RESEARCH ARTICLE

Analysis of Brain Activity and Mask-Wearing Behavior in Middle School Students Following High-Concentration Fine Dust Education: An fNIRS Study

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Abstract

This study aimed to neuroscientifically examine whether brain activity measured by functional near-infrared spectroscopy (fNIRS) during high-concentration fine dust education predicts actual mask-wearing behavior more accurately than self-reported mask-wearing intentions. Eighteen first-year middle school students viewed an approximately six-minute fine dust safety video while prefrontal cortex activation was recorded using a 48-channel fNIRS device. Immediately after viewing, students completed a self-reported mask-wearing intention survey (scored out of 100 on a Likert scale). Actual mask-wearing frequency was then tracked for two weeks. General linear model (GLM) analysis revealed that the above-average mask-wearing group showed significantly greater activation in the left dorsolateral prefrontal cortex (DLPFC; BA 10) and left orbitofrontal cortex (OFC; BA 11) than the below-average group. Multiple regression analysis demonstrated that self-reported intention scores did not significantly predict actual behavior, whereas activation of the left OFC emerged as the only significant predictor of two-week mask-wearing frequency in this exploratory analysis. These findings suggest that neurophysiological responses to educational content may predict future health behavior more objectively and accurately than self-reports. This suggests that fNIRS-based measurement holds promise as a tool for evaluating the effectiveness of health and environmental education programs.

Keywords: Health behavior prediction, fNIRS, brain activation, orbitofrontal cortex, prefrontal cortex

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Introduction

Fine dust has emerged as a serious public health problem transcending national boundaries, with growing concern about its adverse effects on children and adolescents whose respiratory and cardiovascular systems are still developing. The International Agency for Research on Cancer (IARC), a specialized agency of the World Health Organization (WHO), classified PM2.5 as a Group 1 carcinogen (IARC, 2015). Based on this evidence, the WHO (2021) has continuously emphasized the importance of health literacy and education in reducing the disease burden caused by air pollution.

Viewed through Benjamin Bloom's taxonomy of educational objectives, health and environmental education must achieve goals not only in the cognitive (knowledge comprehension) and affective (attitude change) domains, but most critically in the psychomotor domain—producing actual behavioral change such as mask wearing. Evidence consistently shows that positive cognitive and affective changes do not automatically translate into preventive behavior (Webb & Sheeran, 2006; Kormos & Gifford, 2014). A meta-analysis reviewed by Webb and Sheeran (2006) found that behavioral intention accounts for only approximately 28% of the variance in actual behavior, demonstrating that intention alone is insufficient to predict behavior.

Traditional measurement of educational effectiveness has relied heavily on self-reported surveys. The validity of these instruments is compromised by social desirability bias—respondents tend to answer in ways they perceive as socially acceptable rather than reflecting their true intentions (Fisher, 1993). In environmental behavior research, substantial discrepancies between self-reported pro-environmental attitudes and actual behaviors have been repeatedly documented (Kormos & Gifford, 2014).

As an alternative, neuroscientific approaches have attracted increasing attention. Research has demonstrated that neural responses to persuasive messages predict subsequent behavioral changes more accurately than consciously reported intentions (Lieberman, 2010). In particular, activation of the medial prefrontal cortex (mPFC)—especially the orbitofrontal cortex (OFC)—has been identified as a key neural predictor of health behavior change (Falk et al., 2010, 2013). Functional near-infrared spectroscopy (fNIRS) is uniquely suited to educational research because it is non-invasive, portable, and allows participants to sit in a naturalistic posture, making it ecologically valid for classroom-like settings (Boas et al., 2014). In contrast, fMRI requires participants to lie motionless in a noisy scanner, limiting ecological validity (Boas et al., 2014; Scholkmann et al., 2014).

The present study therefore used fNIRS to measure prefrontal cortex activation in middle school students during a high-concentration fine dust education video, and investigated whether brain activation during education or self-reported mask-wearing intention better predicts subsequent two-week mask-wearing behavior. By elucidating the neural mechanisms underlying behavioral change in response to health education, this study provides neuroscientific evidence to support the design of more effective health and environmental education programs.

Research Methods

Research Procedure and Participants

The overall research procedure comprised: literature review, task development and expert validation, participant recruitment, fNIRS measurement and survey administration, data preprocessing and GLM analysis, multiple regression analysis, and conclusion drawing. Participants were 18 first-year middle school students from a school in Cheongju, Chungcheongbuk-do, who voluntarily agreed to participate.

This study was approved by the Institutional Review Board of Korea National University of Education (IRB No. KNUE-202505-SB-0163-01). Prior to recruitment, written informed consent was obtained from all participants and their legal guardians. To control for potential confounds, only right-handed students (Oldfield, 1971) without a history of neurological disorders were included. Participants' prior knowledge of, attitudes toward, and habitual mask-wearing practices regarding fine dust were assessed and equated across participants before the study.

Education Task and fNIRS Measurement

The educational task consisted of viewing an approximately six-minute video on fine dust safety, adapted by the researcher for this study from immersive (VR-based) safety education content originally produced by the Korea Education and Research Information Service (KERIS, 2020). Although the original content was developed as VR-based immersive material, it can also be viewed as a conventional two-dimensional video. The video covered: (1) the definition of fine dust and its pathways of human exposure; (2) health consequences of fine dust; and (3) countermeasures, including correct mask usage. The experimental paradigm was programmed using E-Prime and followed a block design: one minute of eyes-closed rest and one minute of fixation-cross viewing established the baseline, followed by three video segments alternating with 30-second fixation-cross intervals—Segment 1 'Definition and Exposure Pathways' (2 min 11 s), Segment 2 'Health Consequences' (2 min 37 s), and Segment 3 'Countermeasures' (1 min 6 s).

Total duration	534 sec						
Stimulus	1 min	1 min	2 min 11 sec	30 sec	2 min 37 sec	30 sec	1 min 6 sec
	Eyes closed (Rest)	Eyes open	Definition of fine particulate matter and bodily entry routes (Video 1)	+ Fixation	Health damage caused by fine particulate matter (Video 2)	+ Fixation	Health-protective responses to fine particulate matter (Video 3)

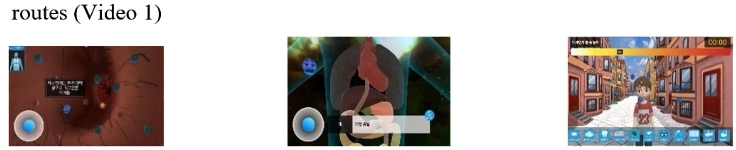

Fig. 1. Task paradigm

Brain activation was measured using the OBELAB Inc. NIRSIT system, a wearable wireless fNIRS device with 48 channels configured via 24 light sources and 32 detectors, sampling at approximately 8 Hz. The device covers the entire frontal region and includes a built-in gyroscope and accelerometer to track and correct head movement artifacts. Channels were mapped to Brodmann areas (BAs) of the prefrontal cortex including dorsolateral prefrontal cortex (DLPFC), ventrolateral prefrontal cortex (VLPFC), frontopolar prefrontal cortex (FP), and OFC (Shin et al., 2024).

Mask-Wearing Intention Survey

Immediately after video viewing, participants completed a self-report questionnaire measuring mask-wearing intention across four situational scenarios: (1) outdoor school activities; (2) indoor school activities; (3) physical education class;

and (4) peer relationships and peer pressure. Each scenario comprised five items scored on a 5-point Likert scale, yielding a total score out of 100 points. The questionnaire underwent four rounds of expert review and validation by one Brain · AI-based education expert and three doctoral students in biology education, achieving an Item-Level Content Validity Index (I-CVI) of 1.00 for all items.

Behavioral Follow-Up: Mask-Wearing Tracking

Actual mask-wearing frequency was tracked daily for two weeks (May 19–30, 2025) following the educational intervention. Tracking employed cross-verification of: (1) students' daily self-report via an online survey; and (2) observation records maintained by two physical education teachers and the researcher. Days on which fine dust levels were rated 'poor' or 'very poor' for two or more hours were flagged for contextual analysis.

fNIRS Data Preprocessing and Analysis

Raw fNIRS data were preprocessed using NIRSIT Analysis Tool (OBELAB Inc.). Preprocessing steps included: channel rejection (exclusion of low-quality channels); conversion from raw light intensity to optical density (ΔOD); motion artifact removal using TDDR and CBSI algorithms; short-channel regression to remove superficial physiological noise; hemoglobin concentration filtering; and data padding.

Two statistical analyses were performed. First, participants were classified into above-average (high-frequency, n = 9) and below-average (low-frequency, n = 9) groups based on two-week mask-wearing frequency. Subject-level GLM derived channel-wise beta coefficients (β) for the education task relative to the eyes-closed baseline. Group-level independent-samples t-tests (α = .05) identified channels showing significantly greater activation in the high-frequency group. Second, a multiple regression analysis (Python, Statsmodels OLS) was conducted with two-week mask-wearing frequency as the dependent variable and self-reported intention score (X_1), left DLPFC activation (Ch20 β, X_2), and left OFC activation (Ch31 β, X_3) as independent variables.

Results

Two-Week Mask-Wearing Behavior Tracking Results

The two-week mask-wearing behavior tracking results for the 18 students following the educational video are presented in Table 1. Over the two-week observation period, a total of 35 mask-wearing instances were recorded across all students, yielding a mean of 1.94 times per student. On days when fine dust levels were rated 'poor' or 'very poor' for two or more hours, total mask-wearing instances were 24, with a mean of 8 instances per day.

Table 1. Two-week mask-wearing behavior tracking results (May 19–30, 2025)

Category	Mon 19	Tue 20	Wed 21	Thu 22	Fri* 23	Mon 26	Tue 27	Wed* 28	Thu* 29	Fri 30	Total / Mean
Mask-wearing frequency (n)	1	0	3	2	4	2	1	9	11	2	35 / 1.94

*Days on which fine dust was rated 'poor' or 'very poor' for ≥ 2 hours

Self-Reported Mask-Wearing Intention Survey Results

The self-reported mask-wearing intention scores are presented in Table 2. The maximum score was 91 and the minimum was 43; the mean was 71.17. The majority of students (n = 12) scored 70 or above indicating a generally high stated intention to wear masks. However, the remaining students (n = 6) scored below 70, revealing individual variability in intention.

Table 2. Self-reported mask-wearing intention scores by participant

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Mean
48	56	66	74	63	84	88	76	77	74	75	87	56	91	75	72	43	76	71.17

Score range: 0–100 points, 5-point Likert scale per item.

Brain Activation Comparison Between High- and Low-Frequency Mask-Wearing Groups

The GLM subtraction results (high-frequency minus low-frequency group) are presented in Table 3. The high-frequency group showed significantly greater activation than the low-frequency group in two prefrontal regions during educational video viewing: the left DLPFC (BA 10, Ch20; $t = 2.249$, $p = .039$) and the left OFC (BA 11, Ch31; $t = 2.229$, $p = .041$). The brain activation map is visualized in Fig. 2.

Table 3. Subtraction contrast results for the higher and lower mask-wearing group ($p < .05$)

Region	BA	Hemisphere	Channel	t	Interpretation
DLPFC	10	L	20	2.249	High > Low
OFC	11	L	31	2.229	High > Low

DLPFC: Dorsolateral Prefrontal Cortex, OFC: Orbitofrontal Cortex, BA: Brodmann Area, L: left

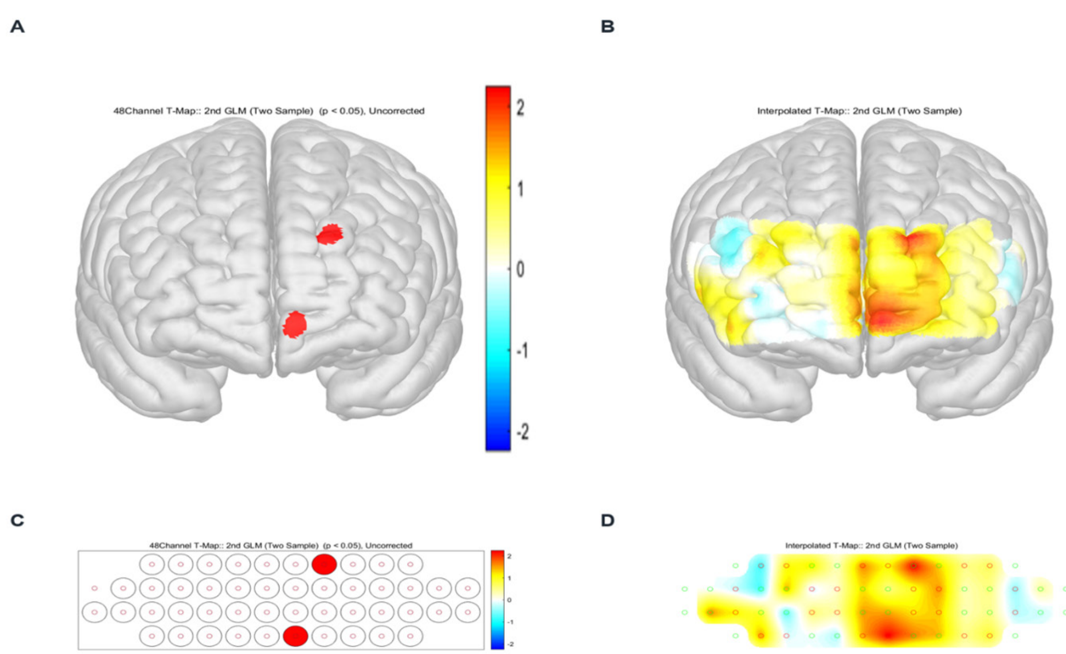

Fig. 2. Brain activation maps for the between-group subtraction contrast between the higher and lower mask-wearing groups (A: channel-wise 3D brain map, B: interpolated 3D brain map, C: channel-wise 2D map, and D: interpolated 2D map, $p < .05$)

Relationships Among Mask-Wearing Intention, Brain Activation, and Mask-Wearing Behavior

The multiple regression analysis results are presented in Table 4. The model explained 37.2% of the variance in mask-wearing frequency ($R^2 = .372$, adjusted $R^2 = .237$; F = 2.762). Although the overall regression model did not reach statistical significance ($F(3,14) = 2.762, p = .081$), the individual predictors were examined on an exploratory basis given the limited sample size. The self-reported mask-wearing intention score (X_1) did not significantly predict actual behavior ($B = 0.031, SE = 0.036, \beta = .088, t = 0.843, p = .413$).

Left DLPFC activation (Ch20; X_2) also did not significantly predict behavior (B = -15,460, SE = 773,000, β = -.004, t = -0.020, p = .984). In contrast, left OFC activation (Ch31; X_3) was the sole significant predictor (B = 1,508,000, SE = 674,000, $\beta = .553, t = 2.238, p = .042$).

Table 4. Multiple regression results: Mask-wearing intention, brain activation, and mask-wearing frequency (*$p < .05$)

Variable	Unstandardized coefficients		Standardized coefficients	t	p
	B	SE	β		
Constant	−0.349	2.604	—	−0.134	.895
Mask-wearing intention (X_1)	0.031	0.036	0.088	0.843	.413
Brain activation Ch. 20 — left DLPFC (X_2)	−15,460	773,000	−0.004	−0.020	.984
Brain activation Ch. 31 — left medial OFC (X_3)	1,508,000	674,000	0.553	2.238	.042*

Model summary: $R^2 = .372$, adjusted $R^2 = .237$, $F(3, 14) = 2.762, p = .081$

Discussions

Brain activation in the prefrontal cortex was measured via fNIRS during viewing of the high-concentration fine dust response education video. When the below-average mask-wearing group was subtracted from the above-average group, statistically significant increases in brain activation were observed at channels 20 and 31 in the left prefrontal lobe. However, when behavioral predictability was analyzed through multiple regression analysis, only the activation of channel 31 was confirmed as the key variable that statistically significantly predicts actual mask-wearing behavior over the subsequent two weeks.

In particular, channel 31 was located in the medial OFC (MNI coordinates: x = −2.3, y = 70.0, z = −7.7), which is closely related functionally to the medial PFC. This region is known to be centrally involved in emotion-based reward value evaluation, self-relevance, autonomous motivation elicitation, approach behavior regulation, and various higher-order cognitive and emotional integration functions (Rolls et al., 2022; Sescousse et al., 2013). These results suggest that the educational stimulus not only delivered simple information but also stimulated the learner's emotional system and motivational structure, and that the process of internalizing the message as a 'personally important value' was connected to actual behavior.

According to the neurobiological framework established by Rolls (2019), the medial OFC forms functional connections with the anterior cingulate cortex and amygdala, serving as a neural hub that regulates the integrative processing of emotional-reward information and behavior selection based on social judgment. This mechanism supports the finding that the activation increase in channel 31 observed in this study reflects not a simple stimulus response, but a transition to actual behavior driven by the internalization of meaningful reward value.

On the other hand, channel 20 (left DLPFC) also showed significant increases in mask-wearing frequency, but did not significantly predict behavior in the multiple regression analysis. The activation at channel 20 (left DLPFC) reflects prefrontal engagement in cognitive control functions such as response inhibition and executive control, indicating the learner's attempt to cognitively interpret information and determine a course of action (Aron et al., 2004). Though, according to the results of this study, DLPFC activation alone was not sufficient to predict actual behavioral practice.

To summarize, the high-frequency group, who actually wore masks more frequently after receiving high-concentration fine dust response education, showed significant brain activation increases in both channel 20 (DLPFC) and channel 31 (medial OFC) compared to the low-frequency group. However, the channel that substantially predicted behavior in the multiple regression analysis was only channel 31. This suggests that behavioral change is not achieved through cognitive processing of simply 'understanding information' alone, but that emotional reward value must be personally internalized before it leads to actual behavior.

These results support the neuroscientific model that behavioral change occurs through the integrated operation of the 'Cognitive Control Network' and the 'Valuation Network' (Hare et al., 2009). The DLPFC is responsible for cognitive control and planning functions, but the final decision and execution are governed by the subjective value signal of reward computed in the OFC, particularly the medial OFC/medial PFC. In other words, no matter how rationally one judges 'I should wear a mask' (DLPFC), if the emotional conviction that 'it is truly meaningful and beneficial to me' (OFC) does not accompany it, it may not lead to actual practice (Hare et al., 2009).

This interpretation is also consistent with the 'brain-as-predictor' approach. According to prior research, the fact that the brain responses of medial PFC and OFC to health messages predict actual behavioral change more accurately than the behavioral intentions reported by individuals has been repeatedly demonstrated (Falk et al., 2012).

Conclusions and Educational Implications

This study analyzed middle school students' prefrontal brain activation patterns during high-concentration fine dust education using functional near-infrared spectroscopy (fNIRS) and examined whether brain activation or self-reported mask-wearing intention better predicts subsequent two-week mask-wearing behavior.

GLM analysis revealed that, during educational video viewing, students with above-average mask-wearing frequency showed significantly greater activation in the left DLPFC (BA 10, Ch20) and left OFC (BA 11, Ch31) compared to those with below-average frequency. In an exploratory multiple regression analysis, left OFC activation (Ch31) emerged as the only significant predictor of two-week mask-wearing behavior ($\beta = .553, p < .05$), whereas self-reported intention was not significant. These findings suggest that neurophysiological responses to educational content—particularly OFC-mediated value computation—may predict future health behavior more objectively and accurately than conscious self-reports.

These findings have important implications for instructional design. Education should move beyond the simple delivery of factual information and support learners in forming subjective value by connecting educational content with their personal experiences, value systems, and perceived relevance. Although both the DLPFC, associated with cognitive control, and the OFC, associated with value judgment, were activated in the high-frequency mask-wearing group, only OFC activation predicted actual behavior. This suggests that cognitive understanding may be necessary but not sufficient for behavioral change, and that OFC-mediated value internalization may serve as a key mechanism bridging education and behavior.

In terms of educational evaluation, fNIRS-derived OFC activation may serve as an implicit neural marker that complements the limitations of self-report assessments, particularly when reported intentions fail to predict actual behavior. By examining whether educational content engages learners' value judgment systems, neuroscientific indicators may provide a useful tool for evaluating the effectiveness of health and environmental education. This study has certain limitations. Given the small sample (N = 18), the regression analysis should be regarded as exploratory, and the findings require replication in larger, independent samples before firm conclusions are drawn. Future studies should replicate these findings with larger samples and explore instructional strategies that specifically promote OFC-mediated valuation processes to maximize behavioral outcomes.

References

Aron, A. R., Robbins, T. W., & Poldrack, R. A. (2004). Inhibition and the right inferior frontal cortex. Trends in Cognitive Sciences, 8(4), 170–177. https://doi.org/10.1016/j.tics.2004.02.010

Boas, D. A., Elwell, C. E., Ferrari, M., & Taga, G. (2014). Twenty years of functional near-infrared spectroscopy: Introduction for the special issue. Neuroimage, 85, 1–5. https://doi.org/10.1016/j.neuroimage.2013.11.033

Falk, E. B., Berkman, E. T., Mann, T., Harrison, B., & Lieberman, M. D. (2010). Predicting persuasion-induced behavior change from the brain. Journal of Neuroscience, 30(25), 8421–8424. https://doi.org/10.1523/JNEUROSCI.0063-10.2010

Falk, E. B., Berkman, E. T., & Lieberman, M. D. (2012). From neural responses to population behavior: Neural focus group predicts population-level media effects. Psychological Science, 23(5), 439–445. https://doi.org/10.1177/0956797611434964

Falk, E. B., Morelli, S. A., Welborn, B. L., Dambacher, K., & Lieberman, M. D. (2013). Creating buzz: The neural correlates of effective message propagation. Psychological Science, 24(7), 1234–1242. https://doi.org/10.1177/0956797612474670

Fisher, R. J. (1993). Social desirability bias and the validity of indirect questioning. Journal of Consumer Research, 20(2), 303–315. https://doi.org/10.1086/209351

Hare, T. A., Camerer, C. F., & Rangel, A. (2009). Self-control in decision-making involves modulation of the vmPFC valuation system. Science, 324(5927), 646–648. https://doi.org/10.1126/science.1168450

International Agency for Research on Cancer. (2015). *Outdoor air pollution* (IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, No. 109). Lyon, France: Author. https://publications.iarc.fr/538

Korea Education and Research Information Service. (2020). *Hwangsa mit misemeonji balsaeng si daecheo yoryeong* [Responding to yellow dust and fine dust events] [Video file]. https://www.schoolsafe24.or.kr/front/rpstr/selectRpstrInfo.do?menuSn=185&upperMenuSn=148&rpstrPstSn=1763

Kormos, C., & Gifford, R. (2014). The validity of self-report measures of proenvironmental behavior: A meta-analytic review. Journal of Environmental Psychology, 40, 359-371. https://doi.org/10.1016/j.jenvp.2014.09.003

Lieberman, M. D. (2010). Social cognitive neuroscience. In S. T. Fiske, D. T. Gilbert, & G. Lindzey (Eds.), Handbook of social psychology (5th ed., Vol. 1, pp. 143–193). John Wiley & Sons. https://doi.org/10.1002/9780470561119.socpsy001005

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. Neuropsychologia, 9(1), 97–113. https://doi.org/10.1016/0028-3932(71)90067-4

Rolls, E. T. (2019). *The orbitofrontal cortex.* Oxford, UK: Oxford University Press. https://doi.org/10.1093/oso/9780198845997.001.0001

Rolls, E. T., Wan, Z., Cheng, W., & Feng, J. (2022). Risk-taking in humans and the medial orbitofrontal cortex reward system. NeuroImage, 249, 118893. https://doi.org/10.1016/j.neuroimage.2022.118893

Scholkmann, F., Kleiser, S., Metz, A. J., Zimmermann, R., Mata Pavia, J., Wolf, U., & Wolf, M. (2014). A review on continuous wave functional near-infrared spectroscopy and imaging instrumentation and methodology. NeuroImage, 85, 6–27. https://doi.org/10.1016/j.neuroimage.2013.05.004

Sescousse, G., Caldú, X., Segura, B., & Dreher, J. C. (2013). Processing of primary and secondary rewards: A quantitative meta-analysis and review of human functional neuroimaging studies. Neuroscience & Biobehavioral Reviews, 37(4), 681–696. https://doi.org/10.1016/j.neubiorev.2013.02.002

Shin, J. H., Kang, M. J., & Lee, S. A. (2024). Wearable functional near‐infrared spectroscopy for measuring dissociable activation dynamics of prefrontal cortex subregions during working memory. Human Brain Mapping, 45(2), e26619. https://doi.org/10.1002/hbm.26619

Webb, T. L., & Sheeran, P. (2006). Does changing behavioral intentions engender behavior change? A meta-analysis of the experimental evidence. Psychological Bulletin, 132(2), 249–268. https://doi.org/10.1037/0033-2909.132.2.249

World Health Organization. (2021). WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. World Health Organization. https://iris.who.int/handle/10665/345329

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