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Motivational and behavioral mechanisms underlying generalized health risking behaviors during the COVID-19 pandemic in smokers

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Under the threat of public health challenges such as the recent COVID-19 pandemic, individual citizens' active and cooperative participation in precautionary measures is crucial. Although non-compliance is recognized as a recurring problem, it remains unknown why some individuals tend to comply less than others and whether violations of preventive behaviors are observed consistently across different public health issues. To test our hypothesis that individuals would show consistent public health behavior transcending domains, we collected self-reports from two independent samples of participants (total N = 2983) on health risk beliefs and behavioral choices. Participants' responses were collected in regard to two separate yet closely related public health issues: smoking and the COVID-19 pandemic. Our data reveal that on average, individuals' beliefs and behaviors are consistent across different public health domains. In particular, smokers showed diminished compliance behaviors during the pandemic, which was mediated by their lower motives to protect public health. These results provide a psychological mechanism of how individuals' health risk behaviors are generalized across different public health domains that may explain why some individuals (here, current-smokers) are more prone to violate public health behaviors.

Keywords Public health, Health risking behaviors, Smoking, COVID-19, Motive

Over the past three years, public health has become a topic of global interest due to the recent COVID-19 pandemic[1]. To minimize the spread of the disease, governments and public health experts emphasized the importance of individuals' cooperation in taking prevention measures, such as social distancing, washing hands, and wearing face masks[2]. However, despite its importance, across many countries, it was shown that a fair amount of individuals expressed disagreement with the government policies (e.g., lockdown and social distancing) and did not comply with recommended prevention measures[3].

Amongst the multitude of reasons explaining why some individuals show weak compliance with public health behaviors, one influential view is that these individuals have incorrect beliefs about the uncertain state of the pandemic due to lack of information or misinformation[4]. It follows that accurate and trustworthy communications from officials and experts regarding the current public health issue are crucial in enhancing public compliance[5,6]. Yet, how and why individuals differ in their responses to the same health-related information is often overlooked and remains unclear[7]. Independent of the amount and quality of information available, individuals' different behavioral and cognitive tendencies (e.g., risk tolerance) may underlie the systematic differences observed in their compliance behaviors. For example, recent studies showed that even when well-informed about potential health risks, smokers persisted in engaging in health risk behaviors (i.e., no reduction in smoking amount[8], lower compliance with prevention measures[9]). Based on this literature, a critical prediction of our hypothesis is that an individual's responses to a novel public health issue can be predicted by their behavioral patterns observed in other public health issues. That is, individuals' tendencies to take health

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risks in one domain would be generalized to another domain, and these consistent behavioral patterns may be accounted for by psychological factors (e.g., beliefs about the health risk they faced in each situation) consistent within an individual.

Here, we focused on smoking, a well-known health-related behavior that has been associated with respiratory diseases[10], as the public health issue potentially linked to individuals' compliance behavior under the COVID-19 pandemic. Particularly after the outbreak of the current COVID-19 pandemic, the World Health Organization (WHO) included smoking as a potential risk factor for COVID-19 based on the reported association between smoking and increased severity of COVID-19 outcomes[11,12]. Although there have been variety of studies on smokers during the COVID-19 pandemic, the focus has been largely on the change of smoking behaviors[13] or on the impact of smoking on the negative health outcomes of COVID-19 (symptom severity and death rates)[14–20]. Despite the close association between smoking behaviors and COVID-19, it remains unknown whether smoking and beliefs about its health risk predict the extent to which they would comply with the recommended public health policies regarding the pandemic. In the current study, we propose that understanding the link between individuals' smoking and prevention behaviors under the risk of COVID-19 may reveal an alternative path how smoking could potentially place individuals at a higher health risk during the pandemic.

Previously, various studies have explored the extent to which smokers perceive the health risks associated with smoking. Most of these studies suggest that smokers tend to underestimate both their personal vulnerability to smoking-related health risks[21–24] and the risks they pose to others through second-hand smoke[25]. However, there is no converging evidence on smokers' risk perception, as findings vary depending on the type of risk judgement assessed by reserachers[26–28]. Despite this variability, a consistent finding across studies is that perceived risk of smoking is linked to smoking behavior, with higher perceived risk being associated with abstinence[29,30]. Recently, several studies investigated the link between beliefs about COVID-19 related health risks and smokers' motivation to quit, suggesting significant, albeit indirect, associations between these two public health domains. Specifically, individuals who reported a greater perceived risk of COVID-19 infection[31–33] or believed in the detrimental impact of smoking on the severity of COVID-19[34–37] were likely to quit or reduce their smoking. However, it remains unclear whether individuals' perceived risk of smoking is associated with their perceived risk of COVID-19, and whether their smoking behavior is linked to the level of compliance with COVID-19 prevention measures.

Considering that decisions to smoke or not are known to have important social consequences other than their impacts on individuals' own health (e.g., smoking has a severe impact on the health of individuals who are around[38]), we expected individuals' beliefs and behaviors regarding smoking would align with those regarding the COVID-19. To test this hypothesis, we measured individuals' behavioral choices on smoking (i.e., being a current-, past-, or never- smoker) and their beliefs about health risks related to smoking from two independent samples. We then examined whether these smoking-related measures were associated with individuals' beliefs and behavioral choices related to the COVID-19 pandemic: perceived risk of infection and behavioral compliance with the recommended prevention policies against the COVID-19 pandemic. In examining these associations, we further noted that individuals' public health choices must affect not only their own but also other individuals' health. The impact of second-hand smoke is well-known as a significant health risk[39] and individuals' violation of prevention measures against contagious infections increases the likelihood of the spreading of the disease[40]. Given such social impacts of health choices, we hypothesized that individuals' concerns for others' health may have a crucial contribution to determining their public health choices across domains. To capture this, we measured individuals' self-reports on the perceived risk of second-hand smoke as well as the perceived risk of direct smoking. Regarding the domain of the COVID-19, we asked individuals to report their motives to follow government policies for preventing the COVID-19 to examine their motives to prevent the spreading of the disease (i.e., protecting public health) apart from protecting their own health.

Throughout the current study, we investigated the following three hypotheses: H1) individuals' beliefs about smoking would align with those about the COVID-19; H2) individuals' behaviors regarding smoking would align with behaviors regarding COVID-19; and H3) concerns for others' health would significantly influence public health choices across different domains. Our data reveal that the beliefs about health risks related to smoking were indeed associated with the beliefs about risks of being infected by coronavirus, and that this association in smokers was distinctive from that of past- or never- smokers. In addition, we show that smokers had lower motives to protect public health behind their decisions to follow government-recommended preventive behaviors, and this motive reduction accounted for their diminished compliance level. These results suggest that individuals' public health choices are tightly linked through domain-independent health risk propensities.

Results

Known demographic characteristics of smokers are well represented in the sampled population

This study was part of a larger online study examining individuals' belief and decision-making under uncertainty. Data were collected during the initial period of the pandemic (Sample 1: April 14–20; Sample 2: April 10–17, 2020) from two independent samples of 1500 and 1530 individuals in South Korea, both of which were nationally representative in terms of age, sex, and areas of residence. Each sample was divided into three groups based on participants' smoking status (i.e., current-smokers, past-smokers, and never-smokers), and we examined the group differences in their beliefs about health risks and behavioral choices under the COVID-19 pandemic. The first sample (Sample 1) included data collected from 1478 individuals (age = 44.54 ± 13.28, male/female = 754/724; see "Methods" section for exclusion criteria; Table S1), comprising 276 (18.7%) current-smokers (S), 271 (18.3%) past-smokers (PS), and 931 (63.0%) never-smokers (NS). The second sample (Sample 2) included 1,505 individuals (age = 44.54 ± 13.12, male/female = 777/728; "Methods", Table S2), comprising 344 (22.9%) current-smokers, 239 (15.9%) past-smokers, and 922 (61.3%) never-smokers.

Given the demographic characteristics of the South Korean smoker population (e.g., males are overrepresented[41]), we expected that our samples may bare demographical differences among individuals with different smoking statuses. To test this possibility, we used stepwise logistic regressions for each of the two independent samples where individuals' smoking status was set as a dependent variable (1 = S, 0 = PS or NS) and demographical factors were set as candidate predictors (e.g., age, sex, education, income, and political ideology; see "Methods" section for detailed regression procedures). Smokers in our nationally representative samples indeed had demographic characteristics distinguishable from past- or never- smokers (Fig. 1). Specifically, factors associated with current-smokers included being a male participant (odds ratio (OR) = 0.15, $P = 1.51e{-}28$, CI [0.10, 0.21]), having lower education (OR = 0.81, $P = 0.0027$, CI [0.70, 0.93]) and political attitudes being liberal than conservative (OR = 0.85, $P = 0.025$, CI [0.74, 0.98]). These demographic characteristics of smokers were replicated in the independent sample (Sample 2; Fig. S1). Our subsequent analyses aimed to investigate the beliefs and behavioral choices of smoker and never-smoker groups in a naturalistic setting as well as after controlling for demographic characteristics. Therefore, whenever it was necessary, we included the three demographic characteristics (i.e., sex, education, and political attitude) as covariates.

Beliefs about the health risks of smoking are linked with beliefs about the COVID-19

The first candidate factor that may be shared across different public health domains is individuals' belief about the health risk they face regarding each domain. To separately examine individuals' health risk beliefs both in perspectives of a potential public health violator (smoker) or a bystander, we asked participants to answer the two questions "How likely do you think people in general may get diseases such as lung cancer from *direct smoking*?" and "How likely do you think people in general may get diseases such as lung cancer from *second-hand smoke*?", respectively. Perceived risks of direct smoking were significantly different across the groups ($F(2, 1475) = 24.97$, $P = 2.16e{-}11$, *Cohen's* $f = 0.18$; Fig. 2A, top). Specifically, both the current- and past- smoker groups reported higher perceived risk of direct smoking compared to the never-smoker group did (S vs. NS: $t(1205) = 5.64$, $P = 2.10e{-}08$, *Cohen's* $d = 0.39$, PS vs. NS: $t(1200) = 4.90$, $P = 1.09e{-}06$, $d = 0.34$), while the reports from current- and past- smokers were not significantly different ($t(545) = 0.75$, $P = 0.45$, $d = 0.065$). Individuals' self-reported beliefs about the risk of smoking showed largely the same pattern in the independent sample (Sample 2; Fig. S2). These results indicate that unlike previously known notions of smokers' underestimation of health risks, smokers overestimate the risk compared to never-smokers.

The group difference in the opposite direction was found for the health risk of second-hand smoke ($F(2, 1475) = 21.93$, $P = 4.11e{-}10$, $f = 0.17$; Fig. 2A, bottom). Contrast to the beliefs about direct smoking, current-smokers reported the lowest level of perceived risk and never-smokers reported the highest level of perceived risk (S vs. PS: $t(545) = -4.10$, $P = 4.76e{-}05$, $d = 0.35$; S vs. NS: $t(1205) = -6.38$, $P = 2.54e{-}10$, $d = 0.44$; PS vs. NS: $t(1200) = -2.23$, $P = 0.026$, $d = 0.15$). This belief pattern was also observed in the independent sample (Sample 2; Fig. S2), suggesting that current-smokers *underestimated* the health risk of second-hand smoke compared to the other two groups. The two types of perceived risk (i.e., beliefs about the risk of direct and second-hand smoking) were positively correlated in never-smokers (Sample 1: $r = 0.30$, $P = 7.41e{-}21$; Sample 2: $r = 0.14$, $P = 2.22e{-}05$). However, such association was not found in past- and current- smokers across the two independent samples (Sample 1: $r_{PS} = 0.025$, $P_{PS} = 0.69$, $r_S = -0.095$, $P_S = 0.12$; Sample 2: $r_{PS} = -0.093$, $P_{PS} = 0.15$, $r_S = -0.41$, $P_S = 4.50e{-}15$). This stark contrast between the never-smokers and the current- or past-smokers suggests that the different beliefs in the health risks of direct vs. second-hand smoke may be part of the possible psychological mechanisms that distinguish smokers from non-smokers.

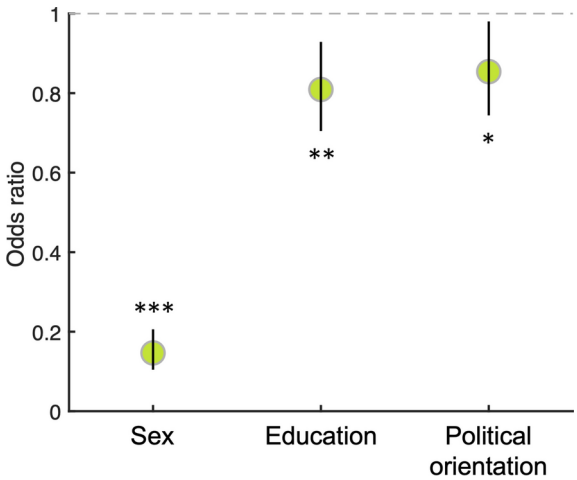

Fig. 1. Smokers have distinguishable demographic characteristics. Smokers (coded as 1) were distinguishable from past- or never- smokers (coded as 0) based on their demographic characteristics. Particularly, smokers had a higher proportion of male participants (0 = male, 1 = female), had lower education, and were more liberal than conservative in their political attitudes (1 = very liberal, 7 = very conservative). Error bars represent 95% confidence interval for each odds ratio. $^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$.

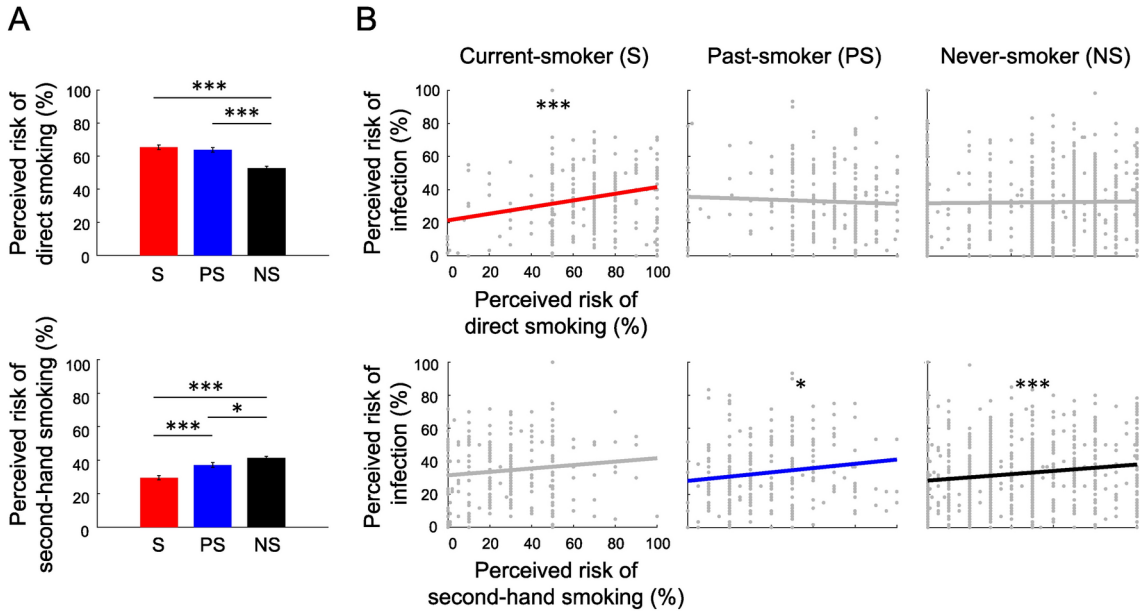

Fig. 2. Smokers show a distinctive pattern in their beliefs about health risks across the two public-health domains. (**A**) Participants were asked to answer two questions: "How likely do you think people in general may get diseases such as lung cancer from *direct smoking*?" and "How likely do you think people in general may get diseases such as lung cancer from *second-hand smoke*?". Current- and past- smokers rated the risk of direct smoking significantly higher than never-smokers, while there was no significant difference in ratings between the two smoker groups. For the health risk of second-hand smoke, current-smokers showed the lowest and never-smokers showed the highest ratings. Red, blue, and black colors indicate current-, past- and never-smokers, respectively. Error bars represent s.e.m. (**B**) Perceived health risk of second-hand smoke was positively correlated with perceived risk of coronavirus infection in the past- and never- smoker groups. In contrast to these two groups, in the current-smoker group, the association between perceived health risks of coronavirus infection and that of smoking was more prominent for direct than second-hand smoke. Each point represents an individual participant, and the red, blue, and black lines are the regression lines between the x- and y-axis measures in current-, past-, and never-smokers, respectively. Gray lines indicate non-significant correlations between two variables. $^{\dagger}P<0.01$, $^{*}P<0.05$, $^{***}P<0.001$.

Next, we tested whether the perceived health risks in different domains (i.e., smoking and COVID-19 pandemic) are consistent within an individual (H1). Considering that a crucial risk factor in the transmission of the COVID-19 is interpersonal interaction, we expected that the belief about the corresponding health risk ("How likely do you think one may get infected with the coronavirus [COVID-19]?"; Table S1; see "Methods" section for the exact measure) to be associated with the belief about the risk of being exposed to *second-hand* smoke. Indeed, reports from past- and non- smokers showed significant positive associations between the perceived health risks of second-hand smoking and COVID-19 (PS: r = 0.15, $P = 0.015$; NS: r = 0.15, $P = 7.66e{-}06$; Fig. 2B, bottom). However, in smokers, this association did not pass the statistical threshold (r = 0.11, $P = 0.061$). Given the importance of social consequences of one's action in both smoking and COVID-19, these results suggest that, for smokers, beliefs about social impacts of health risking behavior (i.e., second-hand smoke) may not be associated with perceived risk of the infectious disease.

Interestingly, in the current-smoker group, the perceived risk of *direct* smoking was significantly correlated with the perceived health risk about the COVID-19 infection (r = 0.24, $P = 4.61e{-}05$; Fig. 2B, top), and this association was not significantly different from the association measured with perceived risk of second-hand smoke (Direct vs. Second-hand using Fisher's r-to-z transformation; Z = 1.57, $P = 0.12$). This was not the case for past- or never- smokers (Direct PS: r = −0.051, $P = 0.40$; NS: r = 0.019, $P = 0.56$; Fig. 2B, top), in that the association with perceived health risk of the COVID-19 infection was significantly lower for direct compared with second-hand smoke (Direct vs. Second-hand PS: Z = 2.32, $P = 0.020$; NS: Z = 2.76, $P = 0.0058$). These results suggest that smokers' health risk belief about the COVID-19 is not associated with their concerns about harming others' health by smoking but rather with that about harming their own health.

Corroborating our interpretation, the health risk belief about the COVID-19 infection was significantly associated with current- and past- smokers' perceived health risk of direct smoking, particularly affecting *their own health* (Sample 1: $r_S = 0.51$, $P_S = 1.60e{-}19$; $r_{PS} = 0.26$, $P_{PS} = 1.06e{-}05$; Sample 2: $r_S = 0.30$, $P_S = 2.02e{-}08$; $r_{PS} = 0.37$, $P_{PS} = 2.88e{-}09$; see "Methods" section for the exact measure). Note that there was no group difference in the average ratings on the perceived risk of the COVID-19 infection (Sample 1: $F(2, 1475) = 1.34$, $P = 0.26$, $f = 0.043$; Sample 2: $F(2, 1502) = 1.22$, $P = 0.30$, $f = 0.073$; Tables S1,S2). All results regarding group differences and belief consistency across domains (direct and second-hand smoke versus the COVID-19) were observed the

same in the Sample 2 (Fig. S2) and remained consistent even after controlling for the demographical covariates differentiating smokers from others (FigS. S3, S4).

Together, these results show that individuals' health risk beliefs are consistent across different public health domains. Moreover, unlike past- or never- smokers whose beliefs across public health domains are aligned toward concern for others' health, smokers have biased beliefs about the impacts of smoking, such that individuals' health risk propensities, which are generalized across health domains, are better represented in their concerns about harming their own health rather than others' health.

Individuals' health risk choices are consistent across two different public health domains

As a main prediction of the current study, we expected individuals' health risk behaviors would be consistent across smoking and COVID-19 (H2). If this is the case, smokers, individuals who *chose* to smoke despite the well-known health risks, would be more apt to violate government-recommended prevention measures intended to reduce health-related risks of COVID-19 (e.g., washing hands, wearing face masks; see "Methods" section for detailed questions). Indeed, individuals' smoking status (current-, past-, and never- smokers) was significantly associated with their preventive behaviors during the COVID-19 pandemic ($F(2, 1475) = 9.34$, $P = 9.28e{-}05$, $f = 0.11$; Fig. 3A,S5). Specifically, current- and past- smokers showed lower level of compliance compared to never-smokers (S: $t(1205) = -4.00$, $P = 6.60e{-}05$, $d = 0.27$; PS: $t(1200) = -2.44$, $P = 0.015$, $d = 0.17$). However, there was no significant difference in compliance levels between current- and past- smokers ($t(545) = -1.28$, $P = 0.20$, $d = 0.11$). The group difference results were replicated in the independent sample (Sample 2; Fig. S6A). Subsequent regression analyses revealed that, after controlling for the demographical factors associated with smokers (Fig. 1), current-smoker status was a significant predictor of lower compliance in Sample 2. In Sample 1, current-smoker status showed a similar directional trend, although the effect did not reach statistical significance (Fig. S7). These results indicate that in extension to individuals' beliefs being generalized across health domains, their health risk behaviors are consistent across two different public health domains.

In our previous study, we showed that individuals' beliefs and motives under the COVID-19 pandemic are strongly connected[42]. For example, individuals may not have motives to comply with the recommended prevention measures against the COVID-19 if they are less concerned for (i.e., have biased belief) health of the public including family, friends, and society as a whole. If such a link translates into other public health domains,

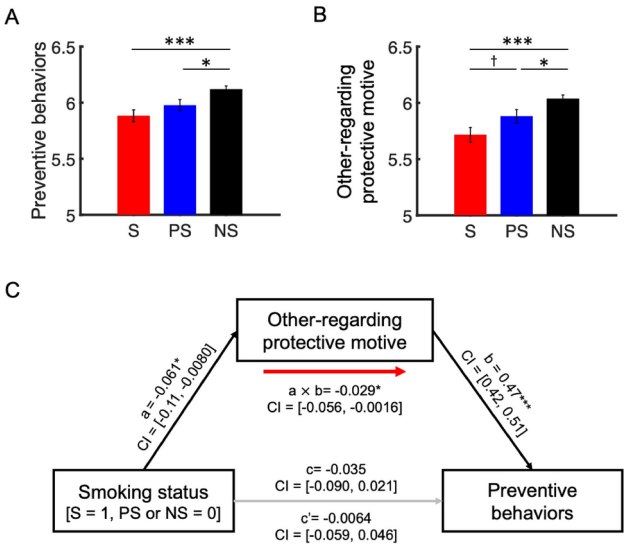

Fig. 3. Smokers' diminished compliance with prevention measures against the COVID-19 is explained by their diminished protective motives. (**A**) Current-smokers complied the least and never-smokers complied the most with the government-recommended prevention measures. Past-smokers showed significantly lower compliance level compared with never-smokers, while the compliance levels between current- and past-smokers were not significantly different. (**B**) Individuals were asked to report the protective motives (higher ratings indicate stronger motives to follow the recommended prevention measures) given their compliance with government-recommended prevention measures. Two smoker groups showed significantly lower motives to protect public health compared to never-smokers. Error bars represent s.e.m. $\dagger P < 0.1$, $^{*}P < 0.05$, $^{***}P < 0.001$. S = current-smoker; PS = past-smoker; NS = never-smoker. (**C**) Smokers' diminished preventive behaviors were accounted for by their motives to protect public health (i.e., preventing social impacts) (a*b: ß = −0.029, $P = 0.035$). Specifically, smokers showed diminished protective motives to comply with prevention measures (a: ß = −0.061, $P = 0.024$), and smokers with lower protective motives indeed showed significantly lower preventive behaviors (b: ß = 0.47, $P < 2e{-}16$). The total effect (c) and the direct path after adjusting for the potential mediation effect (c′) were not significant (c: ß = −0.035, $P = 0.22$; c′: ß = −0.0064, $P = 0.82$). Black and gray arrows indicate significant and non-significant associations between the components, respectively. Red arrow indicates significant mediation effect; $^{*}P < 0.05$, $^{***}P < 0.001$; CI: 95% confidence interval for each of the standardized beta estimates.

we would expect a similar belief-to-motive association in smokers, such that smokers whose perceived health risks about smoking were biased toward concerning for themselves than other individuals would also have diminished motives to comply with the COVID-19 prevention measures to protect others from being affected by the spreading of the disease. To test this hypothesis, we first calculated a composite score for individuals' motives to protect public health in complying with prevention measures ('Other-regarding protective motive'; see "Methods" section for the score definitions). In our data, individuals' smoking status was indeed significantly associated with their protective motives ($F(2, 1475) = 11.57$, $P = 1.03e{-}05$, $f = 0.13$; Fig. 3B). Specifically, current- and past- smokers showed significantly lower protective motives compared to never-smokers (S: $t(1205) = -4.62$, $P = 4.24e{-}06$, $d = 0.32$; PS: $t(1200) = -2.28$, $P = 0.023$, $d = 0.16$). Current-smokers' motive ratings were lower than that of past-smokers, but the difference was statistically marginal ($t(545) = -1.88$, $P = 0.061$, $d = 0.16$). These results were consistently replicated in Sample 2 (Fig. S6B). Furthermore, being a smoker still predicted the differences in protective motives after controlling for the demographical factors that identify smokers (Fig. S8).

Under the assumption that motives precede individuals' responses[43], we then examined whether individuals' motives mediate the relationship between individuals' smoking status and the extent to which they violated preventive measures (H3). We conducted a mediation analysis where individuals' smoking status was set as a predictor, individuals' protective motives to comply with prevention measures as a mediator, and individuals' preventive behaviors as an outcome. Demographical factors (i.e., sex, education, and political orientation) were entered as covariates of no interest. Our data showed that the indirect path (a*b) was significant ($\beta = -0.029$, $P = 0.035$). On the contrary, the total effect (c) and the direct path after adjusting for the mediation effect of individuals' motives (c') were not significant (c: $\beta = -0.035$, $P = 0.22$; c': $\beta = -0.0064$, $P = 0.82$; Fig. 3C). The results from the mediation analyses were largely replicated in Sample 2, while the indirection effect was marginally significant (Fig. S6C). Note that, in stark contrast, individuals' motives to protect their own health ('Self-protective motive'; see "Methods" for the score definitions; Table S1, S2, Fig. S8) did not exhibit any significant mediating effects between their smoking status and their diminished preventive behaviors in both samples (Fig. S9). Consistent with our observations regarding smokers' health risk beliefs, these results emphasize the significant role of social biases (e.g., diminished motives to protect the health of others) underlying smokers' public health behaviors. Note that, in our additional exploratory analyses where past-smokers and current-smokers were categorized together as the 'ever-smoker' group, the mediation effect of individuals' other-regarding protective motives was only marginally significant in both samples (Fig. S11), after controlling for the demographical covariates differentiating ever-smokers from never-smokers (Fig. S10). Together, our data suggest that the diminished preventive behaviors of smokers can be accounted for by their lower motives to comply with prevention measures to protect public health.

Discussion

The current study investigated whether individuals' health risk beliefs and behaviors hold consistent across the public health domains of smoking and COVID-19 pandemic. Smokers' beliefs about health risks of noncompliant behaviors were also consistent across smoking and COVID-19 domains, but the pattern was distinctive from that in past- and non-smokers (H1). In the domain of the COVID-19 pandemic, smokers were more apt to violate the government-recommended preventive measures (H2). The association between the smoking status and the compliance with the preventive measures of the COVID-19 was mediated by individuals' motives to protect public health (H3). Our data suggest that health risk attitudes may be consistent within an individual, and thus, the extent to which one acts regarding a public health issue can be generalized to different domains.

Previously, lack of information (or underestimation)[22] regarding the consequence of smoking has been considered as one of the major reasons why individuals choose to smoke, and thus, a lot of efforts has been taken on smoking cessation campaigns aiming to enhance public health literacy[44]. However, the effectiveness of such tobacco control initiatives in promoting smoking cessation has been controversial across studies[45–49]. Our data provide one possible explanation why there have been mixed results. By delineating perceived health risks of direct smoking and second-hand smoke, we found that smokers perceived higher health risks for direct smoking than for second-hand smoke and the opposite was the case for past- and never- smokers. These results showed that smokers are not ignorant of the health risks associated with smoking, and if there are any biases, such as underestimating these risks, they must be closely linked to the social impacts of their health risk behaviors. Given the crucial role of individuals' beliefs in their decision-making processes, such underestimation of social consequences may underlie a broader range of behaviors in smokers. For example, smokers may mirror the perceived harmlessness of their actions in social environment and view the choices of others as safe to follow. We speculate that this may explain why substance users including cigarette smokers are vulnerable to social influence—one of the major triggers for early initiation of substance use[50–52]. Still, the impact of underestimating risk may be limited to biasing one's beliefs regarding their own influence on others, rather than extending to making them more likely to accept information from the social environment, and thus, future studies should be conducted to directly examine the causal impacts of underestimation of the social risk. Nevertheless, as addiction is once noted as "social disease"[53], our results once more highlight the importance of understanding potential roles of social factors in addiction. Moreover, our results may explain why the classic health education approach is not always effective[54], while social context provides a better prediction about successful smoking cessation.

Since the outbreak of the recent COVID-19 pandemic, smokers have been particularly warned because coronavirus infection is also known to cause respiratory problems and damage one's lung[12], an organ that already has been long known to directly get affected by smoking[55]. Indeed, a large body of studies have already shown an association between smoking and heightened mortality rate or rate of hospitalization during COVID-19[14–20], compared with in never-smokers. Our data expand this view and suggest that diminished behavioral compliance with prevention measures constitutes an additional factor that puts smokers at higher risk of COVID-19. Such behavioral biases are consistent with previous reports of smokers' behavioral choice patterns, in various settings

ranging from well-controlled laboratory-based experiments to field studies, that smokers take more risks[56,57] and act more impulsively[58–60]. These consistent data may inform strategies for recruiting individuals' cooperation to improve public health. Given that individuals' own preferences affect the extent to which they are influenced by external social influence[61,62], a direct attempt to nudge at-risk individuals' actions is *not* expected to have a significant impact. Instead, future studies should examine whether there is a feasible intervention design that focuses on adjusting one's motives (e.g., reinforced prosocial beliefs), which could be an alternative measure to improve safety for risk-seeking (or risk-tolerant) individuals.

There are limitations to the current study. First, our data are correlational in nature and therefore do not elucidate causal directions of the link between individuals' beliefs and behavioral health risk choices. For example, it is uncertain whether individuals' smoking habits biased their beliefs regarding the health risks of smoking, or if, alternatively, individuals with biased health risk beliefs were more likely to develop a smoking habit. We have previously showed that the changes in individuals' depressive mental states between two time points mediate the mismatch between perceived severity of the COVID-19 pandemic and preventive motives[42]. Future studies could explore whether such mechanisms linking beliefs and behavioral choices also generalize across different public health domains. Second, it remains unknown whether the malleability of the beliefs and behavioral choices in these two public health domains are interconnected. Smoking is notoriously associated with a high likelihood of relapse[63], and some neural changes linked to prolonged smoking habits have been reported to persist even after extended periods of abstinence[64]. It would be interesting to investigate whether tendencies to change in one domain could predict individuals' sensitivity to interventions targeting a different public health domain. Third, the possibility remains that unmeasured variables could explain the association between smoking and violations of preventive behaviors. Although our mediation analyses suggest that the indirect path through individuals' other-regarding protective motives significantly accounts for the relationship, the association between individuals' current-smoker status and their preventive behaviors, after controlling for smokers' distinct demographic characteristics, was significant only in Sample 2 but only trending in Sample 1 (Fig. S8). Given the possibility of unmeasured variables, the model's interpretation should be made with caution.

When a new public health issue rises, much effort is dedicated to developing new health policies from which officials and experts aim to recruit public's cooperation and minimize the negative consequences induced by the issue (e.g., spreading of an infectious disease). Repeated exposure to public health awareness campaigns is intended to enhance health literacy[65], but on the flip side, it may have an unexpected consequences of triggering psychological reactance[66] and making individuals pessimistic, anxious, and depressed[42,67,68]. Here, we show that smokers have diminished motives and make different health choices compared to never-smokers for cross-domain public health issues during the pandemic. Our findings could potentially inform policymaking by suggesting that policies can be optimized by taking into account individuals' different motives and behavioral strategies they choose in response to a situation. To sum up, our data highlight that individuals' beliefs and behavioral patterns are generalized across different health risk domains, providing insights into the development of domain-independent public health strategies.

Materials and methods

Participants

Two independent samples were collected in cooperation with Invight, a panel-based research agency (http://www.invight.co.kr). No statistical methods were used to predetermine sample sizes, but our final sample size was set to align with those reported in previous publications examining individuals' compliance with COVID-19 prevention measures[42,69]. To secure sufficient numbers of participants nationally representative for age (20 s including 19, 30 s, 40 s, 50 s, and above 60 s), sex (male and female), and areas of residence (eight provinces including geometrically close metropolitan cities), we aimed for a final sample size exceeding 1,000. The first dataset (Sample 1) was part of a longitudinal project monitoring changes in beliefs about the COVID-19 pandemic, depressive symptoms, and prevention motives in South Korea. Anticipating a retention rate of approximately 70%, we initially recruited 1500 participants. Likewise, we recruited an independent sample of 1530 participants to ensure comparable sample sizes. The research protocol was approved by the Institutional Review Boards of Ulsan National Institute of Science and Technology (UNISTIRB-20–17-C). All participants provided electronically written informed consent before the survey.

- *Sample 1* A total of 1500 participants were recruited. Three participants who responded 'Not applicable' to all questions regarding compliance with prevention measures (questions provided below) were excluded. In addition, participants who exceeded the three standard deviations in the age of smoking initiation (N = 16) and current-smokers who exceeded three standard deviations in the amount of smoking (N = 3) were classified as outliers and excluded. After exclusion, all subsequent analyses included data from 1478 participants (male/female = 754/724, age = 44.54 ± 13.28).
- *Sample 2* In collaboration with the same panel-based research agency, 1530 participants were recruited (not overlapping with the Sample 1). Six participants who reported 'Not applicable' to all questions regarding compliance with prevention measures. In addition, participants who exceeded the three standard deviations in the age of smoking initiation (N = 16) and current-smokers who exceeded three standard deviations in the amount of smoking (N = 3) were excluded. After exclusion, all subsequent analyses included data from 1505 participants (male/female = 777/728, age = 44.54 ± 13.12).

See Tables S1 and S2 for additional participant characteristics.

General data management and analyses

For all analyses, current-smokers who exceeded three standard deviations in the amount of smoking (N = 3 in Sample 1; N = 3 in Sample 2) and participants who exceeded three standard deviations in the age of smoking

initiation (N = 16 in Sample 1; N = 16 in Sample 2) were classified as outliers and excluded. In addition, 3 participants in Sample 1 and 6 participants in Sample 2 who responded 'Not applicable' to all questions regarding compliance with prevention measures were excluded.

Data among groups were first compared using one-way ANOVA, with post-hoc comparisons performed using t-tests. To examine relationships between variables, such as beliefs about the risk of coronavirus infection and the risk of second-hand smoke, Pearson's correlation coefficient was used. Since we aimed to categorized individuals' smoking status in a way that aligned as consistently as possible with the perspective applied to the domain of COVID-19 preventive behaviors, we dichotomized individuals' smoking status into currently smoking or not (past- or never- smokers). To identify demographic characteristics that distinguish current-smokers from either past- or never- smokers, we conducted a stepwise logistic regression (see "Stepwise regression" section for details), using these characteristics as covariates in subsequent analyses. We used robust linear regression analyses, including demographic covariates, to investigate the associations between individuals' beliefs and behaviors across smoking and COVID-19. Mediation analyses were conducted to explore whether individuals' motives mediate the relationship between smoking status and the extent of non-compliance with preventive measures (see "Mediation analysis" section for details). Effect sizes were calculated using Cohen's *f* (small: 0.1, medium: 0.25, large: 0.4) and Cohen's *d* (small: 0.2, medium: 0.5, large: 0.8)[70]. All statistical tests were two-tailed with an alpha level of 0.05. MATLAB R2019a (MathWorks) was used for all the statistical tests.

Stepwise regression

A series of logistic regressions were performed to identify demographic characteristics that distinguish smokers from either past- or never- smokers (Fig. 1). Per a stepwise regression procedure, predictor variables were entered and removed based on their significance. All continuous measures were z-scored before being entered into the model. The significance level for both entering and removing was set at 0.15 (Alpha-to-Enter and Alpha-to-Remove). In each step of the analysis, all candidate variables were sequentially included in the model, and the p-value for the coefficient of each candidate variable was examined. Variables with a p-value below 0.15 were considered eligible for inclusion in the model. Among the qualified variables, the one with the smallest p-value was selected and included in the model, while the remaining variables were retested for the next step. This iterative process continued until no more predictors yield p-values below 0.15, indicating no additional significant predictors to include in the model.

Mediation analysis

Mediation analyses were conducted using R package[71] to examine whether the diminished compliance with prevention measures in smokers is mediated by their protective motives. The analyses included three components (a predictor, a mediator, and an outcome) and covariates-of-no-interest that controls for potential confounding effects. Each individual's smoking status was set as a predictor, protective motive was set as a mediator, and the compliance level of prevention measures was set as an outcome. Two separate mediation models were tested: one for testing the effect of self-protective motive, and the other for testing the effect of other-regarding protective motive. Covariates-of-no-interest included the demographical characteristics that were identified to dissociate smokers from others (i.e., sex, education, and political orientation). All continuous measures were z-scored before being entered into the model. The significance of the effects was estimated using non-parametric bootstrapping method with 5,000 bootstrapping samples, and an alpha level of 0.05 was used to determine statistical significance.

Survey questions overview

Participants answered a series of questions about their belief, motives, and behavioral choices related to their smoking habits (or history) as well as the on-going COVID-19 pandemic. All methods in the current study were performed in accordance with the relevant guidelines and regulations. All the survey questions were in Korean and accessible online via computers and laptops.

Smoking status

Participants self-reported whether they identify themselves as a current-, past-, or never- smoker. For current- and past smokers, we also collected information about their smoking history (amount of smoking, age of smoking initiation).

Beliefs about the health risk of smoking

To measure participants' beliefs regarding the health risk associated with smoking, we asked participants the following questions:

- How likely do you think people in general may get diseases such as lung cancer from *direct smoking*?
- How likely do you think people in general may get diseases such as lung cancer from *second-hand smoke*?

For participants who ever-smoked (i.e., current- and past- smokers), we additionally asked the following question:

- How likely do you think *you* may get diseases such as lung cancer from *direct smoking*?

Participants were instructed to indicate their responses in percentage (0% = never, 100% = very likely).

Beliefs about the health risk of coronavirus infection

To measure participants' beliefs regarding the health risk of coronavirus infection, we asked participants the following questions:

- How likely do you think *you* are to be infected by coronavirus?
- How likely do you think *your family members* are to be infected by coronavirus?
- How likely do you think your *friends* are to be infected by coronavirus?
- How likely do you think your *neighbors* are to be infected by coronavirus?
- How likely do you think *strangers who live in the same area of residence* are to be infected by coronavirus?
- How likely do you think *strangers who live in a different area of residence* are to be infected by coronavirus?

Participants were instructed to provide their responses in percentage (0% = never, 100% = very likely). An average of all six ratings was used as a composite measure of each individual's belief about the general health risk of coronavirus infection.

Motives underlying compliance with the government-recommended prevention policies

To examine participants' motives to comply with the government-recommended prevention measures (as of the time of data collection, [April 10–20, 2020]), we asked participants the following nine questions:

I followed the prevention measures against coronavirus recommended by the government because,

1. I am concerned that I may get infected.
2. I am concerned that my family members may get infected.
3. I am concerned that my friends and acquaintances may get infected.
4. I am concerned of broader viral spreading in South Korea.
5. I am concerned that my action may negatively affect the groups which I am part of (e.g., workplace, school, or religious group).
6. I am concerned of the pandemic becoming more serious than the current status.
7. I know that anyone can get infected based on the public information.
8. I am afraid of being subject to legal penalties.
9. I am afraid that other people may blame my actions when all information is shared by contact tracing.

Participants were asked to provide their responses in a seven-point Likert scale (1 = definitely not; 7 = definitely). For each individual, we created two composite scores; a response to the Item 1 was used to measure an individual's motive to protect her/his own health ('Self-protective motive'), and an average of Items 2, 3, 4, 5, and 6 was defined as a motive to protect the health of the public ('Other-regarding protective motive'). The responses to the last three items were not used in the current study because these items were not designed to capture individuals' concerns toward specific targets (Item 7) or were associated with motives unrelated to health risks (Items 8 and 9).

Average tendency to carry out preventive behaviors

Participants were asked to self-report their average tendency to engage in preventive behaviors, specified as the following eight questions:

For the past two months, even if I did not have any symptoms of sickness,

1. I washed my hands or used hand sanitizer whenever I went to work or came back home.
2. I covered my mouth and nose with sleeves whenever I coughed or sneezed.
3. I did not touch my eyes, nose, or mouth before washing hands.
4. I wore a face mask whenever I visited a medical institution (*e.g.*, hospital, drug stores).
5. I wore a face mask whenever I went out.
6. I refrained myself from visiting crowded places.
7. I avoided meeting people who had symptoms such as high fever or respiratory illness.
8. I refrained myself from going out or visiting other cities.

Participants were asked to provide their responses in a seven-point Likert scale (1 = never; 7 = very frequently). In case that any participants did not have a chance to encounter a certain situation, we additionally provided the option of 'Not applicable'. At the time of data collection (April 2020), the South Korean government was putting consistent efforts to promote the importance of aforementioned list of preventive behaviors, and therefore most of our participants should be familiar with every item. For the regression and mediation analyses (described below), a composite score was calculated by averaging responses to all eight questions, except the items that were marked as 'Not applicable'.

Demographic information

Basic demographic information including age, sex, education, income, and political ideology was collected from all participants. Participants reported their age and sex in either male or female (0 = male, 1 = female in regression analyses). Participants reported their education level following the question below.

- What is your education level?
- 1 = Under middle school
- 2 = Middle school
- 3 = High school

- 4 = Vocational Colleges Course / Graduation
- 5 = Undergraduate Course (4-year university)
- 6 = University Graduation (4-year university)
- 7 = Graduate School Course

Participants reported their income following the question below.

- What is the average monthly income of your household? (If you are not financially independent, please respond based on your parents' income).
- 1 = less than 1 million Korean won
- 2 = 1 million ~ 2 million Korean won
- 3 = 2 million ~ 3 million Korean won
- 4 = 3 million ~ 4 million Korean won
- 5 = 4 million ~ 5 million Korean won
- 6 = 5 million ~ 6 million Korean won
- 7 = 6 million ~ 7 million Korean won
- 8 = 7 million ~ 8 million Korean won
- 9 = 8 million ~ 9 million Korean won
- 10 = 9 million ~ 10 million Korean won
- 11 = more than 10 million Korean won

Political orientation
Participants were asked to report their political ideology in a seven-point scale (1 = very liberal, 4 = moderate, 7 = very conservative).

Existence of neighbors or friends who were infected with the coronavirus
Participants were asked to report whether they had neighbors or acquaintances who were or had been infected with the coronavirus.

Smoking status and history
Participants were asked to report whether they were current- past, or never- smokers at the time of data collection. To assess individuals' smoking history, we asked participants who claimed themselves to be current- or past- smokers to report (1) the number of days they smoked in the last 7 days, (2) average number of cigarettes they smoked per day, and (3) age of smoking initiation.

Data availability
The original contributions presented in the study are publicly available. This data can be found here: https://github.com/dongilchung/covid-smoker

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Author contributions

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Declarations

Competing interests

The authors declare no competing interests.

Additional information

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