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# THE EFFECT OF ICON ARRAYS AND ANALOGIES IN RISK COMMUNICATION AMONG ADOLESCENT CHILDREN

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The aim of the study was to measure the effect of icon arrays and analogies on the comprehension of risk information in adolescents aged 11–15 years. We tested whether icon arrays lead to higher accuracy in simple risk calculation tasks and in difficult tasks such as trade-off and Bayesian problems compared to the numerical format. We also measured whether analogies improved risk understanding. Icon arrays led to better understanding of risk information and more accurate risk comparisons. The effects varied according to the difficulty of the task and the risk literacy of the participants. Analogies were helpful for adolescents with high risk literacy.

*Keywords:* risk communication; graphical format; risk literacy; icon arrays.

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## 1. Introduction

Previous research has shown that presenting medical risks as visual displays improves risk comprehension in adults [3; 6; 9; 30] and children [21; 29]. Different formats have been used, including bars, pie charts, icon arrays (or pictographs) and risk ladders. Several papers compared different formats and showed that icon arrays or pictographs could be more helpful for both patients and physicians than other visual formats or numerical formats [1; 3; 5; 7; 8; 20; 22; 32]. At the same time, some other experiments found that icon arrays were less helpful than some other formats or found no difference between them [4; 28]. The effect varied depending on the design features of the icon arrays, e.g. vertical or horizontal orientation, shading or no shading [17]. Galesic & Garcia-Retamero [9] found that not only visual representations, but also analogies, contribute to the comprehension of medical information in adults. In this way, analogies are used to illustrate information by comparing objects from different domains.

In this paper we aimed to measure the *effect of icon arrays and analogies on the comprehension of risk information* in adolescents aged 11–15 years. Although there are a number of experimental studies with adults and some studies with younger children (6–11 years), there are almost no experimental studies with adolescents. In Experiment 1, with 213 participants, we tested whether icon arrays produced higher accuracy in simple risk calculation tasks and reduced the ratio-bias effect. We also measured whether analogies were helpful in understanding some medical information. In Experiment 2, with 157 participants, we tested whether icon arrays produced higher accuracy in difficult tasks such as trade-off and Bayesian problems.

## 2. Literature Review

There are two theoretical explanations for the use of icon arrays in risk communication [24]. One explanation is based on ecological arguments about the frequency coding of information. Gigerenzer argued that individuals process information more easily and can solve Bayesian problems when probabilistic information is presented in frequency format [13, 14]. In a series of experiments, Cosmides and Tooby [3] showed that frequentist versions of Bayesian problems produce a higher proportion of correct estimates of posterior probabilities. Based on these theoretical arguments, the icon array format should elicit frequentist coding since discrete icons represent specific individuated objects. The other explanation is based on the argument that icon arrays provide a good overview of the general subset relationship between the prior and the posterior probabilities [27; 31]. In a series of the experiments, Brase [1] supported the former theoretical explanation. Some researchers have shown that icon arrays have a stronger effect on the accuracy among low-literacy individuals rather than among high-literacy individuals compared to the numerical format [11]. Previous research has shown that icon arrays produce lower risk perceptions than other formats [16; 23; for an exception see 25]. At the same time, icon arrays have been found to increase the attention to the denominators [11, 12].

Visual displays were found to be efficient in risk communication among both adults and children. Multmeier [21] found that icon arrays were more significant factors for the second- and fourth-graders (7–11 years of age) than frequentist format in solving Bayesian problems. Multmeier [21] found that 22% of second graders and 60% of fourth graders answered all questions correctly in the icon array condition, while these proportions were 11% and 40% in the frequentist condition. Ulph, Townsend, & Glazebrook [29] found pie charts were more helpful for children 7–11 years of age in simple probabilistic tasks compared to frequentist format, percentages or verbal labels (e.g., rarely, often).

It was found that analogies help to understand medical information among adults [9]. Analogies illustrate information by comparing objects from other domains. For example, explaining that a positive mammography screening result does not always mean that a woman has breast cancer by using the analogy that not all activated metal detectors mean that someone is carrying a weapon. Analogies were more helpful to high risk literacy individuals in difficult medical problems, while they were more helpful to low literacy individuals in simple medical problems.

We hypothesized that icon arrays would improve the accuracy of risk comprehension and risk comparison in adolescents. However, in line with previous research, we expected the effect size to vary according to participants' risk literacy and the cognitive difficulty of the task (*Hypothesis 1*). We also expected that icon arrays would lead to lower risk perceptions than numeric format, but would increase attention to the denominators (*Hypothesis 2*). Finally, we expected that analogies would improve the accuracy of risk comprehension and risk comparison in adolescents, but the effect size would vary according to participants' risk literacy and the cognitive difficulty of the task (*Hypothesis 3*). To test these hypotheses, we conducted two experimental studies.

# 3. Methods

## 3.1. Experiment 1

### *3.1.1. Participants*

The experiment was carried out in a school in Moscow, Russia. All children in 6$^{th}$, 7$^{th}$ and 8$^{th}$ grade, aged 11–15 years, participated in the experiment and completed a web survey in computer class. The children were randomly assigned to conditions. The experiment took place in April–May 2016. A total of 213 participants completed the survey. The mean age was 13.8 years (*SD* = 1.1). 58% of the participants were girls. The average risk literacy score was 11.1 out of 15, with no differences between conditions. Those who scored average or below were classified as having low risk literacy and those who scored above average were classified as having high risk literacy. The risk literacy scale was adapted from scales used by [18] and [26]. The graph literacy scale was adapted from the scale developed by [10].

*3.1.2. Design and procedure*

The methodology was approved by the school management and parents were informed about the study. All respondents completed the survey in a computer classroom equipped with 15 PCs. All were provided with paper and pencil for the calculations if they needed it. They were asked not to use calculators. No incentives were given. The children were told about the purpose of the study, what they would be asked to do, and the confidentiality of the information they would provide. They were told that they could withdraw if they felt uncomfortable.

Prior to the fieldwork, we conducted cognitive interviews with 20 adolescents aged 11–15 years and pre-tests with 40 adolescents. The main tasks included risk calculation, risk perception and medical problems with or without analogies.

*– Risk calculations: icon arrays vs. numerical format*

The questions were adapted from [11]. Respondents were asked to calculate the number of treated and untreated people who would die in different scenarios. There were four vignettes. In one vignette, respondents were given the following information

> Astatin is a new drug that reduces the risk of dying from a heart attack. Here are the results of a study involving 1000 patients:
> – 50 out of 500 of those who did not take the drug died of a heart attack,
> – 30 out of 500 who took the drug died of a heart attack.

Respondents were asked to calculate the number of people who did not take the drug and who died of a heart attack and the number of people who took the drug and who died of a heart attack per 1000 people. Icon arrays were generated by iconarray.com (Risk Science Center and Center for Bioethics and Social Sciences in Medicine, University of Michigan). See Figure 1 in the Appendix.

– *Risk perception: icon arrays vs. numerical format*

The questions were adapted from [11]. There were two different icon arrays for treated and untreated individuals. There were four vignettes with two levels of treatment risk reduction (20% and 60%) and two levels of denominator size (100 and 1,000). In one vignette, respondents were given the following information

> Biffiroz is the new infection. Here are the results of a study of 200 patients:
> – 10 out of 100 of those who had no medical screening died of the infection,
> – 8 out of 100 of those who had medical screening died of the infection.

Respondents were asked to rate on a 10-point scale how serious the new infection was and how helpful the medical screening was in reducing the risk of infection. See Figure 2 in the Appendix.

– *Analogies vs. no analogies*

The tasks were adapted from [9] and [26]. There were two simple and two difficult medical problems. In the simple medical problems, respondents were asked to rate what people should know first when they receive positive results from medical screenings. Prior to the simple tasks, participants were told that they should first know that a positive screening result does not always mean that individuals actually have the disease. In the analogy condition, participants were given the following two examples, which have been found to be efficient in adults [9] and clear for adolescents according to the pre-test results: just because a car alarm is making noise does not mean that someone is trying to steal the car; and not all activated metal detectors mean that someone is carrying a weapon.

In difficult medical problems, participants were expected to find the correct answer to the information they needed to know first in order to judge the effectiveness of medical treatments. Before the tasks, they were told that if a drug reduced the risk of a disease by 50%, they first needed to know the risk of contracting the disease. In the analogy condition, participants were presented with two scenarios: in order to judge the usefulness of a flu vaccine in reducing the risk of getting the flu, one should know the probability of getting the flu; and in order to judge the usefulness of daily consumption of broccoli in reducing the risk of getting cancer, one should know the risk of getting cancer.

### 3.2. Experiment 2

*3.2.1. Participants*

The experiment was carried out in two schools in Moscow, Russia. All children were in either 7th or 8th grade and aged 12–15 years. They participated in the experiment and completed a web survey in their computer classes. The children were randomly assigned to the conditions. The experiment took place in November 2016. 157 participants completed the survey. The average age was 13.5 years (*SD* = 0.6). 58% of respondents were girls. The average risk literacy score was 10.2 out of 15.

*3.2.2. Design and procedure*

The data collection procedure was the same as in Experiment 1. The main tasks included difficult calculation tasks: trade-offs and Bayesian problems.

– *Tradeoffs: icon arrays vs. numeric format*

There were two main tasks adapted from [15] and [30].

*Trade-off 1: Total risk before and after treatment*

Two cognitively demanding questions asked respondents to calculate the risk of getting two viruses after treatment and to judge whether the overall risk of getting viruses after treatment had increased, decreased

or remained the same compared to the overall risk before treatment. Two other questions were less cognitively demanding and provided information about the overall risk of getting viruses after treatment. Examples of these questions:
– Cognitively demanding question:

> – Risk of getting virus S: 40 out of 100
> – Risk of getting virus U: 4 out of 100
> A new drug reduces the risk of virus S by three quarters, but also triples the risk of virus U. Does taking the new drug reduce, increase or have no effect on the overall risk of virus S and virus U?

– Simple question:

> – Risk of disease T: 30 out of 100
> – Risk of disease F: 6 out of 100
> A new drug reduces the risk of disease T by two thirds, so that the new risk of disease T is 10 out of 100, but it also triples the risk of disease F, so that the new risk of disease F is 18 out of 100. The total risk is now 28 out of 100. Does taking a new drug reduce, increase or have no effect on the overall risk of disease T and disease F?

In the icon array condition, there were two different graphs before and after treatment. See Figure 3 in the Appendix.

*Tradeoff 2: the risk of operation and side effects before and after treatment*

Respondents were asked to calculate the risks of surgery and two side effects (migraine and pneumonitis) while taking one of the two treatments. For each scenario (no pill, pill A, pill B) the risk of surgery, migraine and pneumonia was given. Participants were asked to answer eight questions in which they had to calculate the risks. An example of a question:

How many fewer people out of 100 would need an operation if they took pill A, compared with people who did not take a pill at all?

In the icon array condition, there were three different pictographs illustrating the risk of surgery, migraine and pneumonia for each treatment (no pill, pill A, pill B). See Figure 4 in the online Appendix.

– *Bayesian tasks: icon arrays vs. numeric format*

The Bayesian task was adapted from Brase [1]:

> A person has a 6 in 100 chance of having the infection. There is a test to detect the infection. But only 4 out of 6 chances of having the infection are associated with a positive reaction from the test. 16 of the remaining 94 chances of not having the infection are associated with a false positive result for infection.

Participants were asked three Bayesian inference questions. See Figure 5 in Appendix.

## 4. Results

### 4.1. Experiment 1

#### *4.1.1. Risk calculation*

On average, participants gave six correct answers out of eight, with no significant difference between the conditions: 6.2 (*SD* = 2.3) in the control condition and 5.8 (*SD* = 2.8) in the experimental condition. Contrary to expectations, icon arrays reduced the mean number of correct answers for participants with low literacy risk: 5.8 (*SD* = 2.6) in the control condition and 4.6 (*SD* = 3.3) in the experimental condition. Almost no difference was found for participants with high numeracy skills: 6.7 (*SD* = 1.7) and 6.9 (*SD* = 1.8), respectively (see Figure 1). ANOVA showed the effect of risk literacy, $F(1, 211) = 23.2$, $p < 0.001$, $\eta^2 = 0.10$, no effect of the icon array format, but a significant small interaction effect between risk literacy and icon array format, $F(1, 211) = 10.3$, $p < 0.01$, $\eta^2 = 0.05$.

#### *4.1.2. Risk perception: the ratio-bias effect*

Mixed-effects linear models showed no difference between the icon array and numeric formats in risk perception and perception of the benefit of screening in reducing risk. Contrary to expectation,

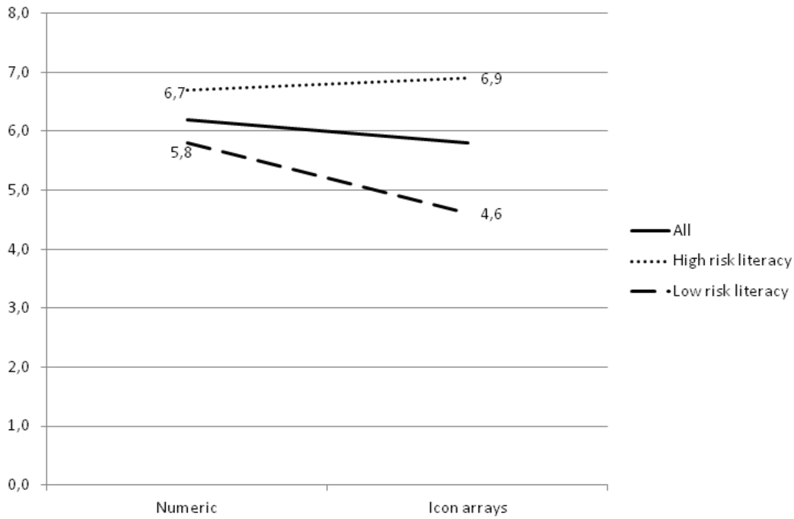


***FIG. 1. Risk calculation tasks***

there was no interaction effect between icon array format and denominator. A larger denominator increased risk perception ($F = 73.1$, $\beta = 0.98$, $p < 0.001$) and a larger relative risk reduction decreased risk perception ($F = 27.2$, $\beta = -0.86$, $p < 0.001$). Similarly, there was no interaction effect between icon array format and denominator for the perceived benefit of screening.

*4.1.3. Analogies*

We calculated the proportion of participants who were accurate on both questions about difficult medical problems and on both questions about simple medical problems. To estimate the effect of analogies, we performed an ANOVA model [2; 9; 11; 19]. Analogies were helpful for highly literate participants faced with difficult medical questions: while 39% gave correct answers in the control condition, 47% did so in the experimental condition (*Chi-squared*(1) = 0.78, $p = 0.377$, Cohen's $d = 0.17$, see Figure 2). No difference was found

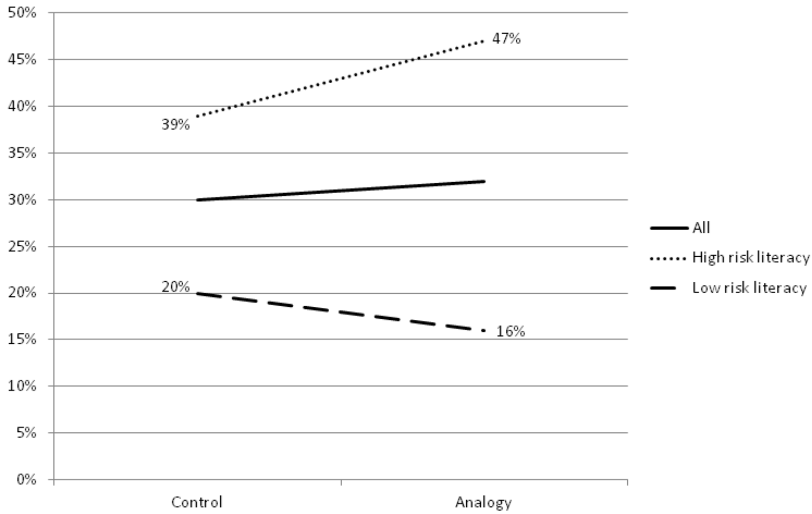


***Fig. 2. Difficult medical problems***

for adolescents with low literacy skills: 20% in the control condition and 16% in the experimental condition. ANOVA showed the effect of risk literacy, $F(1, 211) = 16.4$, $p < 0.001$, $\eta^2 = 0.07$, and the interaction between risk literacy and analogies, $F(1, 211) = 9.5$, $p < 0.01$, $\eta^2 = 0.04$. No effect of analogies was found for simple medical problems.

### 4.2. Experiment 2

#### *4.2.1. Tradeoff 1: total risk before and after treatment*

*Cognitively demanding questions*

In line with the expectations, icon arrays increased the proportion of those participants who gave both accurate answers to cognitively demanding questions: 20% in the numeric format and 43% in the icon array format (*Chi-squared*(1) = 9.95, $p < 0.01$, $d = 0.49$). Higher accuracy among both low risk literacy (an increase from 21% to 38%) and high risk literacy participants (an increase from 18% to 48%) was found in the icon array format (see Figure 3). ANOVA showed the effect of the icon array format, $F(1, 155) = 10.5$, $p < 0.01$, $\eta^2 = 0.06$. No effect of risk literacy was found. A significant interaction between risk literacy and icon array format was found, $F(1, 155) = 7.3$, $p < 0.01$, $\eta^2 = 0.05$.

*Simple questions*

As expected, icon arrays significantly increased the proportion of participants who gave both correct answers to simple trade-off questions: 27% in the numeric format and 61% in the icon array format (*Chi-squared*(1) = 18.66, $p < 0.001$, $d = 0.72$). However, the effect varied by risk literacy: the proportion of correct responses increased from 24% to 30% for low numeracy participants and from 50% to 71% for high literacy participants (see Figure 4). ANOVA showed the effect of risk literacy, $F(1, 155) = 20.9$, $p < 0.001$, $\eta^2 = 0.12$ and the interaction effect between risk literacy and the icon array format, $F(1, 155) = 18.3$, $p < 0.001$, $\eta^2 = 0.11$.

*4.2.2. Tradeoff 2: the risk of operation and side effects before and after treatment*

On average, participants gave 2.5 ($SD = 2.8$) correct answers in the control condition and 2.8 ($SD = 3.0$) correct answers in the icon array format out of eight questions with no significant difference. While icon arrays were helpful for respondents with low literacy risk ($M = 1.3$, $SD = 1.8$, and $M = 2.1$, $SD = 2.9$, respectively), no effect was found for respondents with high literacy risk ($M = 3.7$, $SD = 3.0$, and $M = 3.4$, $SD = 2.9$, respectively, see Figure 5). ANOVA showed the effect of risk literacy, $F(1, 155) = 18.0$, $p < 0.001$, $\eta^2 = 0.10$ and the interaction effect between risk literacy and icon array format, $F(1, 155) = 5.3$, $p < 0.05$, $\eta^2 = 0.03$.

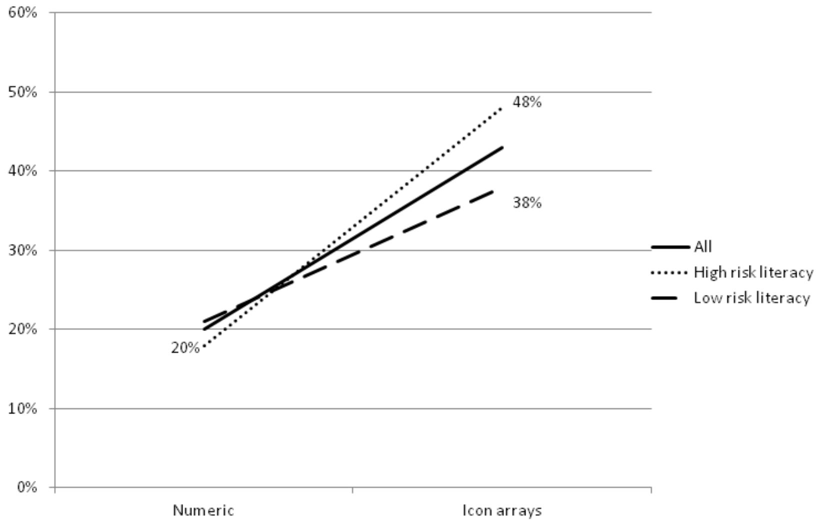


***Fig. 3. Cognitively demanding questions in tradeoff tasks***

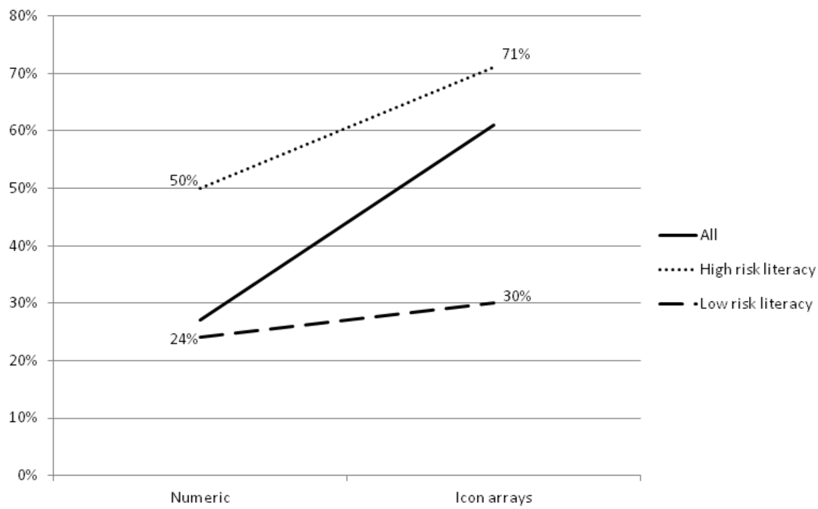


***Fig. 4. Simple questions in tradeoff tasks***

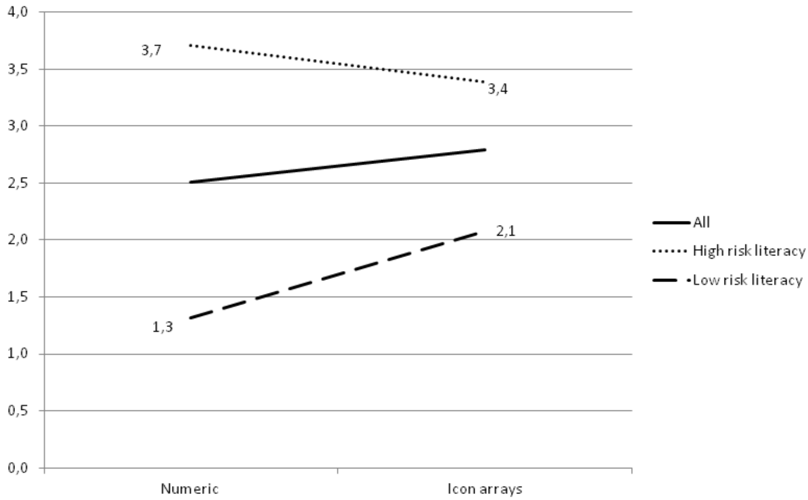


***Fig. 5. Average number of correct responses in tradeoff tasks***

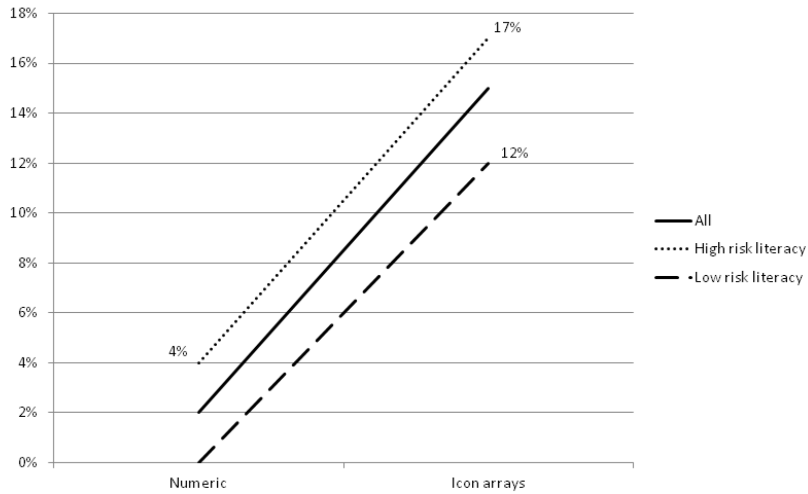


***Fig. 6. Bayesian task***

#### 4.2.3. Bayesian task

The effect was positive and statistically significant in only one of the three Bayesian questions: "If 100 people have a positive test result, how many of them actually have the infection?" Only 8% of participants answered this question correctly. While the proportion of those giving the correct answer was 2% in the control condition, it reached 15% in the icon array format condition (*Chi-squared*(1) = 8.48, $p < 0.01$, $d = 0.48$, see Figure 6). ANOVA showed the effect of the icon array format, $F(1, 155) = 8.9$, $p < 0.05$, $\eta^2 = 0.05$, and no effect of risk literacy or age. The interaction effect between risk literacy and icon array format could not be tested due to the low number of correct responses in the subgroups.

## 5. Discussion and conclusions

### 5.1. Discussion

Two experiments were conducted to measure the effect of icon arrays and analogies in adolescents aged 11–15 years. Icon arrays were helpful to participants in most tasks. As expected, the effect varied depending on the task and the participants' risk literacy (*Hypothesis 1*). We measured the effect of icon arrays in the following tasks: simple risk calculations, risk perception and risk reduction (ratio-bias effect), trade-off tasks and Bayesian problems. As predicted, icon arrays increased accuracy in difficult tasks such as trade-off tasks and Bayesian problems. We can support the results from the experiments with adult trade-off tasks [15; 30] that icon arrays produced a better understanding of risk information. We can also find some support for the results from the experiments with adults [1] and children aged 7–11 years [21] that icon arrays produced more accurate responses in the Bayesian tasks in adolescents.

Overall, we found larger effects than other authors studying adults. Waters and others [30] compared bar graphs with the numerical format and found a small effect size for trade-off problems in adults ($d = 0.09$).

We compared icon arrays with the numerical format and found a larger positive effect of icon arrays on risk comprehension accuracy (*d* varied from 0.49 to 0.72). In scenarios involving more complicated trade-off tasks with side effects, Hawley and others [15] found that the effect can vary from 0.04 to 0.29 (or sometimes be negative) in adults, depending on the questions asked and individual risk literacy. We found that *d* varied from 0.10 to 0.32 in adolescents. In Bayesian tasks, we found higher effects compared to other researchers studying adults, but lower than in studies of younger children. While Multmeier [21] reported that d varied from 0.78 to 1.02 in children aged 7–11 years, Brase [1] found d equal to 0.29 in his experiment with adults. We found *d* equal to 0.48. At the same time, we found that the icon array format was only helpful in one of the three Bayesian questions.

Some results were contrary to what we expected. We found that icon arrays had a negative effect on accuracy in some tasks for adolescents with low risk literacy. Similar to Hawley et al. [15], we found that icon arrays can reduce accuracy in some tasks compared to the numerical format. It appears that in simple calculation tasks, icon arrays can distract children's attention and lead to less accurate responses, particularly in low literacy adolescents. At the same time, we found that in complex tasks, icon arrays may be more helpful for low literacy adolescents than for high literacy adolescents.

We found no effect of icon arrays on simple risk calculation tasks and on the ratio bias effect. Icon arrays did not help reduce the denominator effect (*Hypothesis 2*). We did not replicate the findings of [12] whose study showed that icon arrays produced more accurate responses in simple risk calculation tasks and reduced the denominator effect in adults. People usually pay more attention to the numerator than to the denominator. While we expected that icon arrays would make participants pay more attention to the denominator and thus make more accurate risk estimates, we found no support for this.

We found some support for the hypothesis that analogies help to increase the accuracy of understanding risk information (*Hypothesis 3*).

Galesic & Garcia-Retamero [9] found that analogies were more helpful for adults with high risk literacy in the context of difficult medical questions, and more helpful for adults with low risk literacy in the context of less cognitively demanding medical questions. We found no effect for analogies in the context of less cognitively demanding medical questions. However, we did find that analogies were helpful for adolescents with high literacy when faced with difficult medical problems. Galesic & Garcia-Retamero [9] compared different analogies and found that they were more helpful for individuals when there was a high similarity of the relationship between the objects in the task and the analogies, a low similarity of the objects in the task and an analogy, and when individuals were familiar with the objects described in an analogy. Our findings suggest that analogies can be helpful точadolescents in communicating risk, but more research should be done to explore which analogies are more effective in communicating risk to adolescents.

Our experiments have some limitations. First, we conducted them on a non-probability sample in several schools. It would be useful to replicate these studies using a national probability-based sample of adolescents. Second, we measured the effect of one visual format (icon arrays). A large body of literature has compared different formats in adults (e.g. bar graphs, pie charts, etc.). Future research could compare the effect of different formats on risk understanding in adolescents. Third, we did not examine whether the icon array format led to more optimal decision making. Future research could investigate whether icon arrays lead to more optimal medical decisions among adolescents. Finally, we did not investigate the effect of different analogies on risk understanding. This may have produced slightly different results to the experiment in adults. Future research could investigate which analogies may be helpful for adolescents, especially for adolescents with low risk literacy.

### 5.2. Conclusions

There are three main conclusions from the research. First, icon arrays led to better understanding of risk information and more accurate risk comparisons among adolescents. The effect sizes are mostly larger than those found in adult studies. Second, the effects varied according to the difficulty of the task and the risk literacy of the participants. We found that icon arrays may be more helpful for adolescents with low numeracy in complex trade-off problems. Third, analogies were helpful for the adolescents, but not for the participants with high risk literacy.

### 5.3. Practice implications

The results of two experimental studies showed that icon arrays and analogies are useful in risk communication with adolescents. These results can be used by doctors and those involved in risk communication and health promotion among adolescents. Analogies increased accuracy in understanding difficult medical problems. Icon arrays helped adolescents with difficult tasks such as trade-off tasks and Bayesian problems. Icon arrays led to better understanding of risk information, more optimal risk comparisons and more accurate risk calculations in cognitively demanding risk comparison and risk calculation tasks.

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# Appendix

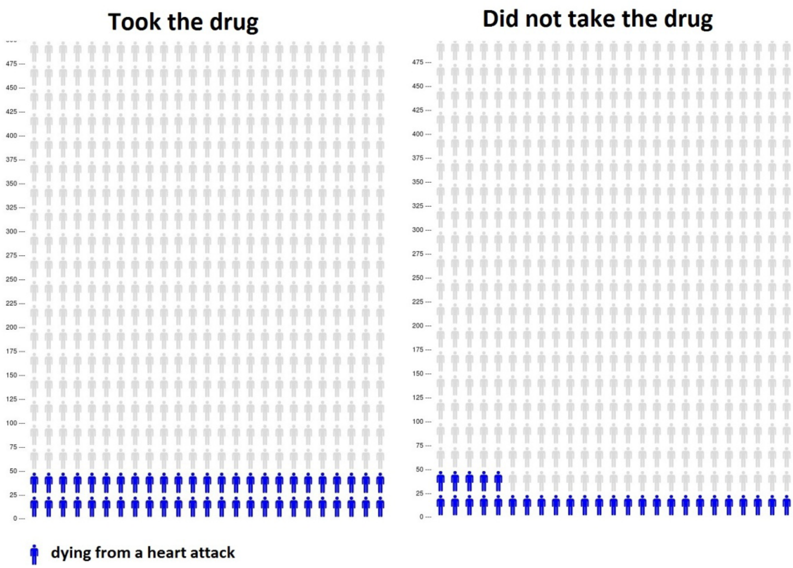


***Fig. 1. Risk calculations***

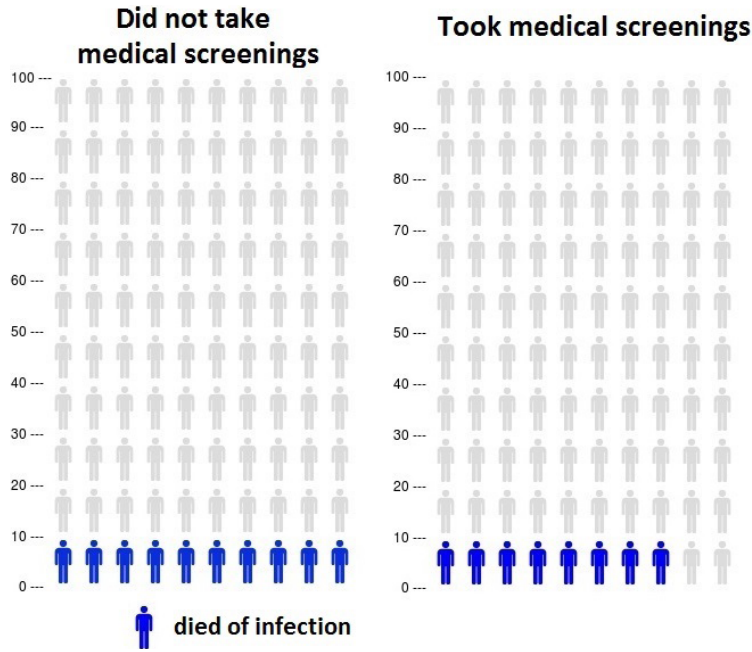


***FIG. 2. Risk perception (ratio-bias effect)***

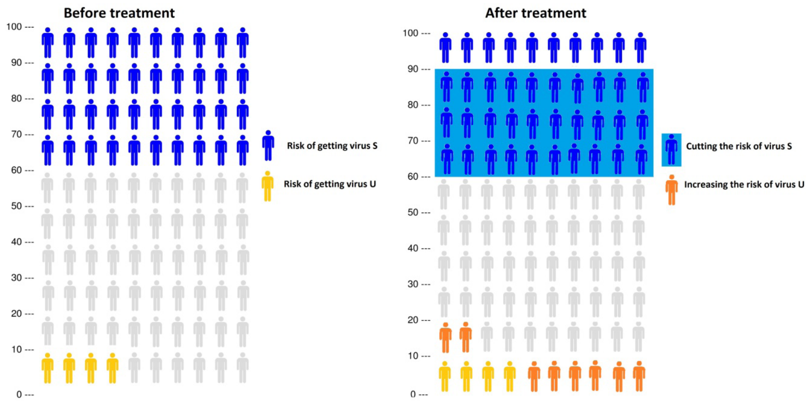


***FIG. 3. Trade-off 1: Total risk before and after treatment***

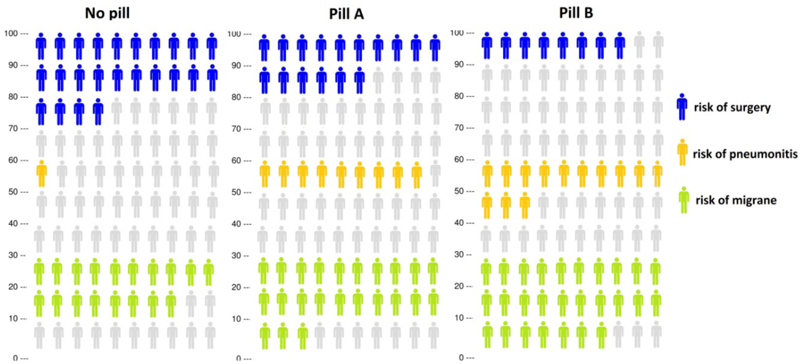


***Fig. 4. Trade-off 2: The risk of operation and side effects before and after treatment***

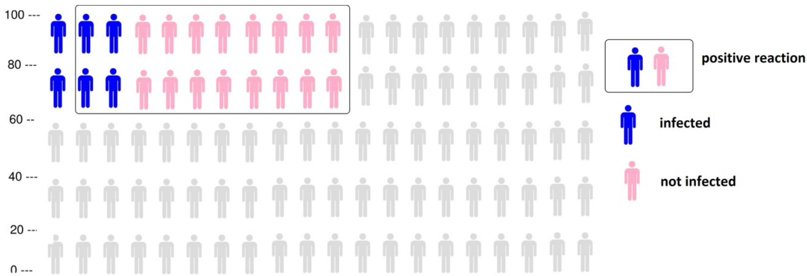


***Fig. 5. Bayesian task***

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# ВЛИЯНИЕ ИСПОЛЬЗОВАНИЯ ПИКТОГРАФИЧЕСКИХ МАССИВОВ И АНАЛОГИЙ НА РИСКОВУЮ КОММУНИКАЦИЮ СРЕДИ ДЕТЕЙ-ПОДРОСТКОВ

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**Для цитирования:** *Климова А. М., Гаврилов К. А.* Влияние использования пиктографических массивов и аналогий на рисковую коммуникацию среди детей-подростков // Социология: методология, методы, математическое моделирование (Социология:4М). 2023. № 57. С. 84–111. DOI: 10.19181/4m.2023.32.2.3. EDN: MHUPFG.

**Аннотация.** Цель исследования – измерить влияние использования подростками в возрасте 11–15 лет пиктографических массивов и аналогий в сообщениях на понимание информации о риске. Была проведена проверка, приводит ли использование пиктографических массивов к более высокой точности по сравнению с применением традиционного числового представления в задачах разной сложности: в простых задачах расчета риска и в сложных, таких как поиск оптимального решения и байесовских вычислений. Также была предпринята попытка оценить, улучшает ли использование аналогий понимание риска. Использование пиктографических массивов привело к лучшему пониманию информации о рисках и более точному сравнению рисков. Эффекты варьировались в зависимости от сложности задачи и грамотности участников в вопро-

сах риска. Аналогии оказались более полезны для подростков с высоким уровнем грамотности.

**Ключевые слова:** рисковая коммуникация, графический формат, рисковая грамотность, пиктографический массив
**Благодарности:** настоящее исследование выполнено при финансовой поддержке Российского научного фонда, номер проекта 22-28-00968 «Окулография в мультимодальном измерении когнитивной нагрузки респондента».

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