

The mediating role of vaccine hesitancy between maternal engagement with anti- and pro-vaccine social media posts and adolescent HPV-vaccine uptake rates in the US: The perspective of loss aversion in emotion-laden decision circumstances

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ABSTRACT

While Human Papillomavirus (HPV) is a prominent cause of cervical cancer and mortality among underserved women, HPV vaccine completion rates remain stagnant (54%) among US adolescents. Our objective is to identify how adolescents' mothers' engagement with anti-vaccine versus pro-vaccine social media content is associated with their children's HPV vaccination rates via increased vaccine hesitancy. We employ the notion of loss aversion escalated in an emotion-laden circumstance in consumer behavior literature given that HPV vaccination decisions directly affect children's well-being. Based on this escalated loss aversion tendency for an emotion-laden decision, we explain why anti-vaccine content disproportionately increases mothers' overarching vaccine hesitancy, while pro-vaccine content does not decrease vaccine hesitancy. We conducted a population-based survey among 426 mothers of US adolescents aged 13–18. Our sample closely mimics the socioeconomic and demographic factors of the population group of mothers of adolescents in the US census. Our results show that anti-vaccine social media posts are associated with increases in mothers' overarching vaccine hesitancy and with decreases in their children's HPV vaccination rates, while pro-vaccine content has no significant association with either.

1. Introduction

During the COVID-19 pandemic, the spread of anti-vaccine information has increased on social media (Pulido et al., 2020), fostering groundless fears about immunization (Reich, 2020). Increasing anti-vaccine content is likely to inflict long-term harm on public health by accelerating the suppression of immunization rates. Among many controversial vaccines on social media, the human-papillomavirus (HPV) vaccine is one of the most debated on social media (Daily et al., 2015), and its uptake rate has been lagging (54.5%, CDC, 2020). The stagnant HPV vaccination uptake rates will exacerbate health disparities by making underserved populations increasingly susceptible to HPV-associated cancers such as cervical cancers, which are among the top causes of mortality among underserved women (Viens et al., 2016).

Efforts have been made to disseminate pro-HPV-vaccine content on

social media to counteract the anti-vaccine content (Ortiz et al., 2019). While these interventions have increased general awareness and knowledge about HPV and HPV vaccines, they have failed in increasing uptake rates (Ortiz et al., 2019). The Philadelphia Department of Public Health's campaign for increasing HPV vaccination rates received 3,400 likes on Facebook over 12 months but only resulted in two additional vaccinated adolescents (Mohanty et al., 2018). While prior studies have examined anti- and pro-vaccine activists on social media (Guess et al., 2020; Johnson et al., 2020), less attention has been paid to adolescents' mothers' engagement with anti-vaccine content and its negative association with their children's HPV vaccination rates (Ashfield and Donelle, 2020). Mothers make over 93% of HPV vaccination decisions for adolescents (Berenson et al., 2014) and gather information about parenting and health from social media (Ashfield and Donelle, 2020). Accordingly, the lack of research on adolescents' mothers is an

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important gap that impedes our understanding of social media anti-vaccine content and HPV vaccination rates.

Our overall objective is to identify how adolescents' mothers' engagement with anti-vaccine versus pro-vaccine social media content is associated with their decisions about vaccinating their children against HPV. To this end, we investigated how mothers' overarching vaccine hesitancy catalyzes (i.e., mediates) the relationship between their engagement with anti/pro-vaccine content and their adolescent children's HPV vaccination statuses. Vaccine hesitancy is defined as a delay or refusal to be vaccinated despite the accessibility of vaccination services (Dempsey et al., 2011). In particular, we focus on mothers' overarching vaccine hesitancy toward the overall vaccine system based on distrust in healthcare and the government and concerns about vaccine safety.

We employ the notion of loss aversion (Kahneman and Tversky, 1979) as a theoretical base. Loss aversion describes individuals' tendency to prefer to reduce potential losses over obtaining equivalent gains when making decisions that involve uncertainty and risks (Kahneman and Tversky, 1979). More specifically, we focus on how loss aversion tendency is escalated in an "emotion-laden" circumstance whereby individuals must make decisions directly affecting the well-being of loved ones (Lee and Benbasat, 2011; Luce, 1998). In these emotion-laden decision situations, individuals choose a status-quo option, or *inaction* in which they *refuse* or *hesitate* to take an action (Lee and Benbasat, 2011; Luce, 1998). Based on the intensification of loss aversion in an emotion-laden context (Lee and Benbasat, 2011; Luce, 1998), we assert that mothers become more receptive to the harms and injuries portrayed in anti-vaccine messages than to the preventative benefits described in pro-vaccine messages. To our knowledge, this is the first study to employ loss aversion in an emotion-laden decision task as a theoretical background for understanding slow HPV vaccination rates among US adolescents.

We conducted a population-based survey among 426 mothers of US adolescents in late December 2019 to mid-January 2020. Our sample closely mimics the socioeconomic and demographic factors of this population group in the US census. We developed a new scale for engagement with social media vaccine posts to overcome the limitations of passive exposure used in prior studies.

1.1. Literature review and research model

The dangers of anti-vaccine social media posts and their potential associations with outbreaks are well documented (Johnson et al., 2020) (Fig. 1). Johnson et al. (2020) applied social network analysis to more than a billion Facebook users and showed the rapid growth of anti-vaccine activities during the measles outbreaks of 2019, while pro-vaccine activities remained unchanged. While pro-vaccine tweets

have declined since 2014, anti-vaccine tweets doubled from 8.1% to 16% between 2015 and 2018 (Gunaratne et al., 2019). Engagement has been higher with anti-vaccine than with pro-vaccine content (Schmidt et al., 2018). Moreover, those who are exposed to anti-vaccine content are more likely to disseminate such content on social media (Dunn et al., 2017) and less likely to have their children vaccinated against HPV (Margolis et al., 2019).

Prior pro HPV-vaccine campaigns have yielded mixed results (Ortiz et al., 2019). Some of these campaigns have had positive effects on knowledge of, attitudes toward, and intention to receive HPV vaccinations, but the campaigns have not had significant effects on vaccination rates (Ortiz et al., 2019). For instance, Cates et al. (2014) utilized a three-month social media campaign accompanied by other media campaigns (e.g., brochures, posters, doctors' recommendations, and news releases) to raise HPV vaccination rates in preteen girls based in rural North Carolina. Compared with non-intervention counties, HPV vaccination rates increased by 2% but did not reach a statistically significant level.

Several researchers have compared the behaviors of anti- and pro-vaccine activists who engage with the formation and growth of respective communities on social media and how these individuals diffuse their views (Guess et al., 2020; Johnson et al., 2020). These researchers have found "echo-chamber effects" or "polarization" in which individuals selectively acquire and consume content that reinforces their existing views about vaccines.

Despite the seminal work on polarization, we should practice caution when applying the findings from anti/pro-vaccine clusters on social media to adolescents' mothers. Whether adolescents' mothers have established consistent views about HPV vaccines in the same way as anti/pro-vaccine activists remains unknown (Ashfield and Donelle, 2020). Johnson et al. (2020) and Guess et al. (2020) have showed that most social media users are rather "undecided," and only small fractions of users constitute anti- and pro-vaccine clusters. As such, whether adolescents' mothers demonstrate polarization similarly to anti- and pro-vaccine activists is unknown. The lack of empirical studies on mothers is therefore a barrier to our understanding of how anti/pro-vaccine content relates to the stagnant HPV vaccination rates among US adolescents. We aim to close this gap through testing the research model presented in Fig. 2.

1.2. Hypothesis development

1.2.1. Maternal engagement with anti/pro-vaccine content and overarching vaccine hesitancy

The predominant cause of vaccine hesitancy is the biased risk-benefit assessments of vaccination (Lane et al., 2018). Anti-vaccine activists skew this assessment by questioning the safety of vaccines, exacerbating



Fig. 1. Examples of anti-vaccine versus pro-vaccine content on Instagram.

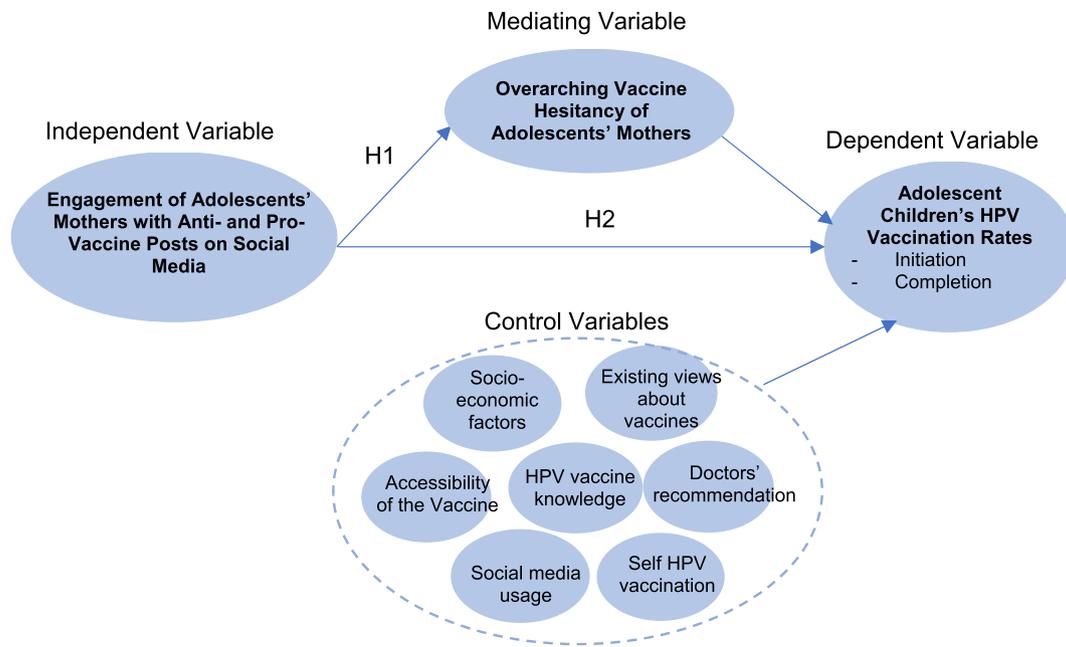


Fig. 2. Research model and hypotheses.

parents' concerns about injuries (Enkel et al., 2018), and fostering the false belief that a healthy lifestyle can supplant the need for vaccinations (Swaney and Burns, 2019). As a consequence, mothers who engage with anti-vaccine content are likely to perceive the safety risks of vaccination to be greater than the benefits (Motta et al., 2018). This disproportionate assessment of the risks to the benefits increases overarching vaccine hesitancy (Ortiz et al., 2019). However, this explanation does not explain why engagement with pro-vaccine content does *not* decrease mothers' vaccine hesitancy. Pro-vaccine content highlights the benefits, just as anti-vaccine content emphasizes the risks.

The concept of loss aversion is useful for explaining the discrepant outcomes of pro-vaccine content (Kahneman and Tversky, 1979). Loss aversion refers to the tendency to prefer avoiding losses to acquiring equivalent gains (Kahneman and Tversky, 1979). Expanding on loss aversion, prior researchers in consumer behavior have added the concept of an emotion-laden decision task wherein individuals perceive a given decision task to bring severe negative consequences to the well-being of people who decision-makers care for (Lee and Benbasat, 2011; Luce et al., 1999). In such an emotion-laden situation, individuals' tendency to avoid losses increases, while their tendency to seek gains decreases because individuals are more likely to feel stress and thus attempt to avoid making a choice (Luce et al., 1999).

Making an HPV vaccination decision for an adolescent is an emotionally challenging task because the potential harm from vaccination can be perceived to be permanent (Dixon, 2017). Accordingly, for an emotion-laden decision concerning their children's welfare, mothers' loss aversion increases disproportionately to their gain seeking (Luce et al., 1999). In a laboratory experiment with an emotion-laden stimuli, participants' tendency to choose a status-quo option (wherein they refuse to take any action) increased disproportionately compared to their choice of options that increased benefits (Luce et al., 1999). Based on this finding, we argue that due to the loss aversion intensified by emotional vaccination decisions, mothers are likely to become more receptive to the risks of vaccines portrayed in anti-vaccine content than to the benefits described in pro-vaccine content. As a result, mothers' engagement with anti-vaccine content will increase their overarching vaccine hesitancy, while their engagement with pro-vaccine content will not decrease vaccine hesitancy.

Hypothesis 1.1. Mothers' engagement with anti-vaccine content is

positively associated with their overarching vaccine hesitancy.

Hypothesis 1.2. No association exists between mothers' engagement with pro-vaccine content and their overarching vaccine hesitancy.

1.2.2. Engagement with anti/pro-vaccine content and HPV vaccination rates

Loss aversion again provides a valuable lens to infer the relationship between mothers' engagement with anti-vaccine content on social media and adolescents' HPV vaccination rates. In particular, parents respond differently to losses based on whether they focus on distant or immediate loss (Nan et al., 2019). Individuals react more positively to gains than to losses when they are focused on the distant future (Brewer et al., 2017). In contrast, they react more to losses than to gains when they are focused on the immediate future (Brewer et al., 2017; Nan et al., 2019). This shift has important implications on parents' HPV vaccination decisions. Immediate losses for HPV vaccines include a fear of needles and pain at the injection site (Burns et al., 2015) and presumably the inconvenience of visiting a healthcare facility for regular checkups without an urgent medical need. When mothers pay more attention to these immediate costs and inconveniences, they are less likely to focus on the benefits of long-term prevention.

Furthermore, as shown in Fig. 1 above, anti-vaccine content is described in terms of "personalized" dramatizations of injuries, while pro-vaccine content is presented in terms of benefits for society more broadly, such as creating herd immunity (Xu, 2019). Although such societal benefits are crucial for improving public health, individuals react more to personal negative consequences than to the benefits for a broader community (Brewer et al., 2017). Based on individuals' attention to immediate and personal outcomes related to HPV vaccination as opposed to distant and societal benefits, we argue the following:

Hypothesis 2.1. Mothers' engagement with anti-vaccine content is negatively associated with their adolescent children's HPV vaccination rates.

Hypothesis 2.2. No association exists between mothers' engagement with pro-vaccine content and their adolescent children's HPV vaccination rates.

1.2.3. Overarching vaccine hesitancy as a mediator between engagement with anti-vaccine content and HPV vaccination rates

We assert that overarching vaccine hesitancy mediates the relationship between mothers' engagement with anti-vaccine posts and their children's HPV vaccination rates. We do not argue for an equivalent role of vaccine hesitancy for pro-vaccine posts, as per our hypotheses that no associations exist between pro-vaccine content and overall vaccine hesitancy (H1.2) or HPV vaccination rates (H2.2). As we maintain in H1.1 and H2.1, anti-vaccine content portrays vaccines as harmful in one's immediate personal future, thus distorting maternal assessments of risks and benefits. As such, mothers' anti-vaccine engagement is associated with increases in overarching vaccine hesitancy and with decreases in adolescent children's HPV vaccination rates. Consequently, we propose that overarching vaccine hesitancy is a mediator between mothers' anti-vaccine engagement and their children's HPV vaccination status.

Although prior studies have not yet identified the mediating role of overarching vaccine hesitancy in the HPV vaccination context, vaccine hesitancy has been inferred as an interference with immunization in general (MacDonald, 2015). Prislín et al. (1998) demonstrated that safety concerns expressed in anti-vaccine content increase negative attitudes toward vaccines, which in turn result in less up-to-date immunizations. In Prislín et al.'s study, attitudes toward vaccines were used interchangeably with vaccine hesitancy, defined as a negative or positive evaluation(s) of behavior and outcome deterring individuals from timely immunizations. Based on the mediating capacity of vaccine hesitancy suggested in prior studies (Prislín et al., 1998), we argue that mothers' engagement with anti-vaccine social media content has a negative association with their children's HPV vaccination statuses through overarching vaccine hesitancy.

Hypothesis 3. Overarching vaccine hesitancy mediates the association between mothers' engagement with anti-vaccine content and decreases adolescent children's HPV vaccination rates.

2. Methods

From late December 2019 to mid-January 2020, we conducted a population-based survey among 426 mothers of US adolescents. In the absence of a prior dataset, we chose a small effect size of odds ratio (i.e., 1.68; Chen et al., 2010). A 28% baseline probability (the percentage of US adolescents who had not initiated the HPV vaccination series [CDC, 2020]) was chosen for pro-vaccine engagement; a 72% baseline probability (the percentage of US adolescents who had initiated the series [CDC, 2020]) was selected for anti-vaccine engagement. We assumed that other predictors explain 50% variance of the main predictor (i.e., pro/anti-vaccine message engagement). Under these assumptions, a sample of 388 achieves a 0.90 power at a 0.05 significance level (two-sided). Thus, we sampled 426 individuals, exceeding 388. Assuming that there are a total of approximately 20 million US adolescents (Statistica, 2019), our sample size of 426 provides a 5% margin of error at a 0.05 significance level (Wonnacott and Wonnacott, 1990).

We hired an online panel service provider, Qualtrics, that maintains respondent pools across diverse US population groups. The vendor contacted their respondent pools to identify a sample that met our selection criteria; Qualtrics incentivized respondents based on their agreements. Approval from the Institutional Review Board regarding human subject protection was received prior to the launch of our survey. Participation in this survey was entirely voluntary, confidential, and anonymous. Consent was obtained from each respondent before they proceeded to the questionnaire. Qualtrics prevented multiple entries from the same individuals by checking their panel IDs, which remain confidential within Qualtrics.

To generalize our findings from the survey to the population, we applied selection criteria to our sampling that mimics the socioeconomic and demographic composition of US parents with co-resident children

under 18 by using US census data. These selection criteria included wide ranges in education, household income, insurance, ethnicity, and region of residence. Table 1 lists the factors pertinent to HPV vaccination among our respondents, including the gender of the eldest child about whom respondents answered the questions (with an even split between males and females) and the age of their eldest child (nearly an even distribution between 13 and 17 years). Fewer 18-year-olds were included (36/426, 8%), presumably because some children at this age no longer co-reside with their parents. Nearly all (423/426, 99.3%) surveyed mothers reported that they solely or jointly make HPV vaccination decisions for their children, which is consistent with Berenson et al. (2014), justifying our choice of mothers as the survey respondents. Regarding social media use, 93% of respondents (396/426) stated that they use social media, which aligns with the 2019 report from Edison Research. On average, respondents spent 166.1 min per day on their preferred social media sites (Standard Deviation [SD] = 176 min).

Furthermore, we chose mothers of adolescents aged 13–18 because we operationalized two levels of HPV vaccination delivery: initiation (whether children had begun the vaccination series) and completion (whether children had completed the series). The Centers for Disease Control and Prevention (CDC) recommends that 11- and 12-year-olds begin a two-dose HPV series over a six-month period (or a three-dose series if immunocompromised). Therefore, even if parents intend to follow this recommendation, some 11- and 12-year-olds may not have begun the series by the time their mothers completed the survey; hence, we did not include 11–12-year-olds. This choice of excluding 11–12 years old is consistent with the selections of respondents in CDC's National Immunization Survey. We included the mothers of 18-year-olds to represent completion rates among adolescents who began the series at age 17, when they were still under parental care.

As shown in Appendix 1, we conceptualized mothers' engagement with anti-vaccine and pro-vaccine content in terms of endorsing, promoting, conversing, and composing content. In contrast to the common belief that social media users are passively exposed to and persuaded by anti/pro-vaccine content, prior researchers have shown that undecided individuals actively search for vaccine-related information on social media (Guess et al., 2020; Johnson et al., 2020). Following these studies, we developed a new instrument for active engagement with social media content distinguished from passive exposure to such content employed in prior studies, such as Dunn et al. (2017). To measure vaccine hesitancy, we revised a pre-validated instrument by Opel et al. (2011). We used binary answers (yes/no) from respondents regarding whether their children initiated and completed the series.

We added 14 control variables that could affect HPV vaccination rates, including socioeconomic statuses (education, health insurance, household income), accessibility, HPV vaccine knowledge, child's gender, age, race/ethnicity, region of residence, mothers' own HPV vaccination statuses, doctors' recommendations, and social media usage behaviors (whether they subscribe to anti-/pro-vaccine accounts on social media and daily social media usage time; Appendix 2).

Throughout the survey, we implemented several techniques to alleviate the common limitations of survey methodology, such as social desirability, recall, and common method biases. We clearly defined anti-vaccine and pro-vaccine content before the respondents were presented with any questions about them and repeated these definitions in each question. Additionally, we included quality checks to prevent the common method bias whereby respondents do not pay attention to the questions and instead choose a neutral option (e.g., three on a five-point scale). Our quality check question was "I am paying attention while filling in this questionnaire," with 1 being "I strongly disagree with this statement," 3 being "neither agree or disagree," and 5 being "strongly agree with this statement." Those who chose 3, 2, or 1 were not allowed to proceed to the following questions. Lastly, we included a warning about the inclusion of these quality check questions to encourage the respondents to answer the questions conscientiously. These instructions functioned as warnings rather than screeners because most of our

Table 1
Respondents' composition.

Sociodemographic factors		Freq.	Percent
Region of residence	South	170	40%
	Midwest	99	23.2%
	West	87	20%
	Northeast	70	16%
Education level	Less than high school	34	8%
	Completed high school	105	24.7%
	Some college or associate degree	122	28.6%
	Bachelor's degree	110	25.8%
Ethnicity/race	Master's degree or higher	55	13%
	White, not Hispanic or Latinx	231	54.2%
	Hispanic or Latinx	96	23%
	Black/African American	47	11%
	Asian	30	7%
	Multiracial	16	4%
	Other	6	1%
Health insurance	Private (provided by employer)	211	49.5%
	Medicaid	109	25.6%
	Uninsured	33	8%
	Private (purchased by individual)	31	7%
	Medicare	29	7%
	Military-provided	13	3%
Income level	Less than \$50,000	170	39.9%
	\$50,000–\$99,999	119	27.9%
	\$100,000–\$149,999	66	15%
	\$150,000–\$199,999	47	11%
	\$200,000 or more	24	6%
HPV vaccine relevant factors		Freq.	Percent
Age of the eldest child	13	76	18%
	14	69	16%
	15	74	17%
	16	78	18%
	17	93	22%
	18	36	8%
Gender of the eldest child	Female	212	49.8%
	Male	214	50.2%
HPV vaccination decision-maker for the eldest child in the family	Myself only	219	51.4%
	Myself and my spouse/partner/child's father	173	40.6%
	Myself and my child	31	7%
	My spouse/partner/child's father only	2	0%
	My child only	1	0%
Social media use		Frequency	Percentage
Social media use per day ^a	None	38	9%
	1–60 min	148	34.7%
	1–3 h	115	27.0%
	3–6 h	60	14%
	6 h or more	65	15%
Social media sites that respondents use most often*	Facebook	269	63.2%
	Instagram	52	12%
	Pinterest	15	4%
	Snapchat	10	2%
	Twitter	14	3%
	YouTube	29	7%
	Others	1	0%
	None*	36	7%
Total		426	100.00%

^a There is a slight discrepancy between the percentage of respondents who said they did not spend any time on social media ($n = 38$) and those who said that they did not use any social media ($n = 36$). Two respondents said that they did not spend any time on social media, but still reported using YouTube presumably because they did not consider YouTube as a social media. This misunderstanding is unrelated to HPV vaccine, so we proceeded without

removing these two respondents.

respondents passed these questions.

3. Results

3.1. Reliability and validity

The descriptive statistics of the key variables including correlations are reported in [Appendix 3](#). We measured and tested the reliability and discriminant and convergent validity of our scales, namely engagement with anti-vaccine/pro-vaccine content and vaccine hesitancy. Our testing results indicate that all three instruments are reliable and valid ([Table 2](#)).

For our statistical analysis, we used Hayes' PROCESS tool (Model 4). We standardized the variables in our model using Z-transformation. Major regression assumptions such as normality, independence of errors, and homoscedasticity were met. No threat of outliers in the data existed. The variance inflation factors for the variables are below 2; thus, multicollinearity is not a concern ([Hair et al., 1998](#)). An exception is the correlation between engagement with anti-vaccine and pro-vaccine content (0.84).

This high correlation suggests that mothers consider both viewpoints about vaccines. These results concur with prior studies that have determined that undecided individuals actively search for vaccine-related information ([Johnson et al., 2020](#)); 84% of [Guess et al.'s \(2020\)](#) participants visit vaccine-related websites annually. [Table 3](#) shows the patterns of information searches by adolescents' mothers in our survey. A total of 302 out of 426 mothers (71% of the sample) engaged with *any* side of vaccine debate, with 176 out of these 302 mothers (58%) engaging with *both* sides of the debate. Of these 302 mothers, 126 (42%) engaged disproportionately with one side of the debate; 61 out of these 126 mothers (52%) were more engaged with pro-vaccine content, while 65 (48%) engaged more with anti-vaccine content.

This high correlation between engagement with anti- and pro-vaccine content, however, could raise concerns about multicollinearity if both were included in the same regression model; thus, we constructed two sets of models—one set for anti-vaccine content and the other for pro-vaccine content.

3.2. Hypothesis testing results

Hypotheses 1.1 and 1.2 concern the association between mothers' engagement with anti-vaccine (H1.1) versus pro-vaccine (H1.2) posts and overarching vaccine hesitancy. [Table 4](#) presents our H1 testing results. Model 1 shows our testing result for H1.1, whereas Model 2 shows that of H1.2. Model 1 illustrates that the coefficient for engagement with anti-vaccine content is significant and positive (0.18, $p < .01$). Model 2 demonstrates that the coefficient for engagement with pro-vaccine content is *not* significant at the 0.05 significance level (0.13, $n. s.$). Thus, these results support Hypotheses 1.1 and 1.2.

Hypotheses 2.1 and 2.2 concern the associations between maternal engagement with anti/pro-vaccine posts and HPV vaccination rates. Because Hayes' PROCESS model does not report the direct effects of the independent variables when the dependent variable is binary, as in the case of vaccine initiation and completion, we ran logistic regressions instead. [Table 5](#) reports the regression results for initiation and completion in Models 1 and 2, respectively. The coefficient for engagement with anti-vaccine posts is significant for initiation (-0.44 , $p < .05$ in Model 1) and completion (-0.42 , $p < .05$ in Model 2) at the 0.05 significance level.

[Table 6](#) reports the results of engagement with pro-vaccine posts (Models 1 and 2). The coefficient for engagement with pro-vaccine content is not significant for either initiation (-0.21 , $n. s.$ in Model 1)

Table 2
Loadings of the indicator variables.

Construct	Composite Reliability	Cronbach α	AVE	Indicator	Loading	Item-to-Total Correlation
Vaccine Hesitancy	0.91	.90	0.88	VH1	0.91	0.76***
				VH2	0.93	0.85***
				VH3	0.91	0.81***
Engagement with Anti-Vaccine Posts on Social Media	0.91	.91	0.80	AV1	0.87	0.76***
				AV2	0.91	0.82***
				AV3	0.92	0.84***
				AV4	0.88	0.78***
Engagement with Pro-Vaccine Posts on Social Media	0.96	.95	0.86	PV1	0.90	0.82***
				PV2	0.94	0.88***
				PV3	0.94	0.89***
				PV4	0.93	0.86***

Table 3
Mothers' engagement with anti-vaccine and pro-vaccine social media content.

		Engagement with pro-vaccine content ^b					Total
		0	1	2	3	4	
Engagement with anti-vaccine content	0 ^a	124	20	0	0	0	144
	1	33	120	19	3	0	175
	2	6	14	33	11	1	133
	3	0	1	8	15	7	31
	4	0	0	1	2	8	11
	Total	163	155	61	31	16	426

^a Scale: 0. Never; 1. Once/month or less; 2. A few times/month; 3. A few times/week; and 4. once/day or more.

^b See Appendix 1 for the four questions about engagement.

or completion (-0.05 , *n. s.* in Model 2). Taken together, the results provide support for Hypotheses 2.1 and 2.2.

Hypothesis 3 states that global vaccine hesitancy mediates the association between mothers' engagement with anti-vaccine content (termed *anti-vaccine engagement* in the results section) and children's HPV vaccination rates. Using Hayes' PROCESS model, we tested whether the mediating effect of vaccine hesitancy is significant. Fig. 3 reports that the indirect effect of anti-vaccine engagement on initiation (-0.09), as mediated by vaccine hesitancy, is statistically significant at a 95% confidence interval (CI) of (-0.24 , -0.01). The indirect effect is also significant in the cases of series completion (-0.10 , 95% CI of $[-0.22$, $-0.02]$). In contrast, the direct effect of anti-vaccine engagement is non-significant for initiation (-0.35 , *n. s.*) and completion (-0.15 , *n. s.*). The results of the indirect and direct effects suggest that vaccine hesitancy fully mediates the relationship between anti-vaccine engagement and HPV vaccination rates. These results support **Hypothesis 3**.

3.3. Robustness checks

We undertook three robustness checks to rule out alternative hypotheses. First, one might raise concerns about reverse causality—that is, mothers are hesitant about HPV vaccine and thus engage with anti-vaccine posts, not the other way around. To alleviate this concern, we included an item, safety concerns (“I am concerned that serious side effects may occur after vaccination”), and tested if safety concerns mediates the relationship between anti-vaccine engagement and overarching vaccine hesitancy. Safety concerns are one of the reasons that mothers become vaccine-hesitant, as we argued in our development for H3 earlier (Prislin et al., 1998). As such, by showing that anti-vaccine engagement increases safety concerns, which in turn affects vaccine hesitancy, we can alleviate the concerns about reversed causality and provide further support to the theoretical reasoning underlying our hypothesis development. Appendix 4 presents the results from two mediation analyses (one hypothesized direction and the other reversed). The results show that anti-vaccine engagement significantly predicts

vaccine hesitancy via increased safety concerns as we hypothesized, but the direction from vaccine hesitancy to anti-vaccine engagement via increased safety concerns was *not* significant. This result alleviates the concerns about reversed causality that vaccine hesitancy fosters anti-vaccine engagement.

One may raise the possibility of “echo-chamber” effects whereby parents' existing views about vaccines result in their decisions to deny/delay immunizations. To resolve this concern, we excluded respondents who subscribed to anti/pro-vaccine accounts on social media. Subscriptions to anti/pro-vaccination accounts mean that respondents opted to receive updates for any new one-sided posts regarding the vaccine debate on social media. After removing these subscribers, our hypothesis testing results remain unchanged (Appendix 5).

Lastly, we addressed the ways in which mothers' anti-vaccine engagement may vary across social media platforms and may affect their HPV vaccination decisions. We tested whether the results hold regardless of the type of social media used (Appendix 6). Since nearly two thirds (269/426, 63.2%) of the respondents reported Facebook as their primary social media platform (Table 1), we created a dummy variable, “Facebook” (1 = Facebook; 0 = not Facebook), and included it in the model. Controlling for Facebook did not affect the results, indicating that the results were not influenced by the type of social media used.

4. Discussion

4.1. Discussion of the findings

To identify the importance of our main predictor (i.e., anti-vaccine engagement) relative to other predictors, we compared the coefficients of (1) ordinal and continuous predictors (including the main and other control variables) and (2) binary predictors. We did not compare those of (1) against (2) because binary predictors tend to have higher coefficients than ordinal/continuous predictors.

Regarding vaccine hesitancy as the dependent variable (Table 4), anti-vaccine engagement has the greatest positive coefficient (0.18), followed by HPV vaccine knowledge (0.14). Welcomeness of the processes (-0.19) has the greatest negative coefficient, followed by ease of scheduling (-0.15). Among the binary predictors, anti-vaccine subscription was the only binary predictor that was significant and positive (0.50), while pro-vaccine subscription was the only binary predictor that was significant and negative (-0.56).

Regarding series initiation as the dependent variable (Table 5), welcomeness (1.02) has the largest positive coefficient, followed by child's age (0.58) and vaccine availability (0.4). Anti-vaccine engagement has the only negatively significant coefficient (-0.44). Among binary predictors, pro-vaccine subscription has the largest positive coefficient (3.28), followed by physicians' recommendations (2.25), race (i.e., Asian, 2.07), mothers' own HPV-vaccination statuses (2.05), and region (Northeast, 1.49). No binary predictor has a significant association.

Table 4
Results of regression on vaccine hesitancy.

	M1: Vaccine Hesitancy (Engagement with anti-vaccine content)			M2: Vaccine Hesitancy (Engagement with pro-vaccine content)		
	Coefficient	SE ^c	P value	Coefficient	SE	P value
Constant	-0.03	0.19	.89	-0.01	0.19	.95
Accessibility: Location	-0.06	0.06	.37	-0.06	0.06	.36
Accessibility: Welcoming	-0.19	0.05	<.001	-0.2	0.05	<.001
Accessibility: Availability	-0.07	0.06	.27	-0.06	0.06	.30
Accessibility: Schedule	-0.15	0.06	.01	-0.16	0.06	.007
Accessibility: Price	-0.02	0.06	.75	-0.02	0.06	.73
Knowledge about HPV Vaccine	0.14	0.05	.006	0.15	0.05	.004
HPV Vaccine Self-received	-0.18	0.11	.12	-0.17	0.12	.14
Doctor Recommended	-0.12	0.13	.34	-0.13	0.13	.29
Child's Age	-0.1	0.06	.08	-0.11	0.06	.05
Child's Gender	0.09	0.09	.33	0.08	0.09	.36
Education Level	0.07	0.06	.20	0.07	0.06	.23
Health Coverage	0.00	0.05	.98	0.01	0.05	.93
Household Income	-0.05	0.06	.44	-0.05	0.06	.43
Race: Asian ^a	-0.19	0.19	.31	-0.21	0.19	.28
Race: Hispanic or Latino	-0.03	0.12	.82	-0.03	0.12	.83
Race: African American	0.09	0.15	.57	0.07	0.15	.63
Race: Multiracial	0.23	0.24	.33	0.21	0.24	.38
Race: Other	-0.09	0.39	.82	-0.11	0.39	.78
Region: Northeast ^b	-0.03	0.13	.82	-0.02	0.13	.91
Region: Midwest	0.18	0.12	.13	0.18	0.12	.14
Region: West	0.18	0.13	.15	0.19	0.13	.14
Subscription to anti-vaccine accounts	0.50	0.22	.03	0.60	0.22	.007
Subscription to pro-vaccine accounts	-0.56	0.20	.005	-0.58	0.21	.01
Daily Social Media Use Time	0.03	0.05	.58	0.04	0.05	.43
Engagement with anti-vaccine Content	0.18	0.06	.002			
Engagement with pro-vaccine Content				0.13	0.61	.35
R-squared	0.1932			0.1826		
MSE	0.8904			0.8962		

^a Race reference group = White, not Hispanic or Latino.

^b Region group reference = South.

^c SE = Standard Error.

Regarding series completion as the dependent variable (Table 5), a child's age (0.74) has the largest positive coefficient, followed by welcomeness (0.66). Anti-vaccine engagement has the only significant and negative coefficient (-0.42). Among binary predictors, pro-vaccine subscription has the largest positive association (2.32), followed by mothers' own HPV-vaccination statuses (1.42), physicians'

Table 5
Results of Regression on Vaccination Rates (Engagement with anti-vaccine content).

	M1: Initiation			M2: Completion		
	Coef ^c	SE ^d	P value	Coef	SE	P value
Constant	-0.95	0.66	.15	-2.13	0.60	<.001
Accessibility: Location	0.12	0.20	.55	0.06	0.18	.73
Accessibility: Welcoming	1.02	0.20	<.001	0.66	0.16	<.001
Accessibility: Availability	0.40	0.19	.04	0.23	0.18	.21
Accessibility: Schedule	0.09	0.22	.69	0.35	0.18	.05
Accessibility: Price	0.11	0.23	.63	0.07	0.18	.72
Knowledge about HPV Vaccine	-0.07	0.20	.72	0.17	0.16	.30
HPV Vaccine Self-received	2.05	0.59	.001	1.42	0.40	<.001
Doctor Recommended	2.25	0.41	<.001	1.33	0.38	<.001
Child's Age	0.58	0.22	.009	0.74	0.19	<.001
Child's Gender	-0.01	0.33	.98	0.38	0.27	.17
Education Level	-0.26	0.20	.19	-0.33	0.17	.05
Health Coverage	-0.06	0.20	.77	-0.07	0.16	.67
Household Income	-0.19	0.20	.34	0.13	0.17	.46
Race: Asian ^a	2.07	0.93	.03	1.16	0.57	.04
Race: Hispanic or Latino	-0.24	0.41	.55	-0.02	0.35	.96
Race: African American	0.74	0.57	.19	0.63	0.48	.19
Race: Multiracial	0.42	0.86	.63	-0.35	0.72	.63
Race: Other	0.47	1.63	.77	1.85	1.32	.16
Region: Northeast ^b	1.49	0.57	.009	0.56	0.41	.17
Region: Midwest	-0.28	0.41	.49	0.08	0.35	.81
Region: West	-0.28	0.43	.52	0.15	0.39	.70
Subscription to anti-vaccine accounts	-0.68	0.88	.44	-0.86	0.78	.27
Subscription to pro-vaccine accounts	3.28	1.05	.002	2.32	0.77	.003
Daily Social Media Use Time	-0.25	0.20	.21	-0.17	0.18	.34
Engagement with anti-vaccine Content	-0.44	0.22	.04	-0.42	0.20	.03
R-Squared	0.4043			0.2972		

^a Race reference group = White, not Hispanic or Latino.

^b Region group reference = South.

^c Coef = Co-efficient.

^d SE = Standard Error.

recommendations(1.33), and race (i.e., Asian, 1.16).

These results once again demonstrate the harms caused by maternal engagement with anti-vaccine content to HPV vaccination rates: Anti-vaccine engagement has the greater coefficients than all binary predictors. These binary predictors include those factors known to be important (e.g., physicians' recommendations, Ortiz et al., 2019), thus attesting to anti-vaccine engagement's interference with immunization.

In addition, while the welcomeness of the processes was significant in all models, Tables 4–6), other accessibility factors (e.g., convenience of locations and price) were not significantly associated with either hesitancy or vaccination rates in any of the models. These results suggest that while the Vaccines for Children Program and the Affordable Care Act may have lowered other accessibility barriers, social and psychological barriers remain. Creating safe places for vaccination, providing privacy, and having friendly staff improve welcomeness of the processes (Shah et al., 2018). Healthcare providers should practice open, comforting, and nonjudgmental communication with vaccinees (McClain et al., 2016). Inclusivity also increases the welcomeness: the representation of diverse sociodemographic groups in all contacts with vaccinees is recommended (McClain et al., 2016).

The importance of region (being in the Northeast) is not a new

Table 6
Results of Regression on Vaccination Rates (Engagement with pro-vaccine content).

	M1: Initiation			M2: Completion		
	Coef ^c	SE ^d	P value	Coef	SE	P value
Constant	-0.96	0.66	.14	-1.71	0.54	<.002
Accessibility: Location	0.11	0.20	.59	0.06	0.16	.71
Accessibility: Welcoming	1.00	0.19	<.001	0.58	0.15	<.001
Accessibility: Availability	0.39	0.19	.047	0.21	0.17	.21
Accessibility: Schedule	0.12	0.21	.57	0.33	0.16	.04
Accessibility: Price	0.11	0.22	.63	0.09	0.16	.59
Knowledge about HPV Vaccine	-0.08	0.20	.68	0.10	0.14	.47
HPV Vaccine Self-received	1.97	0.59	.001	0.79	0.34	.02
Doctor Recommended	2.25	0.41	<.001	1.26	0.35	<.001
Child's Age	0.61	0.22	.006	0.63	0.17	<.001
Child's Gender	0.01	0.33	.98	0.32	0.25	.19
Education Level	-0.24	0.20	.23	-0.23	0.16	.15
Health Coverage	-0.10	0.20	.61	-0.09	0.15	.55
Household Income	-0.17	0.20	.39	0.15	0.16	.34
Race: Asian ^a	2.11	0.93	.02	1.14	0.50	.02
Race: Hispanic or Latino	-0.23	0.41	.58	-0.02	0.33	.96
Race: African American	0.72	0.56	.20	0.31	0.41	.45
Race: Multiracial	0.39	0.85	.65	-0.22	0.69	.75
Race: Other	0.44	1.62	.79	1.77	1.29	.17
Region: Northeast ^b	1.43	0.56	.01	0.11	0.37	.76
Region: Midwest	-0.26	0.42	.53	0.05	0.33	.88
Region: West	-0.32	0.43	.45	-0.12	0.35	.74
Subscription to anti-vaccine accounts	-0.99	0.86	.25	-1.47	0.74	.049
Subscription to pro-vaccine accounts	3.18	1.06	.003	1.96	0.74	.008
Daily Social Media Use Time	-0.29	0.20	.15	0.00	0.14	.98
Engagement with Pro-vaccine Content	-0.21	0.25	.38	-0.05	0.17	.79
R-Squared	0.3973			0.2469		

^a Race reference group = White, not Hispanic or Latino.

^b Region group reference = South.

^c Coef = Co-efficient.

^d SE = Standard Error.

finding from this study as the Northeast region has the highest HPV vaccination rates (66.1%) (CDC, 2020). Asian ethnicity is a new finding in this study as white individuals are conventionally believed to have higher immunization rates than others.

4.2. Contributions to social science and implications for public health

The above results show the relevance of applying a social science theory to identify reasons for stagnant HPV vaccine uptake rates that are likely to increase health disparities. Why do parents uncritically accept anti-vaccine claims despite numerous warnings on social media platforms, thereby jeopardizing their own children's health? Our application of loss aversion helps in answering this question: As mothers engage with anti-vaccine posts, mothers' overarching vaccine hesitancy increases disproportionately owing to the loss aversion that becomes intensified in emotion-laden circumstances such as those involving their children's well-being.

Understanding the significant role of mothers' overarching vaccine hesitancy informs us how important it is to address vaccine hesitancy in the development of future interventions for vaccinations. Public health officials should consider providing education on digital literacy and/or

technical solutions (e.g., fact-checkers and conversational agents) that can "inoculate" mothers against misinformation that fosters vaccine hesitancy. These education and technical solutions will enable vaccinees and their parents (or legal guardians) to consume balanced, credible content about vaccines, and become resistant to vaccine hesitancy.

The lessons learned from this study can also aid the COVID-19 vaccination campaigns. Although COVID-19 vaccination rates are steadily increasing (~40% of Americans received at least 1 dose by April 2021), whether the increases will continue or plateau when vaccination campaigns expand to vaccine-hesitant populations is not known. The results from a recent survey (November 2020) among 2000 US adults showed that 51% are willing to be vaccinated against COVID-19, 28% are not, and 21% are undecided; additionally, African Americans are 64% less willing to be vaccinated than White individuals (Reisdorf et al., 2021). As of April 2021, a vaccine is being tested for adolescents (12–15 years old) but is not yet in use. As demonstrated in this study, the negative roles of mothers' overarching vaccine hesitancy in their immunization decisions for adolescent children suggests that addressing anti-vaccine content may be crucial not only for increasing HPV-vaccinations but for curbing the COVID-19 pandemic.

4.3. Limitations

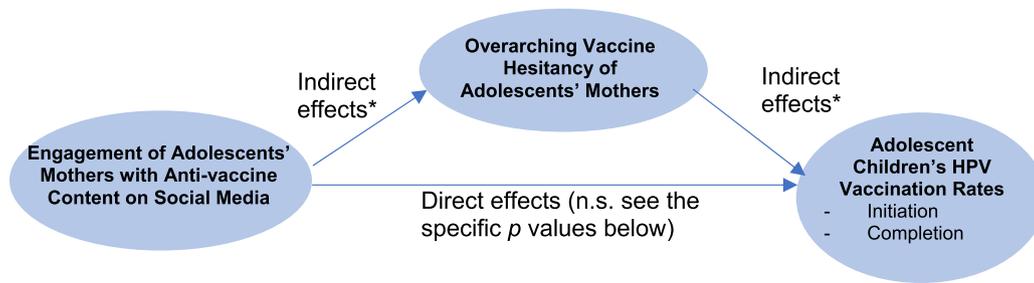
Like any other research, this study has several limitations. First and foremost, we did not manipulate or measure whether mothers' anti-vaccine engagement increases their loss aversion tendency. Ethical concerns and methodological challenges exist.

Firstly, measuring the levels of losses portrayed in anti-vaccine content is cost-prohibitive because of the sheer amount of such content posted on social media and the difficulty of sampling them. Meanwhile, prior studies have shown that anti-vaccine content centers on concerns about vaccine safety and injuries (Kata, 2012; Reich, 2020; Xu, 2019). Given the high costs and known central theme of anti-vaccine content, there was little need to measure the losses portrayed in anti-vaccine posts.

Secondly, we must note social desirability bias. Mothers are unlikely to acknowledge their loss aversion (i.e., the use of heuristics, not a rational, normative strategy) when making decisions that directly affect their children's well-being.

Thirdly, we needed to prevent causing harm to study participants and thus did not manipulate the levels of our respondents' anti-vaccine engagement. Higher levels of engagement with social media content can lead to changes in individuals' attitudes and behaviors (Araujo et al., 2017). As such, the participants' engagement with anti-vaccine content during the experiment could foster vaccine hesitancy among the participants. A debriefing session following the experiment session may not be sufficient for debiasing participants from vaccine hesitancy that they may have acquired from the experiment because vaccine hesitancy is known to be resilient to debunking efforts (Reich, 2020). Vaccine hesitancy, in turn, can have detrimental effects on participants' children's health if it leads to delay/denial of HPV vaccines. HPV is the most common sexually transmitted infection in the US, and over 50% of American teens have ever had sex (Abma and Martinez, 2017).

Beyond the lack of manipulation/measurements, we must note that online surveys are limited in reflecting underserved populations that lack access to broadband Internet. However, smart mobile device ownership has increased among individuals from low-income households due to the greater affordability of such devices (Marler, 2018). Moreover, our online survey could be completed on either desktop or mobile devices. Notably, we did not include other dimensions of engagement, such as positive and negative reactions to vaccine-related posts. Although we developed a scale of mothers' active engagement with vaccine content to alleviate the limitations of passive exposure to vaccine content in prior studies, we acknowledge that the next step would be to expand this scale further to measure the valence of engagement.



Effects ^a	Initiation		Completion	
	Coef.(SE)	95% CI ^b	Coef.(SE)	95% CI
Indirect Effect (Engagement with anti-vaccine content → Vaccine hesitancy → HPV Vaccination Rates)	-0.09 (0.06), <i>Sig</i> ^c	(-0.24, -0.01)	-0.10 (0.05), <i>Sig</i>	(-0.22, -0.02)
Direct Effect (Engagement with anti-vaccine content → HPV Vaccination Rates)	-0.35 (0.22), <i>p</i> = .11 (<i>n.s.</i>) ^c	(-0.79, 0.08)	-0.15 (0.17) <i>p</i> = .38 (<i>n.s.</i>)	(-0.49, 0.19)

^a We used a nonparametric bootstrap estimation approach with 10,000 samples via the SPSS macros PROCESS (Model 4) implemented by Hayes.

^b The PROCESS model reports the *p* values only for the direct effect, but *not* for the indirect effect. The significance of the effect is determined by the confidence intervals. The indirect effect is inferred to be zero if the null of zero falls between the lower and upper bounds of the 95% CI, and it is inferred to be nonzero (and thus significant) if it falls outside the CI (Hayes, 2017).

^c *Sig* = significant, *n.s.* = not significant

Fig. 3. Mediation test results.

4.4. Suggestions for future research and conclusion

Addressing these limitations in a future study is complex because of methodological and ethical barriers, as noted in the prior section. To lower these barriers, future researchers may consider developing a multimethod approach by combining a survey, retrospective data collection, and automatic classifications of vaccine posts collected from various social media sites. A multimethod approach involves 1) a population-based survey (like this study); 2) retrospective and instant collection of the respondents' social media engagement data (with their informed consent); 3) automatic classification of their engagement by a machine-learning algorithm (to represent the objective impact of social media content on vaccination rates); and 4) a statistical testing model that combines heterogeneous data from 1), 2), and 3).

Firstly, a future researcher may want to survey a sample representing US population groups (e.g., adolescents' parents, as in this study) to obtain socioeconomic statuses, geographic locations, and other data that one cannot otherwise harvest from social media due to privacy policies. Simultaneously, to overcome respondents' dishonest or biased answers, future researchers should harvest respondents' objective engagement with vaccine posts from social media sites with respondents' explicit consent. In so doing, future researchers may use retrospective data collection, in which they instantly collect the past few years of the respondents' engagement with vaccine posts to alleviate concerns about respondents' behavioral modifications that may occur when they know that they are being watched. Given the sheer amount of retrospectively collected data, future researchers may consider automatically classifying the retrospectively collected data using a machine learning algorithm.

In addition, as our findings show that Asian race group has the highest immunization rates, future researchers are recommended to examine the differences among the minimum of five racial groups (e.g., (American Indian or Alaska Native, Asian, Black or African American, Native Hawaiian or Other Pacific Islander, and White)) instead of the binary classification as in white vs. non-white individuals. Identifying

differences among all five groups will aid in the development of vaccination campaigns tailored to the needs of a specific group. Also, future researchers are recommended to consider expanding our scale of engagement such that the scale includes the valence or direction of engagement (e.g., positive, or negative).

Credit author statement

Young Anna Argyris: Conceptualization, Methodology, Investigation, Resources, Writing – original draft, Writing – review & editing, Supervision, Project administration, Funding acquisition. Yongsuk Kim: Methodology, Validation, Formal analysis, Writing – original draft and Writing – review & editing, Visualization. Alexa Roscizewski: Writing – original draft, Writing – review & editing. Won Song: Investigation, Resources, Funding acquisition.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.socscimed.2021.114043>.

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