher perceived risk, response efficacy (belief that taking precautionary action will reduce risk), perceived disease severity, and self-efficacy of enacting behavior change will increase behavior change intentions. In addition to the HAPA constructs, we also assessed gist and verbatim information comprehension and affective responses to the information (37, 38) (Figure 2).

Objectives, Hypotheses, and Exploratory Research Questions

Our primary objective was to determine whether a risk ladder, a simple table, or bulleted list best fostered laypeople's ability to draw an accurate and meaningful picture of the impact of physical activity on their disease risk and to increase their motivation to engage in physical activity. We hypothesized that the risk ladder and simple table would each elicit higher comprehension of risk information than the bulleted list (6, 26, 27). We also hypothesized that the risk ladder and the table would each elicit higher intentions to engage in physical activity behavior than the list (Figure 1, (36, 39–41)). We were uncertain whether the risk ladder would be superior or inferior to the table. We adapted the risk ladder and table used for this study from prior research (27, 33, 35).

Our secondary objective was to determine whether the risk communication formats had similar or different effects among people from different socio-demographic backgrounds. Much past risk format research was conducted with samples comprised mostly of participants who were white, highly educated, and women (e.g., (5)). Representation of people of color and other underrepresented groups in risk communication research has

increased in recent years (42), but no studies of risk ladders have been conducted in samples with large proportions of people from underrepresented groups. In addition, numeracy and graph literacy (43) have only recently begun to be investigated in the context of personalized risk communication (e.g., (44)), and only two studies have examined the effect of risk ladders on perceived risk among people with low numeracy) (28, 45). Therefore, we did not draw directional hypotheses about how socio-demographic variables might moderate the effect of the risk formats on primary outcomes.

Our tertiary objective was to examine the process by which risk communication format may affect intentions. We tested whether the cross-sectional patterns of relationships among variables were consistent with the mediational patterns delineated by our conceptual framework. We focused specifically on whether the risk ladder or table increased intentions relative to the list by increasing information comprehension and then increasing risk perceptions or response efficacy. These cognitions were of primary interest because they were directly targeted by the communication formats. We also explored whether these formats might have unexpected ancillary effects on the other cognitive and affective precursors to health behavior change (Figure 2) (46–49).

Methods

Design Overview

The entire intervention was comprised of two sequential components with data collected seven times over 90 days. It was structured as a 3 (risk communication format: bulleted list, simple table, risk ladder) × 2 (mental imagery behavior: physical activity, sleep hygiene) between-subjects factorial design. The methods and results described here are related to the first component, which was administered at baseline and investigated risk communication formats. The second component, which was administered after participants completed the activities for the first component, examined whether a mental imagery-based self-regulation intervention, administered by audiorecording and supported by thrice-weekly text messages, could build upon the first component by helping participants move from behavioral intentions to actual behavior change (50).

The research team was blinded to study condition, but it was not possible to blind participants. All procedures and methods were approved by the Institutional Review Board (IRB) at Washington University in St. Louis. The study is registered on clinicaltrials.gov (NCT03255291). The full questionnaire and all study materials can be viewed at https://osf.io/jnwhq/.

Participants

Participants were recruited from the St. Louis Metropolitan area from July 2017 to August 2018. We recruited strategically with the goal of achieving a sample comprised of 50 percent (+/− 5%) of people from underrepresented racial or ethnic groups and at least 50 percent (+/− 5%) individuals who had no more than vocational-technical training. We augmented recruitment efforts with trained staff from the Washington University Recruitment Enhancement Core (REC). The outreach coordinator attended community events and venues

(e.g., job fairs, beauty salons, barbershops, churches) that are located in predominately African American neighborhoods or have a predominately African American clientele.[1] Recruitment strategies also included posting flyers in local businesses, in-person outreach (i.e., local events, food pantries, and libraries), social media and online advertisements (Facebook, Craigslist), local newspaper advertisements, University listservs, a research participant registry database, and word of mouth.

Individuals were eligible if they were age 30–64 and spoke English. Exclusion criteria were: ≥ 150 minutes physical activity weekly (i.e., meeting U.S. national physical activity guidelines) (53), had three or more of the following comorbidities: diabetes, heart disease, stroke, or a history of cancer (non-melanoma skin cancer was permitted). Cancer qualified as two comorbidities for women because it was important that each participant saw at least two diseases. Since the tool did not provide estimates for diseases the participant already had, women who reported a cancer history would not be shown information for either colon or breast cancer. Because the second study component relied on text messaging, there were also exclusion criteria related to having sufficient text-messaging capabilities (e.g., having texted at least twice in the last month).

The study team screened 1198 participants, of whom 478 (39.9%) were ineligible (online supplemental materials Figure A.1), 140 (11.7%) did not schedule or attend data collection, 26 (2.2%) had problematic screening data, and 554 enrolled (46.2%). Of those enrolled, 49 (8.8%) were excluded because they no longer met eligibility criteria at the time of data collection. 505 (91.2%) completed all baseline data collection activities, however, 5 (1.0%) of those participants were excluded due to serious problems understanding the study materials or procedures. These exclusions resulted in a total sample size of 500.

Procedure

Eligible participants completed a 60-minute in person data collection session, either in a small meeting room in a university building easily accessible by public transportation or another location of their choosing. The research assistant obtained written consent and then used an Android smartphone to enter the participant's study identification number into the study website. This action prompted the website to randomize the participant to one of six study conditions according to the 2×3 factorial design described above (Figure A.1). Next, participants used the smartphone to enter information about their personal demographics, risk behavior, and health history. Then, the website used the information to calculate personalized risk estimates for up to five common diseases: colon cancer, heart disease, stroke, diabetes, and breast cancer (women only). Next, the website displayed participants' personalized risk information in the format to which the participant was randomly assigned (i.e., bulleted list, simple table, risk ladder; Figure 1). After they viewed their personal risk information, participants completed a questionnaire assessing the outcomes of interest. The questionnaire was administered on paper. Then, they completed the baseline activities for the

[1]Only 6% of the St. Louis city population is comprised of individuals who identify as a racial or ethnic group other than non-Hispanic white or non-Hispanic black/African American (51). We included them in the study because there was no scientific reason for excluding them, and, therefore, we considered it unethical to prevent their inclusion. However, discriminatory laws and housing practices that produced and maintain residential segregation result in clearly-identifiable African American and white neighborhoods (52). These factors shaped our choices about where to focus recruitment efforts.

second study component (50) and returned the phone to the research assistant. Participants received a $20 gift card for participating in the baseline study activities.

Stimuli

Participants were shown 10-year absolute risk results described in two ways (Figure 1): given their current activity level and if they were to get ≥ 180 min of physical activity weekly (hereafter "risk reduction information").[2] Risk and risk reduction information was provided using qualitative category labels (i.e., very low, low, medium, high, very high).[3] Participants were not shown risk information for diseases that they reported already having a diagnosis. In the risk ladder condition, results were presented with their current risk on the left side of the ladder and an icon reading "click here to see how your results change with exercise" to the right. After 30 seconds the link became active and their risk reduction information appeared on the right side of the ladder. The bulleted list and simple table conditions presented risk and risk reduction information using static formats. The list condition used two sets of bulleted lists of diseases (one for current risk, one for risk reduction information). In the table, each disease had a separate row. One column was for current risk and another column was for risk reduction information.

For the risk ladder condition, the arrow indicating a participant's risk could be placed anywhere within the box representing a given risk category. Thus, the risk ladder conveyed more precise information than the table and list conditions. In addition, presenting risk information sequentially can facilitate risk comprehension (64). Although it would also be possible for information to be presented sequentially with lists and tables, we allowed the formats to vary in these ways, rather than controlling the variations out of the design, to more closely represent how such formats would likely be used in practice rather than in a tightly-controlled experiment.

Measures

All measures were obtained from prior sources and, where necessary, adapted for relevance for the current study or based on feedback obtained during cognitive interviews (N=20, Online Supplementary Materials Appendix B). The measures used for these analyses, indications of their internal consistency, and sources where the items were located are in Table 1. Two items assessed participants' attention (e.g., "To show that you read carefully, please leave this question blank") (65).

Analysis Plan

In addition to the above mentioned exclusion criteria, participants with a technical or likely technical issue with the risk assessment tool display that made it impossible for participants

[2]The calculations were based on (54, 55), which culminated in a suite of public-facing Internet-based risk assessment tools and studies to improve clinical practice (56–59).

[3]Current recommendations suggest communicating risks with numbers rather than (or in addition to) qualitative labels (12). We did not include numbers, because in (35) we found no reliable statistical evidence that adding numbers to category labels in a risk ladder improved comprehension or affected any message evaluation or health cognitions (including perceived risk), either overall or for any particular demographic group. We also considered: recommendations to remove unhelpful graph elements (8, 60, 61); that the goal of our study (i.e., alerting people of the need to engage in more physical activity) was more consistent with communicating risk categories than numerical estimates (61, 62); and that removing numerical information may increase the tool's acceptability to individuals with limited numeracy (63).

to understand the information (n=81),[4] with incomplete data (n=39, 27 of whom had a personal history of diabetes), or who failed both attention check items (n=9) were excluded for a final analytic sample of 372.

Primary Outcomes—The primary outcomes of interest were gist and verbatim comprehension of risk information, and intentions to engage in physical activity in the next 90 days. We defined gist comprehension as being able to extract the bottom-line meaning of information provided by the website (e.g., the direction of the effect of exercise; if exercising decreased health risk), measured as a sum of four variables coded as correct or incorrect (0=low; 4=high). We defined verbatim comprehension as recalling the *exact* categorical information specific to diabetes risk and the exact number of hours of recommended weekly activity, measured as a sum of three variables coded as correct or incorrect (0=low; 3=high). We describe in supplementary materials Appendix C how each participant's comprehension scores were calculated to accommodate the fact that there were multiple diseases, and that the link between exercise and risk reduction varied by participant and disease. We focused on diabetes risk because (a) assessing verbatim comprehension for all five diseases would have been excessively burdensome, and (b) our preliminary data suggested that diabetes was the disease with the lowest prevalence in our study population and therefore would likely be seen by the most participants. Physical activity intentions were measured as an average of three variables (1=low; 5=high).

Potential Mediators and Covariates—Constructs identified as potential mediators of the effect of risk communication format on intentions included perceived risk, response efficacy, self-efficacy, perceived severity, anticipated regret, worry, affective attitude about physical activity, and affect about the results. An item measuring surprise was separated from the affect about the results scale due to a low Cronbach's alpha (Table 1).

All covariates were determined *a priori*. Models for all three outcomes include sex, race/ethnicity (member of underrepresented population *versus* not member), age (50 years or older *versus* younger than 50 years), education (some college or more *versus* vocational-technical or less), numeracy (continuous), and graph literacy (continuous). For intentions only, baseline minutes of activity per week and self-reported health status were also included as continuous variables. Health literacy was considered as a possible covariate but its distribution had limited variability and therefore was excluded from the analyses.

Statistical Analysis—ANCOVAs were used to test the direct effects of risk communication format on each of the three primary outcomes. If the overall F-test for an outcome was statistically significant, post-hoc tests with a Dunnett adjustment for multiple comparisons were conducted to compare adjusted means of each outcome by format condition. Potential moderation of the effect of format on the primary outcomes by participant characteristics was tested by adding interaction terms to the ANCOVA models.

[4]The technical issue affected 21 individuals in the risk ladder condition whose 10-year risk of any disease was ≥44.9%. Specifically, the display for such individuals provided risk information for the same disease 2–3 times or in nonsensical locations (e.g., above the risk ladder or multiple diseases stacked on top of each other despite having different underlying values). To avoid confounding experimental condition by 10-year risk, we removed people of similar risk levels in the text and table conditions who, had they been assigned to the risk ladder condition, likely would have experienced similar technical problems.

We tested sequential mediation using the SAS PROCESS macro, Model 6 (66). This model conducted a series of path analyses in a particular order, guided by our conceptual framework (Figure 2): from format to comprehension; from comprehension to health cognition; and from health cognition to intentions. PROCESS calculates bootstrap confidence intervals around estimates of indirect effects using 10,000 iterations.

Results

Participants (N=500) were distributed evenly across the six study conditions. Socio-demographic characteristics were distributed evenly across the three risk communication format conditions (ps>0.05). As planned, nearly half (45%) of the sample reported being members of an underrepresented racial or ethnic group. We did not meet our education recruitment goal; only 19% of the sample reported having no more than vocational-technical training. People with less formal education were somewhat more often members of underrepresented racial/ethnic groups ($\Phi = -.23$, $p<.001$). Participants who met all other inclusion criteria but who reported a diabetes diagnosis (n=27) were excluded from the analytic sample because they could not answer the items assessing verbatim comprehension of diabetes risk information.

The distribution of participants across study conditions remained balanced after the dataset was restricted to the analytic sample (n=372). However, participants were more often excluded if they were men, age 50 or older, obese, and had at least one comorbidity. Excluded participants also had lower education, numeracy, and graph literacy, had poorer self-reported health status, and reported less physical activity at baseline than participants who were retained. Table 2 lists descriptive statistics of the analytic sample. On average, men saw information about 3.9 diseases, and women saw information about 4.9 diseases. Supplemental materials table A.1 shows mean values and variability of the constructs of interest, as well as their intercorrelations.

Main Analyses

Contrary to the hypotheses, the direct effects of risk communication format on verbatim comprehension and physical activity intentions were of negligible size and not statistically significant (Table 3). However, there was a small but significant effect on gist comprehension. Participants who saw the risk ladder had, on average, 0.4 points (95% CI: 0.1, 0.7) higher gist comprehension of their personalized risk information than those in the list condition (*post-hoc* p=0.01, Dunnett-Hsu correction for multiple comparisons). There was a non-significant average 0.2 point (95% CI: −0.1, 0.5) difference in gist comprehension between the table and list conditions (*post-hoc* p=0.19) and the ladder and table (*post-hoc* p=0.21) conditions.

Most analyses examining socio-demographic characteristics as moderators of the effect of risk communication format condition on verbatim comprehension yielded effects of negligible size and that were not statistically significant (ps>0.05, partial η^2<0.01). Age was the only exception (F 2, 351)=8.9, p=0.04, partial η^2=0.02). However, *post-hoc* contrasts yielded no statistically significant effects of display on gist comprehension within age category (ps>0.05).

As hypothesized, sequential mediation analyses revealed a sequence of effects such that there was a small beneficial indirect effect of risk ladder *versus* list on physical activity intentions through gist comprehension and then through perceived risk ($b_{\text{Indirect Effect}}$=0.02, 95% CI: 0.00, 0.04; Supplemental Materials Figure A.2). Contrary to our hypothesis, there was no indirect effect of ladder *versus* list on intentions through gist comprehension and then response efficacy ($b_{\text{Indirect Effect}}$=0.01, 95% CI −0.00, 0.03). Furthermore, there was no sequential indirect effect of table *versus* list on intentions through gist comprehension and then through either perceived risk ($b_{\text{Indirect Effect}}$=−0.01, 95% CI −0.00, 0.02) or response efficacy ($b_{\text{Indirect Effect}}$=0.00, 95% CI: −0.01, 0.02).

The analyses also revealed two statistically significant simple mediation pathways. First, perceived risk acted as a mediator of the small beneficial indirect effect of risk ladder *versus* list on intentions ($b_{\text{Indirect Effect}}$=0.10, 95% CI: 0.03, 0.19). Second, response efficacy acted as a mediator of a small beneficial indirect effect of table *versus* list on intentions ($b_{\text{Indirect Effect}}$=0.10, 95% CI: 0.01, 0.21; Supplemental Materials Figure A.3).

There were no direct effects of format on self-efficacy, perceived severity, anticipated regret, worry, affective attitude about physical activity, affect about the results, or surprise about the results) (ps>.05, partial η^2<0.02). Therefore, they are not considered further as potential mediators of the effect of format on intentions.

Discussion

We examined whether a risk ladder, a simple table, or bulleted list best fostered laypeople's ability to draw an accurate and meaningful picture of the impact of physical activity on their disease risk and to increase their motivation to engage in physical activity. To maximize the likelihood that our research could generalize to populations most in need of physical activity support, we recruited a large community sample that included a large proportion of African American participants and participants with only moderate levels of numeracy and graph literacy. Finally, we increased the study's realism by providing participants with personalized risk information that reflected their personal demographic, health history, and behavioral risk factors (rather than hypothetical information). We report three key findings.

Two of the key findings are related: first, the risk ladder elicited higher gist comprehension than the simple table and the bulleted list; second, the effect of the risk ladder on gist comprehension seemed generally comparable across levels of education, numeracy, and graph literacy, and for people who were and were not members of underrepresented racial or ethnic groups. This pair of findings is consistent with the existing literature, which suggests that risk ladders can help people understand and interpret complex risk information (27), even when they have low numeracy (28). We extend that research to demonstrate that risk ladders can also be effective in improving gist comprehension for people with other characteristics that may make them either vulnerable to misunderstanding risk information, including education and graph literacy. We also demonstrate that our findings are generalizable to African Americans, who are a key group at risk for health disparities who are also under-represented in much risk communication research. We note that, although the risk ladder and table were not statistically significantly different from each other in their

effects on gist comprehension, the table was not statistically significantly superior to the bulleted list (Table 3).[5] Therefore, caution should be used when deriving conclusions about the equivalence of risk ladders and tables for increasing risk comprehension in contexts in which multiple disease risks are provided.

The third key finding is that the different risk communication formats appeared to shape behavioral intentions through different mediating mechanisms proposed by our conceptual framework. Even though the initial effect of format on the mediators was not sufficiently strong to extend through the entire pathway to produce between-format differences in physical activity intentions, the findings provide insight into the downstream consequences of researchers' choice of risk communication format. Specifically, whereas the risk ladder shaped intentions through gist comprehension and then perceived risk, the table shaped intentions through response efficacy without affecting either gist or verbatim comprehension. Although some research has examined the effect of risk ladders on perceived risk (26, 27), little work on either risk ladders or tables/drug facts boxes has examined formal mediation processes (but see (67)). Future work dedicated to understanding why the risk ladder and table produced different effects on the different constructs is needed. Nevertheless, these findings are consistent with what would be predicted by health behavior change theories and taxonomies (36, 68); interventions that target one or two health cognitions may lead to some change, but ensuring behavior change likely requires multiple components that target multiple constructs.

It is not possible to say whether the findings were driven by the ability of the risk ladder to convey more precise within-category information than the table and list, by sequential presentation of risk information, the colors used for the risk ladder, or some other aspect of visual design. One eye-tracking study reported that risk ladders may help people with low numeracy better attend to and draw affective meaning from risk information (28). However, it included only one type of risk ladder and did not compare results to other formats. Future research should examine which elements of risk ladders work via which visual, perceptual, and attentional processes to facilitate understanding. There is also critical need to examine whether risk ladders produce unintended adverse events, such as falsely reassuring individuals who are at low risk or promoting comparisons to people they think may be at higher risk (69).

Limitations and Future Directions

Several aspects of the study limit the generalizability of the findings to the broader U.S. population and to specific population segments. We had limited success recruiting men, people with limited formal education, and people who reported Hispanic, Asian, or American Indian ancestry. We excluded individuals younger than 30 years old (to increase the intervention's perceived personal relevance) and older than 64 (the cohorts used to calculate 10-year risk estimates (34) included few people over age 74). We excluded participants with minimal texting experience. Future research should replicate the findings in these groups.

[5]See below for results of sensitivity analyses that included the entire sample rather than the analytic sample.

There are several statistical considerations. First, we needed to remove 128 participants from the analytic dataset (Figure A.1). Removing these individuals likely resulted in wider confidence intervals than we planned for and therefore also likely limited our ability to detect significant interactions between format and socio-demographic characteristics. Second, we did not adjust the significance criterion to account for three primary outcomes. A conservative Bonferroni correction results in the significant effect of format on gist comprehension moving to non-significance (i.e., $p<.017$). Third, the individuals who were removed were disproportionately from populations that experience health disparities. Sensitivity analyses that included everyone except those who were missing data for the primary outcomes yielded results that were generally similar to those for the analytic sample (analyses not shown). The only difference was the appearance of a significant benefit of table *versus* list for gist comprehension. Despite these limitations, we remain reasonably confident that the risk ladder would facilitate gist comprehension in other samples. Not only are our findings consistent with the existing literature (26, 45), sensitivity analyses indicated the findings were robust to differential attrition.

We considered including study conditions that provided (a) *non*-personalized risk information, (b) risk information for only a single disease, and/or (c) a component to increase self-efficacy of engaging in physical activity, but decided to use the current study findings to guide future work examining those issues. Future research should also examine the effect of adding an interactive element to the list and table conditions, not just the risk ladder. Future research should also investigate verbatim comprehension more closely. We assessed verbatim comprehension only for diabetes, not all diseases that a participant viewed. This decision was made to limit participant burden and enable data collection in the field, which was essential for recruiting participants from underrepresented populations. Researchers should explore ways to assess comprehension for multiple diseases in a way that limits participant burden and anxiety. Finally, future research should investigate how to incorporate numerical estimates into a risk ladder, and if doing so provides benefits in promoting comprehension of risk magnitude over and above that provided by tables or bulleted lists. This is an under-studied area; successful integration of numerical estimates into risk ladders could allow them to be used for shared decision making about treatments that have a complex array of benefits and side effects (61).

Conclusions

The risk ladder for this study was used to communicate personalized risk and risk reduction information for diseases related to physical activity. It fostered higher gist comprehension of the importance of physical activity for reducing disease risk relative to a bulleted list. That the benefits of the risk ladder did not seem to benefit one socio-demographic group over another suggests that it may be another tool (alongside icon arrays for medical treatment tradeoff decisions (12, 24)) for communicating gist information about the benefits of different health promoting behaviors with people from underrepresented communities. When combined with strategies to promote actual behavior change, such as self-regulation interventions (36, 50, 68), such versatility could make risk ladders a valuable new tool in the risk communication toolbox.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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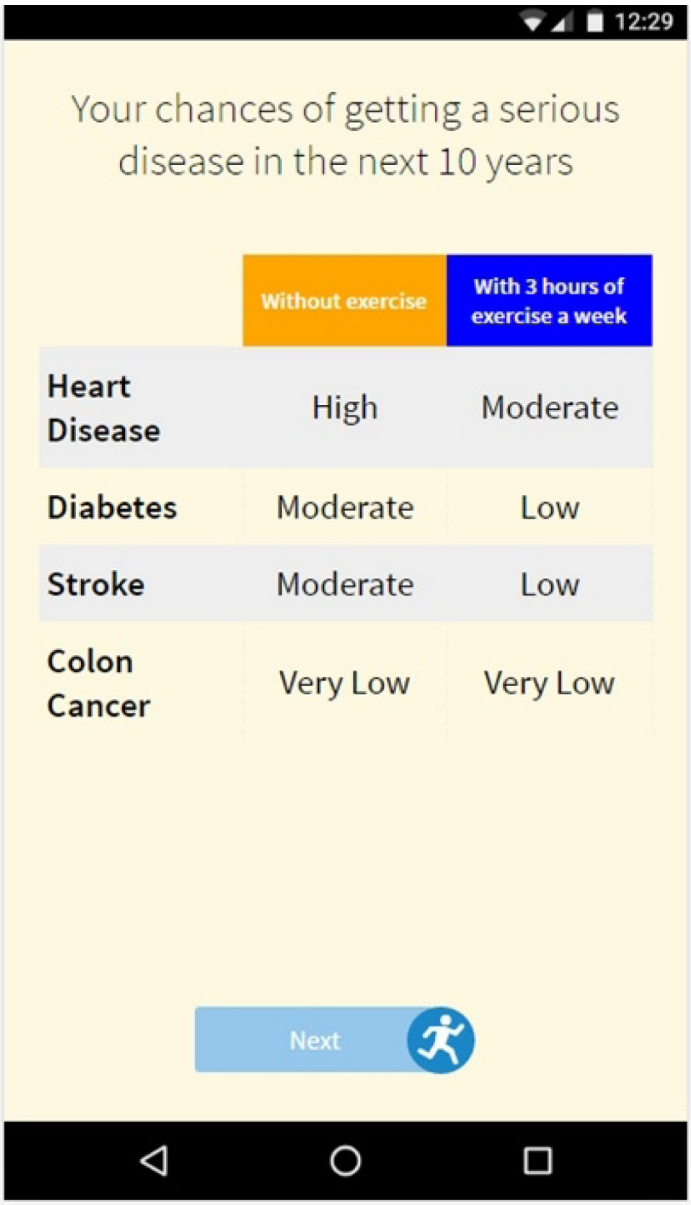

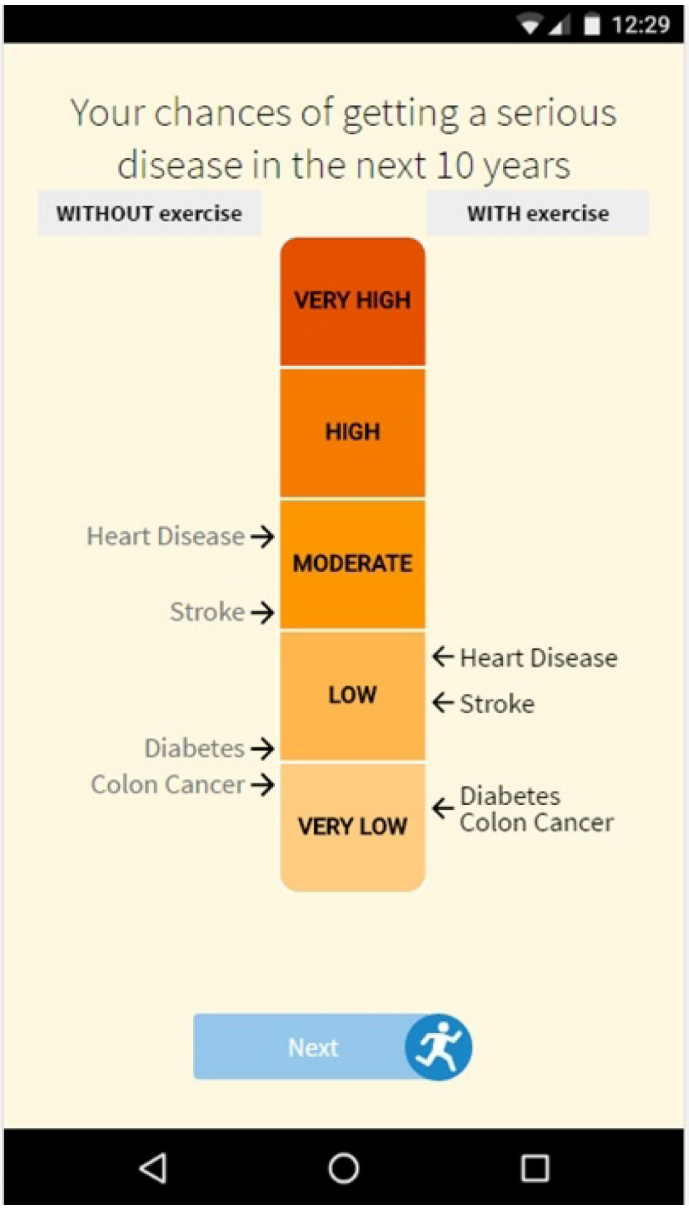

Figure 1.
Three risk communication formats: (A) bulleted list, (B) simple table, and (C) risk ladder.

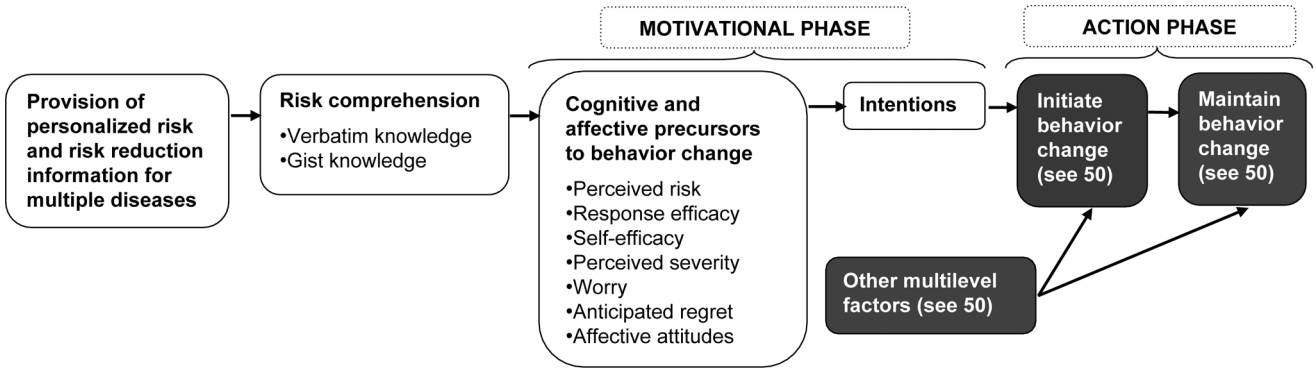

Figure 2.
Conceptual framework

Table 1.

List of constructs, item wording, and indication of internal consistency

Scale *(Cronbach's a where applicable)*	**Question**
Verbatim Comprehension[a] (adapted from (1, 29))	"Think back to what the app said about your chances of getting different diseases. According to the information in the app, what are your chances of getting diabetes if you do exercise?"
	"According to the information in the app, what are your chances of getting diabetes if you do not exercise?"
	"Think back to what the app showed you about exercise. According to the app, how many hours of exercise should you get each week?"
Gist Comprehension[b] (adapted from (1, 29))	"According to the app, if I started exercising my chances of having health problems could…"
	"According to the app, not exercising generally…"
	"According to the app, exercising is generally…"
	"According to the app, if I do not exercise I could be…"
Intentions[c] (70) *(α=0.86)*	"I intend to get regular moderate intensity exercise in the next 3 months."
	"I want to get regular moderate intensity exercise in the next 3 months."
	"I am likely to get regular moderate intensity exercise in the next 3 months."
Affect about Results[d] *(α=0.72)*	"Think back to when the app showed you your chances of getting the diseases. How good do you feel about the results?"
	"How bad do you feel about the results?"
Surprised about Results[e]	"How surprised do you feel about the results?"
Minutes of Exercise in the Previous Week (adapted from (71))	"In the last 7 days, how many days did you do any exercise of at least moderate intensity?
	"Number of days: ____"
	"On the days that you did any exercise of at least moderate intensity, for how long did you do these activities?
	Number of minutes per day: ____"
Self-Efficacy[c] (72) *(α=0.95)*	"I am confident I can get regular moderate intensity exercise in the next 3 months."
	"I am sure I can adjust my life to a physically active lifestyle in the next 3 months."
	"I am certain I can get regular moderate intensity exercise in the next 3months."
Perceived Risk[f] (35) *(α=0.89)*	*Absolute Perceived Likelihood* "Imagine that you do not get regular physical activity. How likely do you think it is that you will get sick from any of these diseases in the next 10 years, if you do not get regular physical activity?"
	Absolute Feelings of Risk "Imagine that you do not get regular physical activity. How easily do you feel you could get sick from any of these diseases in the next 10 years, if you do not get regular physical activity?"
	Comparative Perceived Likelihood "Compared to other people your age and sex, how likely do you think it is that you will get sick from any of these diseases in the next 10 years, if you do not get regular physical activity?"

Scale *(Cronbach's a where applicable)*	Question
Response Efficacy[c] (73) *(α=0.90)*	*Comparative Feelings of Risk* "Compared to other people your age and sex, how easily do you feel you could get sick from any of the diseases in the next 10 years, if you do not get regular physical activity"
	"Getting regular moderate intensity exercise will reduce my chances of getting sick from any of the diseases shown in the app."
Anticipated Regret[c] (74) *(α=0.93)*	"Getting regular moderate intensity exercise is a good way for me to prevent the diseases shown in the app"
	"Getting regular moderate intensity exercise will lower my risk of getting sick from any of the diseases shown in the app."
	"If I got one of the diseases shown in the app because I did not get regular moderate intensity exercise, I would feel regretful."
Affective Attitude towards Exercise[g] (75) *(α=0.85)*	"I would be mad at myself if I got one of the diseases shown in the app because I did not get regular moderate intensity exercise."
	"I would regret it if I got one of the diseases shown in the app because I did not get regular moderate intensity exercise."
	"Getting regular exercise is enjoyable."
	"Getting regular exercise is unpleasant."
	"Getting regular exercise is fun."
Perceived Severity (71)	"Think about 100 people with ANY of the diseases shown on the app. Out of those 100 people, about how many do you think will survive at least 5 years? If you are not sure, take your best guess._____ people will survive" *(This item was reverse-scored for analyses so that higher estimates represent higher perceived severity)*
Disease Worry[h] (71)	"How worried are you about getting sick from any of the diseases shown on the app?"
Education[i] (71)	"What is the highest level of formal schooling you finished?"
Self-Reported Health Status[j] (71)	"In general, would you say that your health is:"
Health Literacy[k] (76)	"How often do you need to have someone help you when you read instructions, pamphlets, or other written material from your doctor or pharmacy?"
Numeracy (77)	"Imagine that we flip a fair coin 1,000 times. What is your best guess about how many times the coin would come up heads in 1,000 flips? _____ times"
	"Imagine that the chance of getting a disease is 1%. If there were 1,000 people, about how many would be expected to get the disease? _____ in 1,000 people will get the disease."
	"Imagine that the chance of getting an infection is 1 in 1,000. What percent of people would be expected to get the infection? _____ % will get the infection."
Graph Literacy (43, 78)	"The graph below shows the percentage of people who die from different types of cancer. About what percentage of people who die from cancer die from cancer B, cancer C, and cancer D combined?"
	"The graph below shows the number of men and women with Disease X The total number of circles is 100 How many more men than women are there among 100 patients with Disease X?
	"You see two magazine advertisements on separate pages. Each advertisement is for a different drug for treating heart disease. Each advertisement has a graph showing the effectiveness of the drug compared to a placebo (sugar pill). Compared to the placebo, which treatment leads to a larger decrease in the percentage of patients who die?"
	"You see two newspaper advertisements on separate pages. Each advertisement is for a different treatment of a skin disease. Each advertisement has a graph showing the effectiveness of the treatment over time. Which of the treatments show a larger decrease in the percentage of sick patients?

[a] 1=Very Low; 2=Low; 3=Medium; 4=High; 5=Very High; 6=Do not know

1=A half hour; 2=1 hour; 3=2 hours; 4=3 hours; 5=4 hours; 6=Do not know

[b] 1=Go Up; 2=Go Down; 3=Not Change; 4=Do not know

1=Increases my risk; 2=Decreases my risk; 3=Does not change my risk; 4=Do not know

1=Good for my health; 2=Bad for my health; 3=Does not affect my health; 4=Do not know

1=Improving my overall health; 2=Harming my overall health; 3=Not changing my overall health; 4=Do not know

[c] 1=Do not agree at all; 2=Agree a little; 3=Agree some; 4=Agree a lot; 5=Agree completely

[d] 1=Not good at all; 2=A little good; 3=Somewhat good; 4=Very good; 5=Extremely good

1=Not bad at all; 2=A little bad; 3=Somewhat bad; 4=Very bad; 5=Extremely bad

[e] Analyzed separately from positive affect due to low Cronbach's alpha. 1=Not surprised at all; 2=A little surprised; 3=Somewhat surprised; 4=Very surprised; 5=Extremely surprised

[f] 1=Not at all likely; 2=A little likely; 3=Somewhat likely; 4=Very likely 5=Extremely likely; 6=Do not know

1=Not at all easily; 2=A little easily; 3=Somewhat easily; 4=Very easily; 5=Extremely easily 6=Do not know

1=Much less likely than others; 2=Less likely than others; 3=About as likely as others; 4=More likely than others; 5=Much more likely than others; 6=Do not know

1=Much less easily than others; 2=Less easily than others; 3=About as easily than others; 4=More easily than others; 5=Much more easily than others; 6=Do not know

[g] 1=Do not agree at all; 2=Agree a little; 3=Agree some; 4=Agree a lot

[h] 1=Not at all worried; 2=A little worried; 3=Somewhat worried; 4=Very worried

[i] 1=Less than a high school degree; 2=High school degree or equivalent; 3=Vocational or technical degree or certificate; 4=Some college, no degree; 5=Associate's degree; 6=Bachelor's degree; 7=Graduate or professional degree

[j] 1=Excellent; 2=Very good; 3=Good; 4=Fair; 5=Poor

[k] 1=Never; 2=Rarely; 3=Sometimes; 4=Often; 5=Always

Table 2.

Frequencies and Mean (SD) of Variables Used in Analyses (N=372)

	Analytic Dataset (n=372)	Original Dataset (N=500)
Variable	**n (%)**	**n (%)**
Age 50–64	163 (43.8%)	253 (50.6%)
Women	315 (84.7%)	407 (81.4%)
Race		
American Indian or Alaskan Native	0 (0.0%)	2 (0.4%)
Asian or Pacific Islander	6 (1.6%)	6 (1.2%)
Black or African-American	124 (33.3%)	185 (37.0%)
White or Caucasian	224 (60.2%)	284 (56.8%)
Multiracial or Other	18 (4.8%)	23 (4.6%)
Ethnicity - Hispanic[a]	12 (3.2%)	17 (3.4%)
Highest Level of Formal Schooling		
Less than high school	3 (0.8%)	11 (2.2%)
High school or equivalent	44 (11.8%)	67 (13.4%)
Vocational-technical training	12 (3.2%)	19 (3.8%)
Some college, no degree	58 (15.6%)	90 (18.0%)
Associate's degree	35 (9.4%)	48 (9.6%)
Bachelor's degree	108 (29.0%)	130 (26.0%)
Graduate or professional degree	112 (30.1%)	133 (26.6%)
Missing	0 (0.0%)	2 (0.4%)
BMI - Obese	161 (43.3%)	258 (51.6%)
BMI - Overweight	106 (28.5%)	127 (25.4%)
1+ comorbidity	24 (6.5%)	92 (18.4%)
Variable[b]	**Mean (SD)**	**Mean (SD)**
Baseline Exercise	54.6 (45.0)	52.4 (44.7)
Self-Reported Health Status	3.2 (0.9)	3.0 (0.9)
Numeracy	1.6 (1.0)	1.5 (1.0)
Graph Literacy	2.5 (1.1)	2.3 (1.1)
Verbatim Comprehension	1.7 (0.9)	1.7 (0.9)
Gist Comprehension	3.1 (1.5)	3.4 (1.2)
Number of Disease Risks Viewed[c]		
Women	4.9 (0.4)	4.8 (0.5)
Men	3.9 (0.3)	3.7 (0.6)

[a] 154 of 372 participants (41.4%) in the analytic sample reported being a member of an underrepresented racial or ethnic group. In contrast, 225 of 500 participants (45.0%) in the full sample reported being a member of an underrepresented racial or ethnic group.

[b] Ranges of continuous variables: Self-reported health status (1–5), verbatim comprehension & numeracy (0–3), gist comprehension & graph literacy (0–4). Higher scores indicate higher levels of the construct.

[c] Women viewed risks for up to 5 diseases; Men viewed risks for up to 4 diseases.

Table 3.

Main effects of risk communication format on primary outcomes

Primary Outcome[a]	F	*df*	*p*	Partial η^2	Risk Ladder Mean (95% CI)	Simple Table Mean (95% CI)	Bulleted List Mean (95% CI)
Gist Comprehension[b]	3.4	2, 363	0.03	0.02	3.6 (3.4, 3.9)	3.4 (3.1, 3.7)	3.2 (3.0, 3.5)
Verbatim Comprehension	0.7	2, 363	0.49	0.004	1.6 (1.4, 1.8)	1.6 (1.4, 1.8)	1.5 (1.3, 1.7)
Intentions to Exercise	2.0	2, 361	0.14	0.01	3.9 (3.7, 4.1)	4.0 (3.8, 4.2)	3.8 (3.6, 4.0)

[a]Adjusted for sex (men / women), race (non-Hispanic white / member of underrepresented group, age (<50 / ≥50 years, education (vo-tech or less / some college or more), numeracy (continuous), graph literacy (continuous), baseline exercise

(continuous; intentions only), self-reported health status (continuous, intentions only)

[b]The difference in gist comprehension between the risk ladder and bulleted list conditions is statistically significant (0.4, 95% CI 0.1, 0.7, p=0.01) after employing the Dunnett-Hsu adjustment for post-hoc comparisons. Overlapping confidence intervals in the table are an artifact of reporting least-squares mean values per condition, which are calculated differently from the test of differences between means.