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EMPIRICAL ARTICLE

A note on judgments and behavior: Distancing and Corona virus exposure

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Abstract

In a questionnaire, participants judged the increase in SARS-CoV-2 virus exposure when moving closer to an infected person. Earlier studies have shown that the actual increase in virus exposure is underestimated and the present study replicated and extended these studies. The primary purpose was to investigate to what extent questionnaire judgments about hypothetical situations can predict judgments and actual behavior in real physical space. Participants responded to a questionnaire and the same participants also took part in a parallel study that was conducted in a room with a mannequin representing a virus infected person. The earlier reported bias in the perception of exposure as a function of distance to a virus source was replicated in the questionnaire and the physical laboratory study. A linear function connected median exposure judgments at the same distances from a virus source in the questionnaire and in the laboratory, $R^2 = 0.99$. When asked to move to a distance that would give a prescribed exposure level, a linear function described the relationship between questionnaire distance judgments and moves to distances in the physical space, $R^2 = 0.95$. We concluded that questionnaire data about perceived virus exposures are reliable indicators of real behavior. For health reasons, the significant underestimations of the steep increase of virus exposure during an approach to a virus source need to be stressed in communications to policy makers, the public, professionals working close to clients, nursing staff, and other care providers.

1. Introduction

A fundamental motivation for the study of human judgments is their asserted relationship with behavior. To illustrate, preference judgments are studied because of their correlation with decisions and attitude judgments are studied because of their association with social behavior. In a series of studies, Svenson (2022) and Svenson et al. (2020, 2024a, 2024b) studied judgments of SARS-CoV-2 virus exposure under different conditions, but they never explored the link to actual behavior. Therefore, the present study aimed at exploring the link between questionnaire judgments of virus exposure and behavior in a realistic physical setting. We also wanted to further verify previous findings that people underestimate the effect on virus exposure when the distance to an infected person increases or decreases.

It is well known that keeping a distance from a virus source is one way of protecting oneself against infection with airborne viruses like the Corona virus (Balachandar et al., 2020; Bourouiba, 2020). A number of researchers have studied objective exposure and risk of infection when people are at different distances from a person who is infected with an airborne virus (Bolashikov et al., 2012; Chu et al., 2020; Fu et al., 2022; Liu et al. 2017; Olmedo et al., 2012, 2013; Setti et al., 2020; Wang et al. 2021). But, there are only a few studies of how perceived exposure and risk depend on distance to an infected person (Heffetz and Rabin, 2023; Svenson, 2022; Svenson et al., 2020, 2024a). The latter studies have shown systematic underestimations of the effect on exposure when distance to an infected person changes. To specify, when approaching an infected person, the approaching person does not understand how fast virus exposure increases with decreasing distance to the virus source. Correspondingly, when a person withdraws from the infected person she or he does not understand how fast exposure decreases with increasing distance (Heffetz and Rabin, 2023; Svenson, 2022; Svenson et al., 2020). The relevance of these studies depends on the assumption that questionnaire responses generalize to actual behavior. The present study will test this assumption. In other words, to what extent can we trust that questionnaire judgments about behavior in an airborne virus context also reflect the corresponding judgments in connection with actual behavior in a physical setting?

The objective relationship between distance to a virus infected person and physical exposure to the virus in a calm environment can be approximated by a power function with the exponent of approximately −2.0. This estimate was based on empirical studies as those presented below and can be related to a theoretical model describing virus particle spread in a room over time, Equation (1) (Svenson et al., 2020). Melikov (2020) presented a review of empirical studies with exposure as a function of distance and the results were summarized showing a decreasing function that can be approximated by a power function with an exponent equal to −2.0 or smaller (Bourouiba, 2020, Fig. 1). Wang et al. (2020) found a similar relationship and Bjørn and Nielsen (2002, Fig. 15) reported exposure to another person's normal breathing in a calm laboratory face to face setting with different distances (0.4 to 1.2 m). The power function Exposure = 1.90 × Emission × Distance $^{-2.2}$ described their results. In another empirical study by Nielsen et al. (2012, Fig. 8) the power function was Exposure = 4.3 × Emission × Distance $^{-2.3}$ (0.35 to 1.10 m). Ball et al. (2021) studied airborne droplets exposure at different distances from a source with and without a face mask. In the unmasked condition, they reported that the inhaled fraction for normal breathing was 67%, 10%, and 4% at the distances of 0.40, 0.80, and 1.20 m from the source. This can be described by a power function with exposure as a function of distance with the exponent = −2.6 (Ball et al., 2021, Fig. 3). Different kinds of face masks lowered the curve, but the exponent remained approximately the same and smaller than −2.0.

Svenson et al. (2020) used Equation (1) to model a person's exposure. In the equation, Epv is exposure and a function of virus emission E (virus units per second), distance, D (meters), and time, t (seconds). The exponent n describes the rate at which exposure changes with distance, and a is a constant.

$$\text{Epv} = a \times E \times t \times D^{-n} \quad D > 0.5, t > 0. \tag{1}$$

The Virus Exposure Model, VEM with n = 2.0 was used to describe physical exposure as a function of distance. It was clear from the empirical studies cited above that this exponent, if anything, underestimates how fast exposure decreases with increasing distance in an open space when the interpersonal distance is greater than 0.5 m and the expiratory jet spread angel is wide (Bolashikov et al., 2012). However, empirical evidence shows that perceived exposure follows a less curved function than Equation (1) with exposure approaching a linear function of the inverse of the distance corresponding to the negative exponent n = −1.0 in Equation (1) (Svenson et al., 2020).

In the following, participants will judge, in a questionnaire, exposure at different distances from a virus source. The same participants will also make judgments and move in an indoor space. We will test the applicability and the exponent of Equation (1) for both conditions in a follow up and extension of earlier studies (Svenson et al., 2020, 2024a). More importantly, the results will also inform us about the validity of questionnaire data for predicting real behavior. Stevens and Galanter (1957) reported that magnitude estimates of distance were linear with objective distance for the range of distances investigated in the present study. Therefore, we hypothesize that questionnaire judgments of distance

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will correspond to real distances enabling participants to judge change of virus exposure in the same way for imagined (questionnaire) and real (laboratory) distances.

2. The experiment

2.1. Method

2.1.1. Participants

The participants were recruited via the Accindi home page (https://www.accindi.se/) and awarded movie tickets for their participation. The mean age of the 26 participants was 36.8 (SD = 15.2) years and their levels of education were: high school (5 participants), some college (3), college graduate (13), and more than college graduate (5).

2.1.2. Material and procedure

The study was performed in a room designed for interviews (questionnaire condition) and in an adjacent well-ventilated laboratory with a mannequin doll representing an infected person (real distance condition). A participant was welcomed and asked to fill out a form of consent and informed that she or he could terminate the study whenever she or he wanted. The ethics guidelines at Stockholm University were followed and the study adheres to the tenets of the Declaration of Helsinki.

In the lab condition, the experimenter placed the participant at different distances from the doll (Figure 1) and asked about virus exposure at that distance in percent of a reference distance (100%) exposure. Short very discrete pieces of tape on the wall marked different distances from the mannequin. This was to aid the experimenter when she moved the participant to a given location for a judgment. The markings were on different distances known to the experimenter and the markings were hardly noticed by a participant (Figure 1). In another part of the study design the lab condition study, the participant was asked to move to a position to reach a target exposure given by the experimenter. The

Figure 1. *A participant facing the mannequin model representing a Corona-infected person.*

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Table 1. *Design of study.*

	Exposure response	Regulating distance, distance response
Imagined distance	Questionnaire: exposure at given distances	Questionnaire: movement to distance at which given target exposure would be received
Real indoor distance	Laboratory: exposure at given distances (participant moved there by experimenter)	Laboratory: participant (her-himself) moves to distance at which given target exposure would be received

distance from the doll to the participant was measured nose to nose with a laser meter (Leica Disto X310). The study was performed in 2 sessions, one was performed in the laboratory and the other in the adjacent room in which the participants filled out a questionnaire with questions corresponding to the tasks performed in the laboratory but with no action. In both conditions, the problems were presented in sequences describing successive movements away or toward a given reference exposure/distance in the orders given in Tables 2 and 3. In summary, the design followed a 2 × 2 factorial design (exposure response/distance response) × (imagined distance/real distance) as shown in Table 1.

2.2. Questionnaire

2.2.1. Judged exposure at an imagined distance

The instruction read as follows. *Assume that you are talking to a Covid virus infected person face to face, for example, 2.0 m from her or him (in a clean well ventilated room with no draft). Then, you are exposed to airborne viruses from that person. In other words, she or he becomes a virus source exhaling viruses towards you. In this situation, you are exposed to a given amount of virus particles/second = 100%.*

If you move closer, the original exposure increases and becomes greater than 100%.

If it is two times the exposure at the first place it is 200%, if it is 5 times, 500% 10 times 1000% etc

An example of a problem was:

If you move closer from 2.00 m to 1.50 m, what will your exposure be?
The exposure will be __________ % of the exposure at 2.00 m.

The instruction for a person moving away from an infected person was the same but with the changes of the moving closer instruction needed for a moving away condition. The complete questionnaire can be found in the suplimentary material. The numbers used in the different problems are given in Table 1.

2.2.2. Regulating exposure by changing imaginary distance

> Assume that you are talking to a Covid virus infected person face to face 0.50 m from her or him (in a clean well ventilated room with no draft). Then, you are exposed to airborne viruses from that person. In other words, she or he becomes a virus source exhaling viruses towards you. In this situation, you are exposed to a given amount of virus particles/second. If you move away, the original exposure decreases and becomes smaller than 100% compared with the original distance of 0.50 m with 100% exposure.

An example of a problem was the following: '*If you want to reduce your exposure to 50% of the exposure at 0.50 m, how far away from the infected person should you move?*
I should move to (use decimals) ___.___ m from the infected person'.

There was also a set of problems when exposure increased and the problem text was adjusted to fit that condition. The reference distances and target exposures can be found in Table 2.

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Table 2. *Judged virus exposure at different distances to which the participant was moved, imagined, and real.*

Original comparison distance (m)	Participant was moved to real or own imagined distance (m)	Judged exposure at real distance % 95% confidence interval, *N*	Judged exposure imagined distance % Median (25–75%), 95% confidence interval, *N*	Judged exposure at real distance % Mean (SD) 95% confidence interval ()	Judged exposure imagined distance % Mean (SD) 95% confidence interval ()	Virus exposure model prediction
2.0	2.0			100	100	100
2.0	1.5	150, (129–200), [145, 190], 26	150, (125–180), [125, 180], 22	165, (34.8), (151, 179)	159, (30.5), (146. 173)	178
2.0	1.0	260, (200–400), [200, 400], 26	225, (188–400), [200, 400], 24	290, (114), (244, 336)	290, (150), (226,353)	400
2.0	0.5	500, (318–1000), [385, 1000], 26	400, (275–850), [350, 700], 23	659, (432), (485, 834)	529, (313), (394, 665)	1600
1.5	1.5			100	100	100
1.5	1.0	200, (150–200), [150, 200], 26	180, (150–200), [150, 200], 21	200, (64.4,) (174, 226)	219, (116), (167, 272)	225
1.5	0.5	450, (225–800), [300, 700], 26	300, (192–500), [200, 500], 20	516, (303), (394, 639)	387, (250), (270, 504)	900
1.0	0.5	350, (200–500), [200, 400], 25	300, (200–388), [200, 375], 18	378, (235), (281, 475)	331, (196), (233, 428)	400
0.5	0.5			100	100	100
0.5	1.0	55, (50–70), [50, 67.5], 26	50, (50–50), [50, 50], 24	58.7, (14.8), (52.7, 64.6)	48.7, (14.5), (42.6, 54.8)	25
0.5	1.5	25, (25–40), [25, 40], 25	27.5, (25–50), [25, 50], 22	32, (14.6), (26–38)	41.6, (30.9), (27.9–55.3)	11
0.5	2.0	10, (5–11), [5, 10], 25	10, (5–18), [5, 17.5], 18	10.5, (10.8), (6.04, 14.9)	12.8, (11), (7.39, 18.3)	6
1.0	1.0			100	100	100
1.0	1.5	70, (50–75), [55, 75], 26	50, (42.5–72.5), [55, 67.5], 23	64.6, 14.2, (58.8, 70.3)	52.5, (17.9), (44.8, 60.2)	44
1.0	2.0	40, (25–50), [25, 50], 26	50, (22.5–60), [27.5, 50], 23	36.7, (22), (27.8, 45.5)	46.5, (34.7), (31.5, 61.5)	25
1.5	1.5			100	100	100
1.5	2.0	65, (50–75), [50, 75], 26	50, (25–75), [25, 75], 22	57.7, (27.2), (46.7, 68.7)	46.1, (28.3), (33.6, 58.7)	75

Note: *N*, number of participants; SD, standard deviation, confidence intervals for medians, bootstrapping percentile method.

Table 3. *Participant moved her/himself to distance at which target exposure would be received.*

Original comparison distance (m)	Target exposure (%)	Participant has moved to real distance (m) Median (25–75%), 95% confidence interval, *N*	Judged imagined distance (m) Median (25%–75%), 95% confidence interval, *N*	Participant has moved to real distance (m) Mean (SD), 95% confidence interval	Judged imagined distance (m) Mean (SD), 95% confidence interval	Virus exposure model prediction (m)
0.5	*100*	*0.50*	*0.50*			*0.50*
0.5	50	1.14, (0.99—-1.4), [1.02, 1.36], 26	1.0 (0.75–1.0), [0.78, 1.0], 25	1.17 (0.26), (1.07, 1.28)	0.88, (0.28), (0.77, 1.00)	0.71
0.5	25	1.47, (1.14–1.9), [1.24, 1.75], 26	1.5 (1.0–1.5), [1.13, 1.5], 25	1.52 (0.54), (1.30, 1.74)	1.32, (0.92), (1.13, 1.15)	1.00
0.5	10	1. 86, (1. 45–2.45), [1.6, 2.25], 26	1.85 (1.5–2.05), [1.5, 2.0], 24	1.94 (0.71), (1.65, 2.23)	1.90, (0.91), (1.50, 2.29)	1.58
1.0	*100*	*1.0*	*1.0*			*1.00*
1.0	50	1.88, (1. 64–2.08), [1.64, 2.07], 26	1.5 (1.5–2.0), [1.5, 1.75], 25	1.90 (0.35), (2.07, 2.61)	1.58, (0.45), (1.39, 1.72)	1.41
1.0	25	2.27, (1.85–2.81), [1.87, 2.72], 26	1.8 (1.75–2.3), [1.75, 2.15], 25	2.34 (0.67), (2.07, 2.61)	2.08, (0.95), (1.69, 2.47)	2.00
1.0	10	2.67, (2.1–3.34), [2.21, 3.11], 26	2.2 (1.9–2.6), [1.9, 2.6], 25	2.71 (0.87), (2.36, 3.07)	2.80, (2.13), (1.93, 3. 69)	3.16
1.0	*100*	*1.0*	*1.0*			*1.00*
1.0	200	0. 69, (0.53–0.78), [0.59, 0.77], 26	0.5 (0.5–0.71), [0.5, 0.7], 20	0.69 (0.16), (0.62, 0.75)	0.59, (0.2), (0.50, 0.68)	0.71
1.0	400	0.44, (0.3–0.57), [0.33, 0.56], 26	0.4 (0.25–0.5), [0.25, 0.5], 21	0.45 (0.22), (0.37, 0. 53)	0.42, (0.22), (0.32, 0.52)	0.50

Note: *N*, number of participants; SD, standard deviation, confidence intervals for medians, bootstrapping percentile method.

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2.3. *Laboratory experiment*

The instructions were the same as for the questionnaire with the difference that the participant was moved to a given position and asked about exposure or was asked to move to receive a target exposure level.

2.3.1. Judged exposure at a real distance and regulating exposure by changing real distance

The laboratory session was introduced as follows. '*As you can see, there is a model head in the room. The head represents a person with whom you are having a conversation for 3 minutes. " ..." The person who is infected is represented by the model head and your task is to judge the virus exposure at different distances from the "virus exhaling head") Assume that you are talking to a Covid virus infected person represented by the model head, then, you are exposed to airborne viruses from the mouth of the person. In other words, she or he becomes a virus source exhaling viruses towards you. > If you move away from the virus infected person, the virus exposure becomes smaller. > If you move closer to the virus infected person, the exposure becomes greater*'.

2.4. *Results*

The problems that could be paired across the lab and questionnaire sessions are listed in Tables 2 and 3. We excluded judgments that did not follow the instruction that exposure decreases if the distance becomes longer and increases if the distance becomes shorter. The number of responses used in the analyses is given in Tables 2 and 3.

2.4.1. Exposure at different distances

The problems and results of the exposure judgments sessions are shown in Table 2.

2.4.2. Judgments of exposure and objective exposure

As mentioned earlier, previous studies have shown that judgments of virus exposure as a function of distance were biased (Svenson, 2022; Svenson et al., 2020). Specifically, judgments of exposure were underestimated when a person approached a virus source and overestimated and when the person moved away from a source. Figure 2 illustrates these biases with the black circles representing objective exposure in both panels.[1] The curves show that movements in the laboratory room and the questionnaire problems produce the same biased exposure judgments.

2.4.3. Regulating exposure by change of distance

Next, we investigated participant movements to reach a given exposure level. If the exposure in an approach is underestimated, a participant should move closer than objectively motivated to reach a given target exposure level. Correspondingly, if a participant overestimates exposure when moving away, a participant should move further away than objectively motivated to reach a target exposure level. The results of the movement to target exposure sessions are given in Table 3.

[1]We did not adjust the heights of the mannequin model to the height of each participant. If a participant's height differs from the model's height, the nose to nose distance will be slightly longer than the distance marked on the wall. Assuming that the average person is 15 cm taller or shorter than the model, then the real distance will be 0.52 m instead of 0.50 m and the standard VEM exposure is 92% instead of 100%. An increase of exposure distance to 1.0 m on the wall will be slightly longer than 1.00 m in reality (depending on the parallax) and will give a VEM predicted exposure of 26.5% instead of 25% for the black circles in Figure 2 for moving away. For longer distances, the parallax effect becomes even smaller and will not be analyzed further. In summary, if taking the participants height variation into account, the VEM curve becomes slightly flatter but far from the judged exposure values as evident from Figure 2 .

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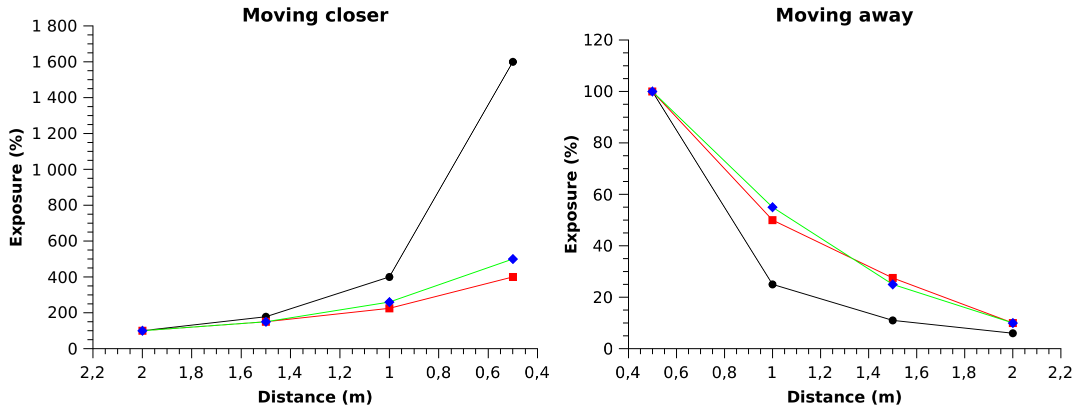

Figure 2. *Judged median exposure as a function of distance to virus source. In the left panel, the exposure at 2.0 m from the source which was set at 100% as a reference value and the participant was moved closer to the virus source and asked for an exposure judgment. In the right panel, the exposure at 0.5 m was set at 100% and the participant was moved away from this distance. Red squares = judgments in lab, blue diamonds = questionnaire judgments, black circles = correct actual exposure predicted by VEM.*

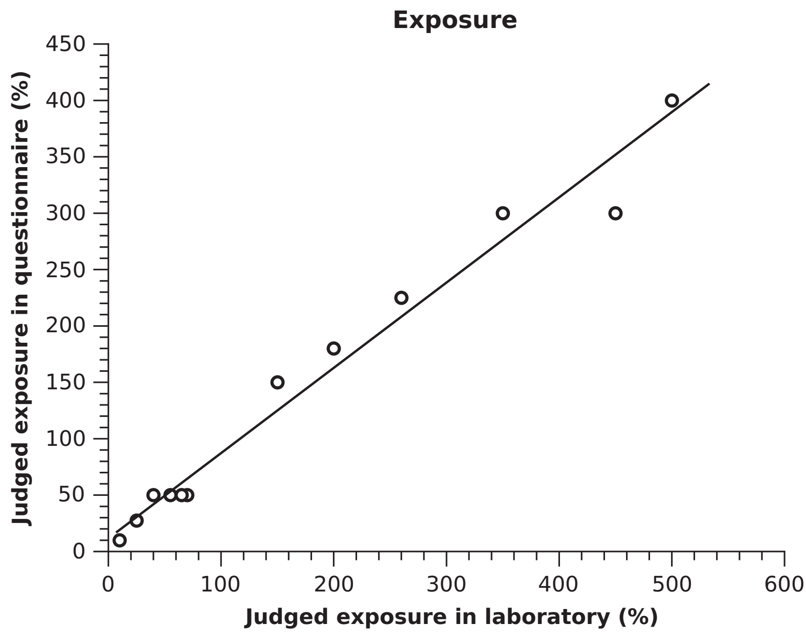

Figure 3. *Median judged exposure in questionnaire plotted against laboratory judgments, medians.*

2.4.4. Comparisons of questionnaire and laboratory responses

Figure 3 shows that the function relating laboratory judgments with questionnaire responses was linear, Questionnaire = 0.75 • lab judgment + 13.23, $R^2 = 0.99$. On average, the lab judgments were greater than the questionnaire judgments.

Figure 4 shows that the relationship between questionnaire and laboratory exposure regulating data was linear, Questionnaire = 0.87 • lab judgment + 17.06, $R^2 = 0.95$. The explained variance was only slightly smaller than for exposure judgments and the distance in the laboratory was on

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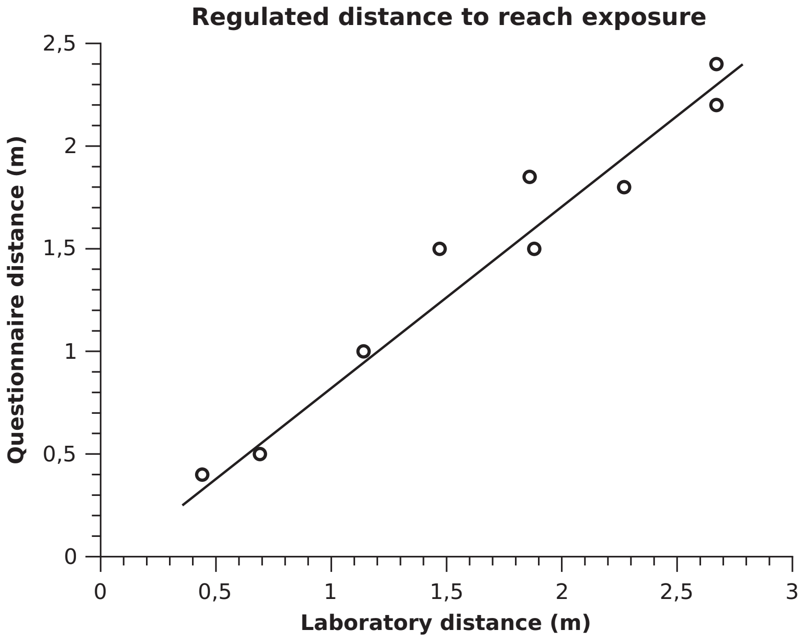

Figure 4. *Median judged distance with target exposure in questionnaire plotted against laboratory distances.*

average somewhat greater than the questionnaire responses. In summary, we found that judgments in a questionnaire predicted behavior in a physical environment quite well and that laboratory judgments and behavior tended to produce higher/longer responses than the questionnaire.

3. Discussion

Most studies of judgments and behavior in a Covid-19 context study self-reported behavior on a general (Bruine de Bruin and Bennett, 2020; Magnan et al., 2021; Raude et al., 2020) or more detailed level, for example, choice of vaccination or not (Cai et al., 2022; Han et al., 2023). This contrasts with the approach chosen in the present study. We did not ask about how often a person was distancing from another person or how far away she or he moved away from that person when distancing. Instead, we investigated cognitive and perceptual models of exposure as a function of distance.

It was interesting to find that judgments in a questionnaire of judged exposure at an imagined distance from a virus source corresponded so well to judgments made in a physical laboratory environment with the average median laboratory judgments about 20% greater than the questionnaire judgments. When the response was a move to a position to reach a prescribed exposure level, the questionnaire and laboratory physical space results corresponded quite well with the average median laboratory movements about 15% greater than the questionnaire judgments.

The relationship between judged exposure and distance could be described by power functions with exponents greater than the physical relationship and closer to linear functions. Also, the results showed that the judgment biases in the questionnaire were not amplified when translated into behavior in the physical space. Rather, they were reduced by the selection of slightly greater distances to an infected person in the laboratory than in the questionnaire judgments.

The greater the virus exposure, the greater the probability of a higher virus load and infection in a person (Ai et al., 2019; Armstrong and Haas, 2007; Riediker et al., 2022; Sze To and Chao, 2010). Because, there is a positive correlation between a person's virus load and infection risk Equation (1)

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can be used as an approximation of objective infection risk if the variable *Exp* is substituted with an infection risk measure. Svenson et al. (2024a) showed that judgments of infection risk were biased in the same way as exposure judgments.

The results that judgments of a curved function were biased were also reported in research concerning other fields of psychology, such as forecasting, economic growth and household finance (Ebersbach et al., 2008; Gonzalez and Svenson, 2014; Stango and Zinman, 2009; Wagenaar and Sagaria, 1975). These biases mean that judgments are more linear or proportional than required when judging, for example, exponential growth. Brehmer (1971) suggested a mental hierarchy of operations and functions in which those higher in the hierarchy are elicited more easily. This means that addition and linear functions, who are high in the hierarchy, are attempted first when judging quantitative relationships (Juslin et al., 2008; Svenson, 2016). The hierarchy explains distortions of curved functions toward linear functions as illustrated by the present research.

We have found that questionnaire judgments are closely related to behavior and judgments in a physical environment, but we do not know how this generalizes to everyday behavior during a pandemic. For example, do participants who judge virus exposure as relatively higher at given distance also distance themselves more frequently in daily life or consider a longer distance to an infected person as safe compared to participants who judge virus exposure at that distance as relatively lower. A recent study (Svenson et al., 2024b) found no or only spurious correlations between exposure judgments and self-reported frequency of distancing episodes. However, there are no observational studies of people distancing in their daily lives related to judgments of exposure at different distances so we have to rely on self reports when we interpret the independence between exposure judgments and every day behavior. Participants who indicated a longer distance as safe against infection also tended to give higher exposure judgments in a questionnaire (Svenson et al., 2024a).

From a fundamental research perspective, the present study is interesting because it links judgments to behavior, not always done in judgment research. From an applied perspective it is important for communications about the steep increase in risk with decreasing distance to an infected person. In times of airborne viruses, this is of great importance for all of us and for professionals with close personal contacts, as in nursery homes, hospitals, schools, public gatherings, transports, and so forth. Awareness of this fact may lead a person to ask, for example, shall I take this crowded metro train or can I wait for the next one? Is it necessary to move so close to this person in a nursery home or in a school?

Supplementary material. The supplementary material including raw data for this article can be found at http://doi.org/10.1017/jdm.2024.28.

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Competing interest. The authors declare none.

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