Empirical evidence to understand the human factor for effective rapid testing against SARS-CoV-2

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Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) rapid antigen point-of-care and home tests are available to laypeople. In four cross-sectional mixed-methods data collections conducted between December 2020 and March 2021 (n = 4,026), we showed that a majority of subjects were willing to test despite mistrust and ignorance regarding rapid tests' validity. Experimental evidence shows that low costs and access to events could increase testing intentions. Mandatory reporting and isolation after positive results were not identified as major barriers. Instead, assuming that testing and isolation can slow down the pandemic and the possibility to protect others were related to greater willingness to get tested. While we did not find evidence for risk compensation for past tests, experimental evidence suggests that there is a tendency to show less mask wearing and physical distancing in a group of tested individuals. A short communication intervention reduced complacent behavior. The derived recommendations could make rapid testing a successful pillar of pandemic management.

SARS-CoV-2 | rapid tests | behavioral insights | health communication

Rapid testing with antigen tests, and the subsequent isolation of individuals who tested positive, is a strategy for controlling and potentially decreasing the disease dynamics in the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) pandemic—given that a relevant part of the population gets tested regularly (1–7). Some governments offer free weekly tests to asymptomatic people (8), and home tests are increasingly available in shops to everyone. However, little is known about the reliability of the human component in testing (9), as interpreting test results involves conditional probabilities, factoring in the current infection rate or community prevalence, sensitivity, and specificity of a test, which may all vary over time and across products (10). The complex interplay of nonperfect tests and the human factor has been pessimistically called the "failure of the test or the tested" (11). The availability of rapid tests to laypeople raises the following research questions: What are the drivers and barriers of people's willingness to use rapid point-of-care (PoC) and home tests; what are the gaps in their understanding of the results (12); and what are the psychological and behavioral consequences of positive and negative results (13)? Accordingly, this contribution aims at answering these questions to make recommendations on how to communicate details on the test strategy, conducting tests, the behavior after a test, and the validity of test results.

While previous work has shown a "substantial concordance" between participant- and clinician-administered tests and interpreted results (14) (preprints without peer review: refs. 15 and 16), it is unclear whether test users trust the results of a test and whether this affects their behavior after receiving them. Moreover, allowing self-determined testing for everyone could elicit risky behavior and complacency (11, 13) (risk compensation). While for other pandemic and preventive behaviors (mask wearing, HIV prevention, bicycle helmet wearing, and cervical cancer prevention) there was no evidence of risk compensation (17, 18), it is unclear whether rapid tests could invite such compensation. If people do become more complacent, it is crucial to understand whether appropriate health communication can reduce this effect.

A further precondition for the success of the test strategy is rapid reporting of positive results for contact tracing (2), which makes mandatory reporting desirable. In Germany, positive PoC test results require reporting, while positive home tests results do not (at the time of the study) (19, 20). Thus, it is important to explore whether the mandatory reporting of positive results creates a barrier to getting tested.

Decreasing infection rates may not be the only reason to increase testing capacity. Shops, theaters, and restaurants have suffered from prolonged lockdowns and were closed for months in many countries (21). Being allowed to visit these facilities with a negative test result may serve as an incentive to get tested [test-to-enable" (8)]. However, little is known about whether people would actually use this offer and whether this may depend on current community infection rates.

Costs may be an additional factor affecting the willingness to test, with high costs potentially disadvantaging those with lower economic means (10). Currently in Germany, home tests are available for 5 Euros each; 1 US dollar (roughly 0.84 Euro) has been suggested as a feasible price (11). Visiting a person with high risk of severe COVID-19 after performing home tests can be an expensive undertaking for families and may compromise good intentions. Moreover, it is unclear whether people intend

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Significance

Rapid testing with antigen tests accompanies efforts for controlling the disease dynamics in the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) pandemic. A high willingness to carry out these tests and high test literacy of potential users are needed. In four cross-sectional data collections with more than 4,000 participants, we showed that incentives can increase the willingness to undertake a test, while mandatory reporting was not perceived as a major barrier. However, participants had difficulties correctly interpreting test results. A short health communication intervention effectively reduced complacent behavior after negative test results. In sum, rapid tests have great potential to help fight the SARS-CoV-2 pandemic but only when effective health communication enables people to test and act appropriately.

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to use tests before they see other people (i.e., out of prosocial motivation) or after they meet with others. Evidence regarding the underlying motivations would aid the design of effective health communication and successful implementation of the testing strategy.

It is unclear whether trust in government (and, thus, potentially increased attention to the government's messages) fosters understanding of testing and increases the likelihood of using rapid tests [as it does for other preventive measures (22)]. Moreover, during a pandemic, curfews and stay-at-home measures limit citizens' fundamental rights and force people into a passive state of waiting and perseverance (23). Various studies have reported increased feelings of helplessness, indicating increased psychological strain (24–28). Offering rapid testing could provide a feeling of agency and reduce helplessness. However, evidence supporting this idea is lacking.

We explored these issues in four waves of the German large-scale serial cross-sectional COVID-19 Snapshot Monitoring (COSMO) (29). The first wave assessed testing behavior and reasons for getting tested just before Christmas 2020, when PoC testing was relatively new in Germany. More testing facilities were available in mid-February, and free weekly PoC tests were offered by the German Minister of Health in early March 2021. Home tests were also available in shops from early March. We therefore explored whether rapid testing increased over time and what motivated people to take PoC and home tests. We also explored the impact of psychological factors that usually increase protective pandemic behaviors (e.g., trust or risk perceptions). Moreover, we assessed people's intuition about the meaning and behavioral implications of positive and negative rapid test results. We conducted three survey experiments to causally test the effect of important determinants, including the costs of home tests, mandatory reporting of positive results, incentives for testing, and communication measures.

Results

Four cross-sectional data collections in mid-December 2020, mid-February 2021, and mid- and late March 2021, with ∼1,000 participants each ($n = 4{,}026$), were analyzed to determine individuals' behavior and perceptions related to PoC rapid tests and home tests. The participants were randomized to one of several experimental conditions as detailed in the descriptions of the respective experiments. As all questions were explorative, the experiments were not preregistered. All data and analyses are available online (https://osf.io/geha9/) (30).

PoC Antigen Tests. Over the course of the four data collections, the number of people who had already been tested with a PoC test increased (14%, 23%, 27%, and 31%, respectively). The fraction of people who knew where to get such a test also increased (36%, 43%, 51%, and 56%, respectively). Notably, even in late March, almost half of the participants did not know or were unsure about where to get a PoC rapid test, even though these tests were offered at no cost to all citizens starting in early March. The self-reported reasons for getting a rapid test changed over time. While in mid-December most PoC rapid tests were performed after traveling (20%) or after contact with infected individuals (21%), in spring, the most common reasons were contact with persons at risk (34%) or friends and family (21%). For the future, most participants planned to use PoC rapid tests if they experience COVID-19 symptoms (70%) or after having contact with an infected person (63%). For full results, see *SI Appendix*, Fig. S1.

Correlates of Having Been Tested with a PoC Test. Across all four data collections, having been tested in the past was positively related with frequent use of other protective behaviors, such as mask wearing or physical distancing (odds ratios between 1.81 and 4.34; *SI Appendix*, Fig. S2). We further regressed having been tested with a PoC test in the past on demographic and psychological variables that had been related to pandemic protection behaviors in previous studies (*SI Appendix*, Table S1). To obtain a subset of predictors that best predicted the outcome, a binary genetic algorithm (GA) based on Scrucca's (2013) (31, 32) "GA package" for the statistical software program R was used for model selection; for a more detailed explanation of the method and the parameters used, see *Methods* and *SI Appendix*, respectively. The algorithm started with a large set of demographic

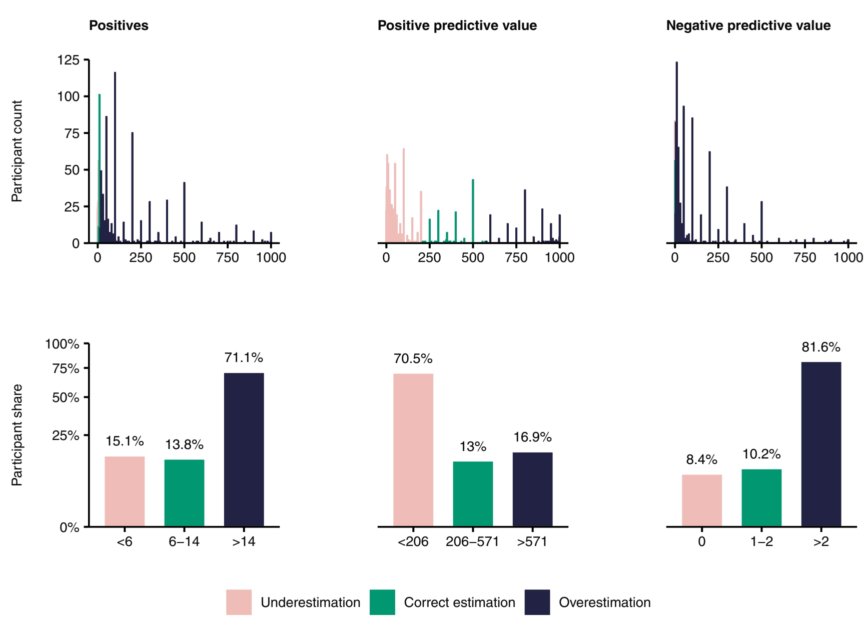

Fig. 1. Estimates of the validity of positive and negative test results. The results indicate that participants overestimated the number of positive tests to be expected at that time (positives; *Left*), underestimated the number of positive test results actually indicating an infection (positive predictive value; *Middle*), and overestimated the number of actual infections given a negative test result (the complement of the negative predictive value; *Right*). Thus, the results suggest that a majority may think, "Rapid test will turn out positive quite often, but this result is false anyway. If it is negative, it is probably also not true."

variables (gender, age, children, education level, household income, regional incidence at the time of the survey, belonging to the COVID-19 risk group, working in the health sector, and infections among family and friends) and psychological variables (trust in the federal government; own information frequency; perceived pandemic fatigue; affective risk and helplessness; perceived efficacy to prevent the disease; probability, susceptibility, and severity of infection with COVID-19; the rejection of current measures; reactance and worries regarding the economy; one's own financial situation; and health and potentially increasing social inequity and divide). Only 7.5% of the variance was explained by the model. In contrast to other pandemic behaviors, having been tested was not related to predictors such as age, affective risk, or pandemic fatigue (18). Only people who worked in the health sector (odds ratio [OR] = 4.77 [95% CI: 3.76 to 6.06]) had infections in their social environment (OR = 1.55 [1.33 to 1.80]) or were from regions with higher incidence rates (medium incidence: OR = 1.52 [1.28 to 1.80]; high incidence: OR = 1.96 [1.29 to 2.40]), and people who did not feel efficacious in avoiding infections (OR = 0.94 [0.89 to 0.99]) showed significantly higher test rates. Overall, the data suggest that having been tested is not an indicator of complacency and seems mainly driven by the question of whether one could be infected after having been in touch with potentially infected others.

Determinants of the Willingness to Participate in Weekly Rapid Test Screenings. In the late March survey, 72% (n = 729 of 1,014 participants) stated that they would get tested twice a week to contribute to public health screenings to quickly identify contagious individuals. The same joint regression reported in *Correlates of Having Been Tested with a PoC Test* showed that health care workers would be more willing to participate in such a screening (OR = 1.93 [95% CI: 1.04 to 3.75]). In addition, other variables that have already been shown to be relevant for other protective behaviors predicted the willingness to participate in the screening, such as perceived affective risk (OR = 1.22 [1.05 to 1.42]), trust in the government (OR = 1.12 [1.01 to 1.24]), and own information frequency (OR = 1.29 [1.16 to 1.45]). Meanwhile, women (OR = 0.71 [0.51 to 0.98]) and people who found the measures exaggerated (OR = 0.87 [0.78 to 0.96]) showed less willingness to participate. People who were more concerned about the economy were more likely to be willing to participate (OR = 1.26 [1.09 to 1.47]), while people who were more concerned about their own financial situation were less likely to be willing to participate (OR = 0.85 [0.78 to 0.93]).

Understanding Test Results. People do not know how valid positive and negative test results are, as evident from Fig. 1. First, we wanted to know how likely people thought that a test result would be positive assuming the current infection rates. The participants largely overestimated the number of positive test results. The correct answer (given the parameters outlined in the *Methods*) was between 6 and 14 per 1,000 tested people; the participants' estimates were considerably higher (mean [M] = 149.80; SD = 213.49; median [Md] = 50).

We further tested how well people estimate the positive and negative predictive value of the tests when used to detect infections. To this end, we asked them how many people out of 1,000 with a positive test result are really infected (positive predictive value). Correct answers of actual infections among 1,000 positive tests were between 206 and 571. The participants both largely over- and underestimated this (M = 220.09; SD = 305.62; and Md = 50). Only 13.2% of the estimates were within the correct range; 70.5% underestimated and 16.9% overestimated the actual number. While this demonstrates that people know that not every positive result means that they actually are infected, they struggle to gauge the validity of positive tests and underestimate the validity of positive test results. In order to understand people's intuition about the validity of negative test results, we had the participants estimate how many of 1,000 negative test results are false negative (the complement of the negative predictive value). In settings in which most people are not infected, most negative test results are true. The correct answer was therefore that about 0.5 to 2 in 1,000 negative tests are false negative. As only integers could be entered, we counted 0 as underestimation, 1 to 2 as correct, and >2 as overestimation. The modal value was 10, and the number was overestimated by 81.6% of the sample (M = 93.83; SD = 164.03; and Md = 20).

In sum, the participants overestimated the number of test results that would turn out positive. They were further unsure about the validity of rapid tests, as they underestimated the validity of positive and negative test results. The general assumed validity of PoC tests can thus be summarized as very low.

Incentives and Barriers for Getting Tested with PoC Rapid Tests. While nonessential shops were closed at the time of data collection in early March, an experiment described two different shopping scenarios to identify potential incentives for testing (no tests were mentioned versus access to the city was granted only for people with negative rapid test results). The participants indicated whether they liked the described scenario, their willingness to go shopping under the given circumstances, and their willingness to take a rapid test. Moreover, in a third test scenario, it was stated that a positive test result would have to be reported, followed by a PCR test and quarantine to explore whether mandatory reporting could be a potential barrier. As can be seen in Fig. 2, the participants generally agreed more with opening the city for shopping when PoC rapid tests were offered than when no tests were mentioned [$F(2{,}991) = 11.92$, $P < 0.001$; see *SI Appendix* for Tukey post hoc tests]. Nevertheless, the mean willingness to attend the shopping opportunity was relatively low and increased only marginally in the condition where only people with negative PoC rapid test results could enter the city. The shopping situation still served as an incentive, as the mean willingness to get tested was significantly higher when testing was related to the opportunity to go shopping [$F(2{,}991) = 6.56$, $P = 0.001$]. As evident from the 95% CIs in Fig. 2, there was no evidence that knowing about mandatory reporting of positive test results or having to isolate and get another PCR test immediately affected the intention to get tested (all $P > 0.12$). Surprisingly, the judgments did not differ between

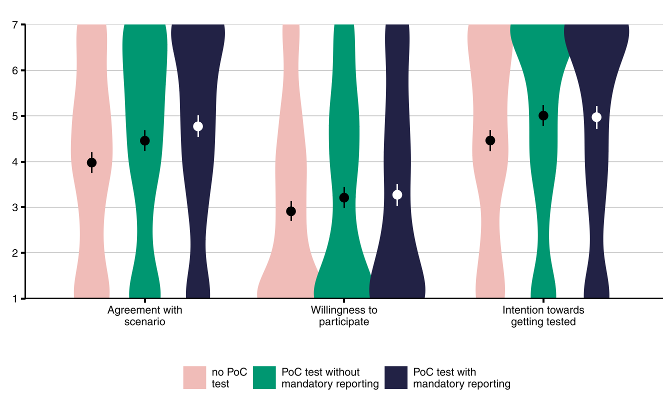

Fig. 2. Results of Experiment 1 assessing incentives and barriers for rapid testing. Offering shopping only to those with negative rapid test results could serve as an incentive, as the willingness to take a rapid test increased (*Right*). While the agreement with opening shops after testing was generally higher than when tests were not mentioned (*Left*), the willingness to go shopping was still low (*Middle*). Learning that positive test results would be reported and followed up by a PCR test and quarantine did not serve as a barrier to PoC test willingness. Violin plots show the density distribution, dots indicate mean values, and whiskers are the 95% CIs.

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participants in high-risk (average 7-d infection rate >100) and low-risk areas (<50) (*SI Appendix*, Fig. S3).

Reasons for and against Using Home Tests. In addition to PoC tests, home tests became available in shops in Germany in mid-March 2021. We used open text fields to explore the reasons why people would or would not use such tests. We found that 79% were generally willing to use home tests, while 21% were not willing. *SI Appendix*, Tables S5 and S6 provide an overview of the reasons for their answers. The most frequently mentioned reason for using home tests was the desire for certainty and reassurance (23%), followed by the motivation to meet but protect close people or people with higher risk of severe COVID-19 infections (16%), the possibility to take part in leisure activities (15%), and to avoid getting infected and infecting others (14%); 8% explicitly stated that they would use a test to learn whether they are infected. When summarizing the categories further, two major motivations emerged: 42% wanted to do a home test to answer the question "Do I have Corona?", and 53% wanted to answer the question "Could I infect someone?" The main reasons against using home tests were mostly distrust in the validity of the test (27%), insecurity about how to conduct a test (14%), or because the person did not show any symptoms (13%). A small number of people rejected tests in general, as they assumed that the situation was exaggerated (7%) or a conspiracy (4%). Summarizing the categories further led to two motivations against testing: a lack of understanding of why or how to do it (54%) and doubts regarding the validity of the tests (27%). Thus, while PoC tests were used mainly to identify whether the tested person might be infected, home tests may be a vessel to facilitate ostensibly safe social contacts, rendering the behavioral implications of positive and negative test results especially important. Information about how to conduct these tests and what the test results mean is therefore crucial.

In order to compare the relative impact of those motives, in the next survey (late March), we included items that captured the importance of these motives and regressed the willingness to conduct a home test (yes/no) on them as well as the demographic and psychological variables used in the joint regressions above (n = 1,014, R^2 = 0.40). As Table 1 reveals, women were less willing (OR = 0.54 [95% CI: 0.35 to 0.82]) and higher educated people (OR = 2.64 [1.48 to 4.68]) were more willing to take a home test. Confidence in a tests' validity also predicted willingness (OR = 1.21 [1.04 to 1.40]) as well as higher self-efficacy regarding testing (feeling able to do a test [OR = 1.30 (1.15 to 1.48)]; belief that tests are easy and quick to do [OR = 1.16 (1.00 to 1.35)]). The motivation to protect others (OR = 1.25 [1.09 to 1.43]), searching for information frequently (OR = 1.15 [1.01 to 1.32]), and acknowledging that isolating infected people could curb the spread of the pandemic (OR = 1.22 [1.06 to 1.40]) also increased the willingness to take a home test, while the idea that tests are unnecessary because COVID-19 is not dangerous (OR = 0.70 [0.61 to 0.81]) and the idea that tests are being used by the government to artificially inflate the pandemic (OR = 0 to 86 [0.75 to 0.98]) decreased it.

Costs of Using Home Tests. While the willingness to use home tests seems to be high when people know how to do it, home tests entail financial costs that could reduce their use. In order to assess the causal effect of monetary (also compared to the free PoC tests) as well as social costs (isolation and quarantine after mandatory reporting of results), we set up five between-subject experimental conditions, comparing home tests at no cost, 1 Euro, and 5 Euros and free PoC tests with and without mentioning that positive tests would have to be reported. The participants indicated for several social and risk situations whether they wanted to get tested or take a home test before and after the respective events. The results are shown in Fig. 3. The willingness to use both home tests and PoC rapid tests was highest before meetings with risk groups and after meetings with symptomatic individuals. Costly home tests were generally less attractive than free PoC tests [Welch two-sample t test; $t(6{,}072.1) = -11.65$, $P <$ 0.001]. The intended use of home tests depended on their price [$F(2, 4{,}605) = 65.27$, $P < 0.001$]. A total of 5 Euros per test significantly reduced the willingness to take a home test compared to free tests or those costing 1 Euro (post hoc Tukey tests, $P < 0.001$). There was no evidence that a price of 1 Euro could lower the willingness to perform home tests compared to free tests ($P = 0.147$). The projected use of PoC rapid tests did not depend on whether the individual was informed that positive results would be reported to health authorities and followed by isolation and PCR testing [Welch two-sample t test; $t(3{,}318.8) = -1.01$, $P = 0.31$]. The willingness to use home and PoC rapid tests was slightly higher before private meetings with friends and family than the willingness to use these tests after such meetings [$t(3{,}973.1) = 7.65$, $P < 0.001$], suggesting a prosocial motivation for home testing. The willingness to use home testing after private meetings with close friends and family was significantly lower than after meetings with strangers [$t(1{,}157.2) = -3.41$, $P < 0.001$]; this is in line with previous findings showing that people perceive less infection risks when they meet people they feel close to (33–35).

Projected Behavior after a Positive Home Test. A majority of the participants, 58.8%, thought that reporting a positive home test result was mandatory [which was wrong at the time of data collection: Only PoC positive results have to be reported (20, 36)]; 24.55% indicated that they did not know, and 16.6% thought that they do not need to report a positive result. Given a positive result, 85% stated that they would isolate until the result is verified (8% undecided and 7% disagree), 82% indicated that they would get a PCR test for verification (9% undecided and 8% disagree), 80% would inform all contacts they had over the last 14 d (10% undecided and 10% disagree), and 54% would take a second home test to validate the result (15% undecided and 32% disagree).

Psychological and Behavioral Consequences of Home Testing. Participants in the previously reported data collections had frequently indicated that they intended to use home tests before they would meet family and friends. In order to estimate the risk of complacent behavior, we conducted an experiment in which participants imagined being invited to a birthday party with 10 people from three households (which was allowed given low incidence rates at the time of data collection). Fig. 4 displays the results; 95% CIs allow for direct comparison. Testing indeed tended to decrease the likelihood of exhibiting protective behaviors, as the participants indicated that they would be somewhat less likely to wear a mask (post hoc Tukey test, $P = 0.053$) or keep distance from other guests ($P = 0.187$) in the test as compared to the control condition—although the effects do not reach conventional levels of significance. The pattern was even weaker for paying attention to good ventilation and referring others to hygiene rules; there was no effect on sharing a glass for drinks (floor effect) or shifting the party to the outside (ceiling effect). Having received information about the validity of negative results reduced this tendency (mask wearing test versus test with information: $P = 0.029$; distancing: $P = 0.024$). Information about the validity of negative tests also increased the perceived probability to get infected at the party [$F(21{,}011) = 16.81$, $P < 0.001$, test versus test with information: $P < 0.001$] as well as the worry of infecting others [$F(21{,}011) = 5.23$, test versus test with information: $P = 0.006$]. This could be a potential mechanism that renders the communication intervention effective. Helplessness/agency (i.e., feeling that one is helpless versus can actively do something) did not change as a function of testing.

Table 1. Willingness to perform home tests

Variables	Willingness to perform a home test		
	Odds ratios	95% CI	P
Gender (reference: male)	0.54	0.35–0.82	0.005
Parents of a child under 18	0.76	0.48–1.20	0.244
At least 10 y of education (reference: <10 y of education)	2.64	1.48–4.68	0.001
Regional 7-d incidence rate: 50–100 (reference: <50)	1.06	0.69–1.63	0.800
Frequency of search for information on the topic	1.15	1.01–1.32	0.037
Confidence in validity	1.21	1.04–1.40	0.011
Containing the pandemic by isolating infected individuals through testing	1.22	1.06–1.40	0.005
Protect others through self-tests	1.25	1.09–1.43	0.001
Self-testing is unnecessary because Corona is not dangerous	0.70	0.61–0.81	<0.001
Feeling able to perform a self-test	1.30	1.15–1.48	<0.001
Self-tests are being used by the government to artificially inflate the pandemic	0.86	0.75–0.98	0.024
Self-tests are quick and easy to perform	1.16	1.00–1.35	0.046
Observations		1,014	
R^2 Tjur		0.398	

Discussion

While most current scientific contributions explain the opportunities and challenges of using rapid tests on asymptomatic individuals, this contribution aims at unpacking the black box of human cognition and behavior and takes a people perspective on rapid testing. Data from 4,026 participants from four cross-sectional surveys, including three experiments, suggest that they were tested mainly to answer the question of whether they could be infected. Thus, early rapid testing was not as much a screening endeavor but rather a response to a current need after risky situations (e.g., health care personnel at work, after traveling, or having seen someone with symptoms). The willingness to take part in regular screenings (e.g., twice a week) was high (72%), and it was partially related to trust in the government or perceiving higher risks due to the pandemic. Regarding the incentives for and costs of testing, evidence from several experiments showed that low financial costs and granting access to events (e.g., shopping) could increase testing behaviors. However, it is important to note that rapid tests should not be used as door-openers for settings in which one missed infectious individual could potentially infect many others or people with high disease risks, and, thus, they may not work as a strategy for reopening society after controlling a pandemic wave (4, 37, 38). The fact that positive results have to be reported and are followed by isolation was not identified as a major barrier. Instead, those who thought that testing and isolation were suitable for curbing the spread of the disease were more willing to get tested. The vast majority indicated that they would self-isolate after a positive result.

While so far the data seem to suggest that people take a rather pragmatic approach to rapid testing, the data on the assumed validity of the tests indicated that the participants did not perceive the test results as particularly valid. This seems somewhat at odds with the high willingness to use tests. However, the expected validity of a test was only weakly related to the willingness to get tested, and aspects of self-efficacy (whether one expects the procedure to be easy and knows how to do it) and the motive of protecting others were other relevant predictors. Prosocial motives of testing have already been identified in previous studies (39). Therefore, limited effectiveness of the measure was obviously not as important as a potential prosocial benefit given one knew how to test. Addressing prosocial motives (protect the vulnerable and reduce transmission through isolation) is a promising communication strategy that has already demonstrated its value in other areas, such as vaccination (40). Some scholars worry that people would not isolate when home tests return positive results (9). The low trust in the validity of the tests also points in this direction. However, there seems to be a social norm of reporting positive results, suggested by the fact that the majority thought it was mandatory to report a positive home test result (which it was not at the time of the study). The willingness to self-isolate and show the correct behaviors was relatively high. However, it must be considered that this was when ticking boxes in a questionnaire. It still remains an open question whether people would adopt these behaviors themselves in the potentially stressful situation of a positive test result. Half of the participants wanted to take another test when having a positive result. Some scholars indeed suggest that another test from a different company (41) could help to reduce the possibility of false positives. Overall, there seems to be some uncertainty about the correct behavior, indicating an urgent need for communication. Offering an app or a hotline where any result, positive or negative, should be reported may offer help to those who are uncertain and assist those with a positive result in arranging a PCR test (42). It could also facilitate certification processes so the test results could be used for participation in public life and, of course, surveillance. This study did not assess the willingness to register test results nor did it address the question of certifying the results or the willingness to contribute to contact tracing. These are important aspects that should be incorporated in future research. Moreover, little is known about how test intentions may develop when a positive rapid test result is proved to be a false positive by a PCR test, which is especially likely when disease prevalence is low (10). People may lose trust in the validity of positive rapid test results, which is worrisome since the number of true positive tests is already underestimated. It can only be speculated why trust in the validity is quite low, but bad press at the beginning of the introduction of the tests and a lack of decent health communication could have contributed to this lack of knowledge and trust. In any case, a precise communication strategy is needed to foster self-isolation after any positive rapid test results and stabilize the intention to take a PCR test to verify the positive result.

An important argument against making rapid tests available is that people may become complacent and stop following protective behaviors (11). In a United Kingdom–based study, 62% of the respondents said that they would likely not change their behavior given a negative test (39). While we did not find evidence for risk compensation for past tests, the experimental evidence suggests that a group of 10 people might indeed have a tendency to show less mask wearing and physical distancing when all have negative

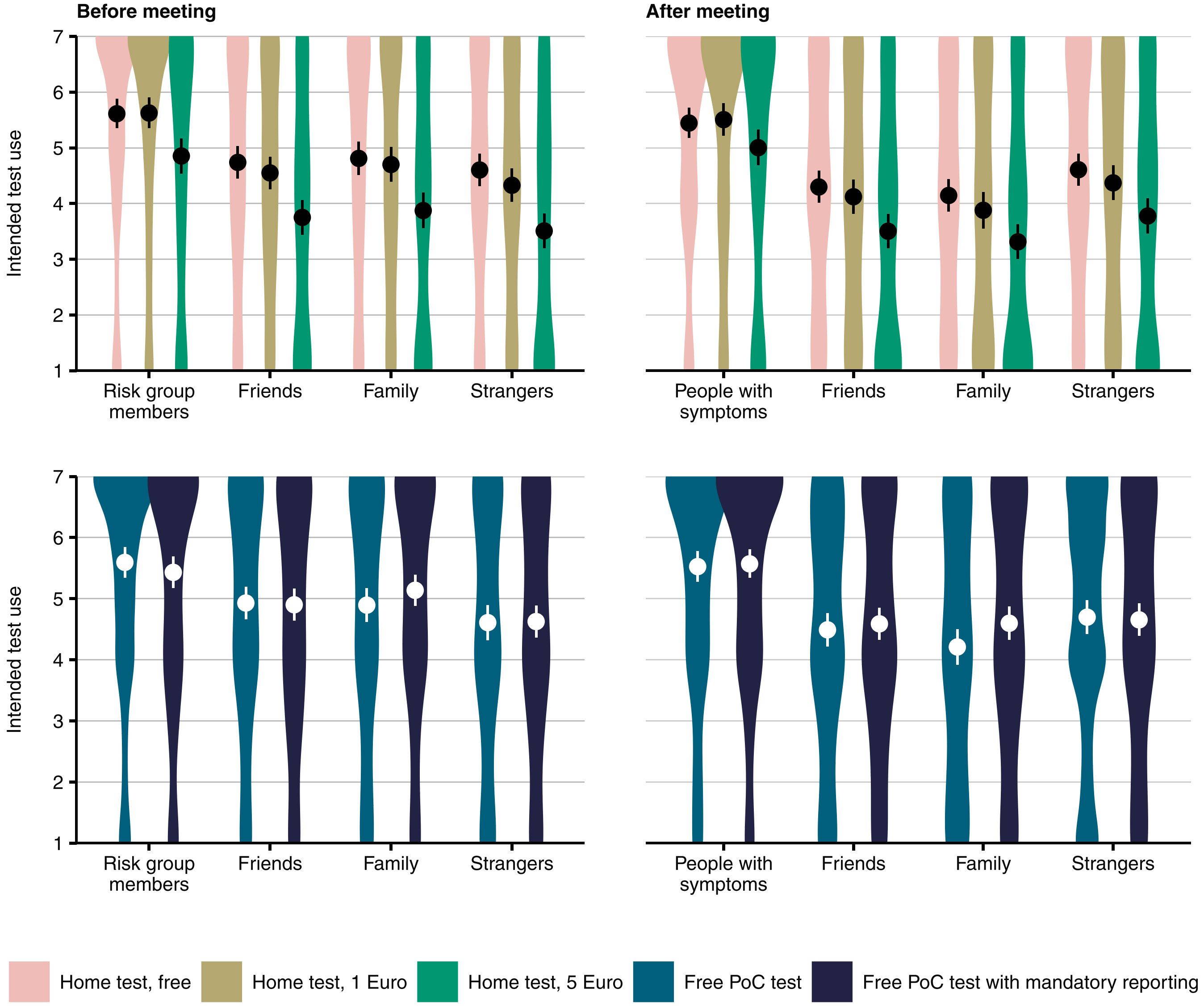

Fig. 3. Results of Experiment 2 assessing the willingness to use home tests or PoC tests as a function of financial costs (home tests) and awareness of mandatory reporting of positive results (PoC tests). The willingness to use both home tests and PoC rapid tests was highest before meetings with risk groups and after meetings with symptomatic individuals. The closer people were to others, the less they intended to test after a meeting (family and friends versus strangers). Higher costs of home tests reduced the willingness to use the test. Whether people were made aware of mandatory reporting of positive results did not affect the willingness to get a PoC test. Violin plots show the density distribution, dots indicate mean values, and whiskers are 95% CIs.

test results. This effect may be intensified, as people wanted to test more before they see family and friends, and other data have shown that people do not perceive family and friends as a relevant source of infection risk and show less protective behaviors with them (33–35). This is also backed up by the present data showing that people do not want to test as often after having seen family and friends but they are more likely to do so after having seen strangers (Fig. 3). Luckily, a short communication intervention pointing out that negative tests can still be false reduced the intended complacent behavior. Here, it is also important to keep in mind that, on the population level, regular antigen rapid testing could improve pandemic outcomes, even if some protective behaviors are followed less in some situations, as long as enough infected people self-isolate—which is supported by the present data. Nevertheless, Experiment 3 demonstrates that it is crucial to explicitly communicate the limits of rapid tests. Likewise, two-thirds of the participants thought that a negative test means that they cannot infect somebody the next day. A negative test indicates that the risk of being infectious is reduced at the time of testing. The more time has passed since the test, the more this risk reduction wanes (43). This fact should also be emphasized in communication around testing.

We did not find that testing decreased helplessness (or increased agency) regarding the pandemic. A lack of relevant information (e.g., about where tests are available and why people should get tested regularly) could hamper this potential beneficial effect. Future field data could provide a more pronounced picture here.

Data collection took place about 6 mo after first rapid tests became available in Germany and when home tests had just become available. The findings that both the number of tests and the knowledge about where to get tests increased over time suggest that increases in knowledge can be expected in other areas as well. Thus, while the present analyses are only a snapshot, they provide broad insights into how people could be supported to participate in a successful testing strategy. As a further limitation,

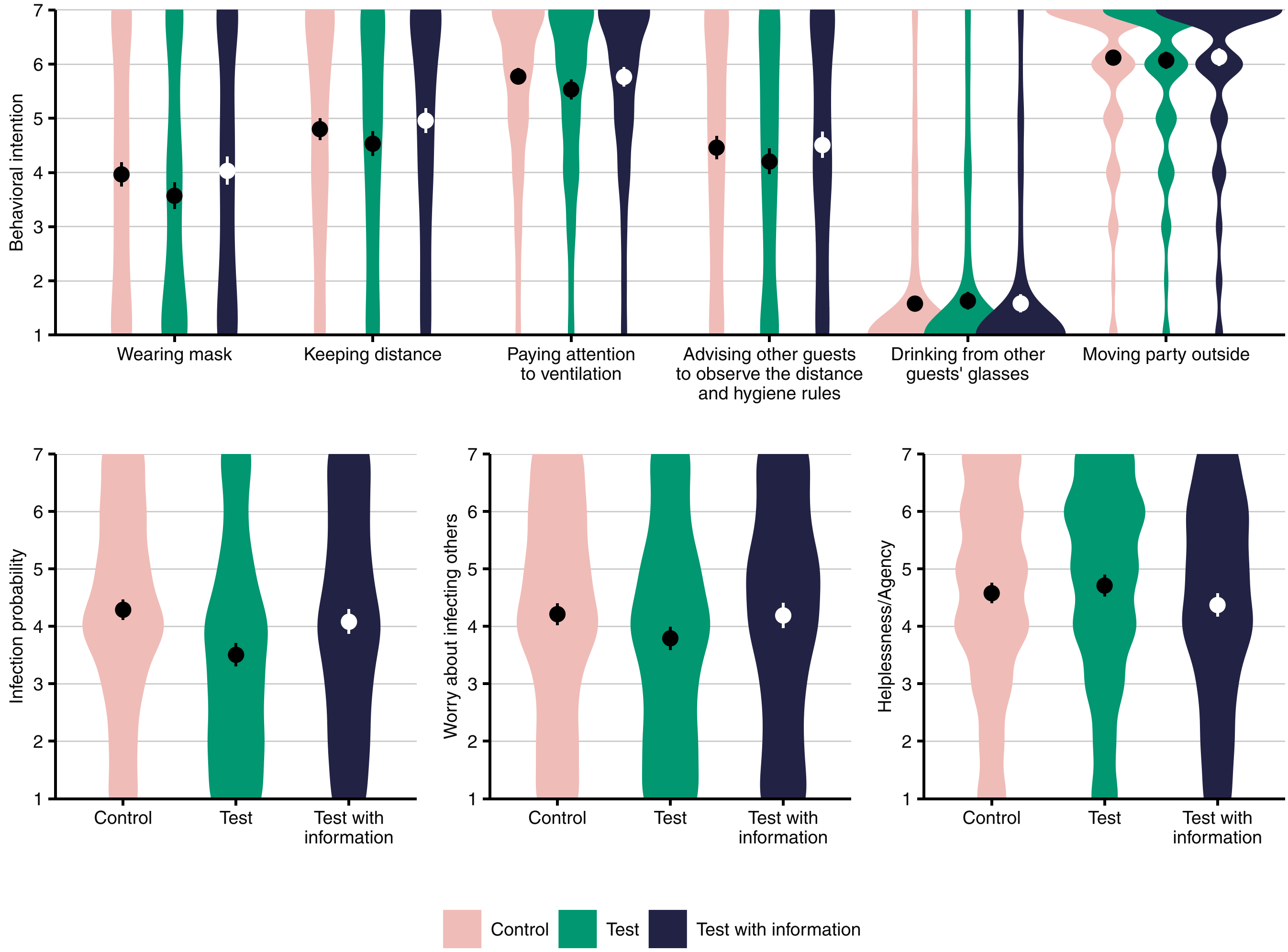

Fig. 4. Results of Experiment 3 assessing psychological and behavioral consequences of negative home tests in close social settings. Having a negative home test result before a social gathering decreased some preventive behaviors such as mask wearing or keeping physical distance to a small degree. Most protective behaviors were unaffected. Information about the limitations of negative test results could reduce this tendency. Information about the validity of negative tests also increased the perceived probability of getting infected at the party as well as the worry of infecting others. Helplessness/agency did not change as a function of testing. Violin plots show the density distribution, dots indicate mean values, and whiskers are 95% CIs.

we note that the age of the participants was limited to 18 to 74. Students are a large group who get tested in school; assessing their knowledge and behaviors is therefore crucial as well, as they represent large groups with many contacts and are therefore important clusters in the disease dynamics. Moreover, the elderly may have difficulties handling the home test, as pipettes, etc., are rather small (14). Since self-efficacy was an important driver of testing behavior, supporting the elderly in using home tests is advisable, although we cannot present data on this group. While we used samples in which the distribution of age × gender, as well as federal state, was representative for the German population, we did not use probabilistic sampling procedures. Thus, the samples were generally higher educated and understanding of the tests, and their knowledge may be overestimated, while the effectiveness of communication may be underestimated. Indeed, in the analysis on the willingness to participate in weekly tests, we found that higher educated participants (>10 y of education) were more willing to get tested than participants with less than 10 y of education. This could indicate that early adopters of science-based behaviors could be found in better educated parts of the society. This calls for better and low-threshold health communication as well as the need for fast and broad distribution of the information on what should be done when and why.

In sum, the majority seems to be willing to use PoC or home tests, as they want to make social contacts safer and are willing to comply with screenings to curb the spread of SARS-CoV-2. People will be more likely to use tests if they are available at a low cost and are easy to use or if they are a key (given low infection rates) to gaining access to public and social life. However, people urgently need information about what a test result means and how they should behave. Recommendations based on the present findings are summarized in Table 2. While the data were collected in Germany only, the pattern of results points to principles that are inherent in human behavior. Moreover, the interpretation and behavioral implications of test results are the same around the globe. Thus, we are confident that the derived recommendations are valuable in other countries as well. These findings will thus be important at a time when antigen rapid tests and self-testing is being rolled out (e.g., in low- and middle-income countries). Activities that support people in isolation and quarantine (e.g., regarding PCR testing and well-being while isolating) could increase the willingness to adhere to the regulations (8). Political action that reduces the financial burden of testing (of buying tests, of self-isolation, and not being able to work and earn money) will be necessary to support testing activities. The present work shows that interpretation of tests is

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Table 2. Suggestions for communication to improve behavior around rapid and home testing

Topic	Recommendations
Test strategy	Communicate that widespread frequent testing with rapid tests can help detect nonsymptomatic but nevertheless infectious people. This can help break chains of infection and, over time, help to stop the spread of SARS-CoV-2. The more people get tested regularly and isolate when tested positively, the more effectively we can break infection chains.
	Assist people to find testing sites early on (e.g., by inviting the local media to the testing sites) or by repeated advertisements on the radio, on billboards, etc.
	Communicate whether rapid tests and home tests can detect different variants of SARS-CoV-2 similarly well.
	Tests are imperfect and people are still willing to use them for screening, testing, and isolating those who are infected. Policy makers can expect a high degree of compliance from citizens given they provide them with understandable information and facilitate the desired behaviors afterward.
	People are motivated to protect others. Addressing prosocial motives and offering incentives, such as taking part in public and social life (at low community prevalence and/or with social distancing, mask wearing, etc.), could increase test rates.
	Communicate that there are two types of antigen rapid tests: PoC test and home tests. The technology is the same. Only the person who conducts the test differs: either a trained person in a PoC facility or a lay person testing themself.
Conducting tests	Strengthen people's self-efficacy in using tests; explain how home testing works, where to get high quality tests, and how to read the results.
Behavior after a test	Consider that people may have had risky contacts and ask "Do I have COVID-19?" Consider that the other motivation is that they intend to meet others, wondering "Could I infect someone?" In both cases, they expect a yes or no answer from the test. A "no" answer may elicit a tendency for complacent behavior, especially as tests are taken to protect close family and friends. Thus, information is needed about why and which protection is still necessary. A "yes" answer requires information about isolation and PCR follow-up testing.
	Communicate what people need to do after a positive test result. Explain that a positive test result is not a diagnosis. It indicates that a person might be infected and infectious and that the positive results need to be taken seriously. Therefore, positively tested individuals should immediately isolate themselves as best they can. Furthermore, they should get a PCR test from their health care provider to confirm their result as soon as possible. Offer support and information for isolation.
	Communicate what people need to do after a negative test result. Explain that a negative test means that the risk of being infectious is reduced but it is not zero. Therefore, it is still safest to continue other protective behaviors such as keeping physical distance and mask wearing. This also helps to avoid getting infected.
Validity of the test result	Consider that people may wonder "Does the test tell the truth?" Consider that people may have no good intuition about the validity of the test. People will also not consider that the test result has different validity given a positive or a negative result or different incidence rates. Communicate the action requited after either test result.
	Communicate that the more time has passed since the test, the less meaningful its result becomes. Therefore, the test is only valid on the same day.
Distribution of information	While some people may have a sincere interest in finding out about the scientific background behind the behavioral rules, for the majority, it may suffice to clearly explain the behavioral part. A "bite, snack, meal approach" could offer easily accessible information regarding the WHAT TO DO; for those interested, it could be supported by the WHY, based on HOW the test, disease, and tested person interact.
	All information should be provided in a language that laypeople can understand to increase understanding, self-efficacy, trust, and confidence.
	Information should be provided at relevant touchpoints, such as test centers, home test information leaflets, schools, and the workplace. It is important that health information is also offered by nongovernmental institutions (as trust in those may decrease over time). Trusted organizations in local communities such as sports clubs, organizations of faith, etc., could serve as multipliers.
	Information should be provided in multiple relevant languages and complemented by illustrations to reach minorities as well as those with low health literacy.

difficult and it cannot be taken for granted that correct behavior will be shown after positive and negative test results. PoC and home tests thus have great potential to be another building block for fighting the SARS-CoV-2 pandemic, but only when effective health communication enables people to test and act appropriately.

Methods

COSMO (29) assesses roughly 1,000 participants in weekly (after May 26, 2020, fortnightly) online serial cross-sectional data collections. Study participants were members of an ISO (International Standard Organization) e26362:2009–compliant online panel (respondi.de, https://www.iso.org/standard/43521.html), and the data collection company compensated them financially for participation at their usual rate. The results support the German government's policymaking and crisis communication. The present data were collected in four COSMO data collections in December (December 15 and 16, 2020), February (February 23 and 24, 2021), mid-March (March 9 and 10, 2021), and late March (March 23 and 24, 2021). Shutdown measurements were in place during the first three data collections (shops, barbers, and nonmedical services were closed; a private contact restriction policy was in place). Since October 2020, rapid testing has been offered in hospitals and nursery homes. In December, general practitioners started to offer rapid asymptomatic PoC testing for private payment. Weekly PoC tests became free of charge in early March. At the same time, home tests became available in shops.

Participants. Each wave's sample is quota-representative for age (18 to 74 y old) × gender and federal state in Germany. Demographics are presented in *SI Appendix*, Table S7 and German quotas at https://osf.io/geha9/ (30).

Measures. All original and translated items are available online (https://osf.io/geha9/) (30). An overview of all surveys in the COSMO series is also available online (35). In all data collections, demographics were assessed first, followed by the psychological variables. Experiments were placed toward the end of the questionnaire. In the paragraphs below, we report only the relevant variables used in this contribution.

Demographic variables. Education was assessed as low (up to 9 y of schooling), medium (at least 10 y [without A level]), and high (at least 10 y [with A level]). For the regressions, it was categorized as low (up to 9 y) and high (at least 10 y). Income was assessed as household net income, with seven levels ranging from <1,250 to >5,000 Euros. For family status, participants indicated whether they had children under 18 y of age (yes/no). Occupation in the health sector and infections among family or acquaintances were also collected as yes/no answers. Membership in the at-risk group was collected as yes/no/don't know. Daily numbers of new confirmed COVID-19 cases as well as the 7-d incidence rate per postal code area were collected by the German Robert Koch Institute. By matching the numbers with the postal code, these indicators of infection in the participant's area were added to the dataset. For data protection reasons, the data are provided in categories only (<50, 50 to 100, and >100).

Psychological variables. Psychological constructs were assessed with seven-point Likert-type scales and used single items for the following economic reasons: trust in the federal government (1 = very little trust, 7 = very much trust) and probability, severity, and susceptibility regarding COVID-19 infection (1 = extremely unlikely, completely harmless, and not susceptible to 7 = extremely likely, extremely dangerous, and very susceptible). The participants indicated how often they search for information on the topic (1 = never, 7 = very often) and whether they found the measures exaggerated (1 = don't agree at all to 7 = fully agree). The self-efficacy item asked how hard or easy it is for them to avoid infection with COVID-19 in the current situation (1 = extremely difficult to 7 = extremely easy). Helplessness/agency regarding COVID-19 was also rated (1 = something I feel helpless about to 7 = something I can actively do something about). Affective risk is the mean score of three semantic differential items (frightening to not frightening, worrying to not worrying, and something I think about all the time to something I almost never think about), assessed on scales ranging from 1 to 7 (Cronbach's alpha = 0.81). Worries were assessed with 10 items; the participants rated the degree to which they worried about different aspects regarding the economy (small businesses filing for bankruptcy, economic recession, or social life being restricted in the long term), one's own financial situation (losing job or loss of income), health (getting infected yourself, losing someone you love, or health care system becoming overburdened), and potentially increasing social inequity and divide (increasing the gap between rich and poor, with society becoming more selfish) on scales ranging from 1 (very little) to 7 (a lot).

Protective measures. To assess whether participants who had been tested show more or less protective behaviors, we assessed the self-reported frequency of wearing a mask, washing hands, physical distancing, using the Corona Warning App, and avoiding close contacts (1 = never; 5 = always). The participants could also indicate if this did not apply to them, leading to missing values.

PoC rapid tests. The participants indicated whether they had already been tested with a PoC rapid test (yes, no, or don't know) and whether they know where to get such a test (1 = strongly disagree; 7 = strongly agree). In February and early March, the participants who had already been tested selected all reasons that applied for the previous test and projected situations in which they thought they would get tested in the future (visiting people with a high risk of severe COVID-19, visiting friends and family, own symptoms, having been in contact with an infected person, or after traveling; yes/no; multiple answers possible). Additionally, in late March, the participants were asked whether they would consider getting a rapid test twice a week for screening purposes (yes/no).

Individuals' understanding of test results was examined in early March. The participants were asked to estimate the tests' positive predictive value (how many people would be infected out of 1,000 people with a positive rapid test result) and the complement of the negative predictive value (out of 1,000 people with a negative rapid test result, how many are in fact infected but not being discovered). For both answers, an open text field was provided, allowing integers only. To determine the range of correct answers, we used the present infection rates of 70 per 100,000 inhabitants at the time of the survey, assuming that approximately one-third of cases are reported (which results in 4.4 infected people out of 1,000 according to https://covidstrategycalculator.github.io/), a test sensitivity between 60% [mean sensitivity (44)] and 90% [which is the lowest sensitivity as provided by the test manufacturers of all available tests in Germany (45)], and a specificity between 99% (45) and 99.7% (37). These parameters yield a probability of being infected given a positive test result of 20.63 to 57.14% (positive predictive value) and a probability of not being infected given a negative test result of 99.82 to 99.96% (negative predictive value; https://rki-wiko.shinyapps.io/test_qual/). Consequently, answers were counted as correct when the participants stated a number between 206 and 571 (number of people with positive test results who are actually infected) and 1 to 2 (number of people with negative test results who are in fact infected). The correct answer range for the number of positive test results given 1,000 rapid tests was 6 to 14. Participants answering with numbers outside of the 0 to 1,000 range were excluded from the respective analysis (four for the true positive and one for the false negative analysis). Note that we asked people about the tests' validity to indicate an infection. In public health screening settings, the tests might be used to mainly detect asymptomatic infectious people. While test performances might differ for this use case, they would have the same order of magnitude. We therefore would not expect the results to notably differ.

Home tests. Participants in both March data collections were asked whether they intend to perform home tests (yes/no). In early March, a qualitative assessment of their reasons for (non)testing was followed with open-answer questions. The participants further rated whether they would show a certain behavior given a positive home test result (isolate and, until the result is verified, get a free PCR test, informing close contacts of the past 14 d, and do a second rapid test; 1 = definitely not to 7 = definitely) and indicated whether they think reporting of positive home test results is legally mandated (yes/no/don't know). For reporting, the variables were recoded as no/disagree (1–3), unsure/undecided (4), and yes/agree (5–7).

Building on the open answers from early March, items were created capturing the motives of home testing. A total of 10 items were developed, and participants rated their agreement (1 = definitely not agree to 7 = definitely agree) with statements regarding their confidence in the validity of home tests; whether they found home tests to be easy to perform and felt confident in doing so; whether they considered them to be an adequate means of identifying infected people, to reduce transmission, to allow more contacts; whether they knew why people without symptoms should get tested; and whether they would support mandatory testing. Additionally, the participants rated whether they believed home tests were unnecessary because COVID-19 posed no threat and whether they saw them as a means of the government to artificially inflate the pandemic.

Experiment 1: Incentives. In early March, the participants were asked to imagine that they had the chance to go shopping in the city center on the upcoming weekend. Regular hygiene rules (wearing a mask and physical distancing) would still apply. They were randomly allocated to three conditions either proceeding directly to the dependent variables (control, n = 330), a condition suggesting that everyone would be required to get tested (PoC rapid test, n = 351), or one suggesting everyone would be tested and positive results would be officially registered and followed up by a PCR test (PoC test with registration, n = 313). We chose the evaluation of the procedure, the willingness to go shopping in the given circumstances, and the willingness to take a rapid test as dependent variables, all assessed on scales ranging from 1 (not at all good/definitely not) to 7 (very good/definitely).

Experiment 2: Costs. In early March, the participants were randomly assigned to one of the following five experimental conditions. They were asked to imagine that they had the chance to get tested in a PoC test center (n = 418) or to do a home test (n = 576). In a nested design, costs were varied for the home test only (no costs [n = 197], 1 Euro [n = 185], and 5 Euros [n = 194]), while the PoC test was available at no cost. For the PoC rapid test, it was further varied whether the participants learned (n = 215) or did not learn (n = 203) that positive test results would be officially reported and followed up by a PCR test. Participants then answered four questions indicating how often (1 = never to 7 = always) they would use such a test before they meet people from a risk group, friends, family, or people they do not know well and how often they would use such a test after they met people with COVID-19 symptoms, friends, family, or people they do not know well.

Experiment 3: Consequences of home testing. In late March, the participants were randomly assigned to one of the following three conditions, each describing a scenario of a small private birthday party involving 10 people from three households, which was in accordance with legal regulations at the time of data collection. In the control condition, testing was not mentioned. In the two experimental conditions, all guests, including the participant, were tested negative with a home test prior to the gathering. The participants received or did not receive additional information about false-negative tests ("Please note that in rare cases a test can also be wrong. It is therefore possible that you or your friends are infected with the coronavirus, but the test does not indicate this. This may be the case if you have only recently been infected or have almost overcome the infection. Then the viral load is

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too low to get measured by the test but you could still infect others. Or it may be the case that a test was performed incorrectly."). Dependent variables were helplessness/agency (the Coronavirus is something. . .1 = I feel helpless about or 7 = against which I can actively do something), perceived probability of infection during the party (1 = not at all likely to 7 = very likely), the likelihood of showing certain behaviors at the party (e.g., wearing a mask, physical distancing to other guests, asking other guests to be aware of the restrictions, or drink from another's glass; 1 = not at all likely to 7 = very likely), and worries about infecting another person at the party (1 = not at all to 7 = a lot).

Ethical Approval. The study, including all reported data collections, obtained ethical clearance from the University of Erfurt's Institutional Review Board (#20200302/20200501), and all participants provided informed consent prior to the data collection.

Data Availability. Data, analysis code, details of all statistical analyses, and supplementary methods are provided at the Open Science Framework (https://osf.io/geha9/) (30).

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