Maternal Engagement with Vaccine-Skeptical and Advocating Content on Social Media and Their Adolescent Children's HPV Vaccination Rates: A Web- and Mobile-Based Survey among US Mothers of Adolescents

Young Argyris, Yongsuk Kim, Won Song, Alexa Roscizewski

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Young Argyris[1] PhD; Yongsuk Kim[2] PhD; Won Song[1] PhD; Alexa Roscizewski[3] MA

[1]Michigan State University East Lansing US
[2]Sungkyunkwan University Seoul KR
[3]University of Delaware Newark US

Corresponding Author:
Young Argyris PhD
Michigan State University
404 Wilson Road
East Lansing
US

Abstract

Background: The propagation of vaccine misinformation during the COVID-19 pandemic suggests that the pandemic may pose long-term harm on public health via depressed immunization rates. Between February 2020 and April 2020, the uptake rates of the HPV vaccine have decreased by 73%. Missing the critical age for HPV vaccination (i.e., 11-12 years old) will make adolescents susceptible to HPV-associated cancers in the next 20-30 years. Despite the importance, very few pro-vaccine interventions conducted on SM have succeeded in increasing HPV vaccination rates.

Objective: Our overall objective is to identify the reasons why anti-vaccine messages effectively lower HPV vaccination rates while pro-vaccine messages do not increase such rates. In so doing, we suggest that overarching vaccine hesitancy is a reason for the discrepant outcomes of anti- vs. pro-vaccine SM posts. Our objective is pursued in two specific aims: we compare anti- and pro-vaccine posts in terms of (i) their roles in fostering overarching vaccine hesitancy among mothers (the main HPV vaccine decision-makers), and (ii) accompanying HPV vaccination rates among their adolescent children.

Methods: In late December of 2019-mid January of 2020, we conducted a population-based survey among 426 mothers of US adolescents aged 13–18. The outbreak of the novel coronavirus in China occurred in December 2019, and awareness regarding the virus was increasing in the US during this time. Therefore, our data collected during this time allow us to infer the impact of increasing overarching vaccine hesitancy on HPV vaccination rates, while excluding the effects of access restrictions to healthcare facilities imposed since March of 2020. We developed a rigorous scale for engagement with anti- and pro-vaccine SM posts, measured adolescents' HPV vaccination rates along the series initiation to completion, and conducted path analyses to assess the associations among them.

Results: Our survey results show that mothers' engagement with anti-vaccine content is negatively associated with their children's HPV vaccine vaccination rates via their increased overarching vaccine hesitancy. In contrast, maternal engagement with pro-vaccine SM content is not associated with either overarching vaccine hesitancy or HPV vaccine vaccination rates. These results remained significant after controlling for socioeconomic, demographic, and accessibility factors, suggesting that mothers' engagement with anti-vaccine messages on SM explains above and beyond what other known factors explain.

Conclusions: Our results suggest that increasing overarching vaccine hesitancy, heightened by the infodemic, can substantially reduce HPV vaccination rates, even after accessibility factors are controlled. Our results imply that the negative impact of the COVID-19 pandemic can be extended for many years to come through depressed HPV vaccination rates. As a result, there is an urgent need to develop interventions to increase HPV vaccination rates and to address vaccine hesitancy among mothers who feel emotionally challenged during the pandemic. Clinical Trial: N/A

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INTRODUCTION

Background and Specific Aims

In 2018, the HPV vaccine completion rate was 53.7% and 48.7% among adolescent females and males, respectively [1], far below the Healthy People 2020 targets of 80%. HPV is a cause of cervical cancer and mortality among underserved women [2]. Over 70% of HPV-associated cancers occurring in the US could have been prevented by the current HPV vaccines [2]. The stagnant HPV vaccine delivery rate has attracted considerable attention towards the influential role that vaccine-skeptical social media content plays in reducing HPV vaccine delivery [3,4]. As a result, efforts have been made to disseminate HPV vaccine-advocating content via social media to counteract the skeptical content [5,6]. While these interventions have increased the general awareness and knowledge about HPV and HPV vaccines, only a few have succeeded in increasing vaccination rates [7]. For instance, 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 [8].

Our overall objective is to identify how adolescents' mothers' engagement with vaccine-skeptical versus advocating social media content is associated with their decisions' about vaccinating their children against HPV. In so doing, we investigate how maternal vaccine hesitancy catalyzes (i.e., mediates) the potential impact of vaccine-skeptical versus advocating content on US adolescents' HPV vaccination rates. Vaccine hesitancy is defined as a delay or refusal to be vaccinated, despite the accessibility of vaccination services [9,10]. In particular, we focus on maternal overarching vaccine hesitancy toward the broad vaccine system based on distrust in healthcare and the government [11] and concerns about vaccine safety [12–14]. Our choice of this broad definition of vaccine hesitancy also helps us expand the implications of our findings to the plethora of vaccine misinformation and increasing vaccine hesitancy during the COVID-19 pandemic [15].

Our objective is pursued in two specific aims: We compare vaccine-skeptical and advocating social media posts in terms of (i) their roles in fostering overarching vaccine hesitancy among US adolescents' mothers, and (ii) HPV vaccination rates among their adolescent children. While several prior studies were dedicated to the communities of pro- or anti-vaccine activists on social media [16–19], less is known about adolescents' mothers' engagement with vaccine-related content on social media, and subsequent vaccine hesitancy and their children's HPV vaccination rates [20]. Nonetheless, mothers make over 93% of HPV vaccination decisions for adolescents (both females and males) [21] and tend to trust social media content about parenting and health [20,22]. As such, there is *an urgent need* to examine how adolescents' mothers engage with vaccine-skeptical and advocating content on social media, and to examine their accompanying overarching vaccine hesitancy and their children's HPV-vaccination rates.

Vaccine-Skeptical vis-a-vis Advocating Content on Social Media

The danger of vaccine-skeptical social media posts and their potential associations with outbreaks are well documented [23] (**Figure 1)**. Johnson et al. [23] applied social network analysis to more than three billion Facebook users and showed the rapid growth of anti-vaccine activists' activities during the measles outbreaks of 2019, while pro-vaccine activists' activities were unchanged. While pro-vaccine tweets have declined since 2014, anti-vaccine tweets have doubled from 8.1 to 16% between 2015 and 2018 [24]. Engagement has been higher with vaccine-skeptical than with vaccine-advocating content [25,26]. Moreover, those who are exposed to vaccine-skeptical content are more likely to disseminate such content on social media [26,27] and are less likely to have their daughters vaccinated against HPV [12,28].

Prior research on HPV vaccine-advocating campaigns have yielded mixed results [7,29]. Some of these campaigns have had positive effects on knowledge, attitudes, and intention toward the HPV vaccinations, but have not had significant effects on the vaccination rates [7,30]. For instance, Cates et al. [31] 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.

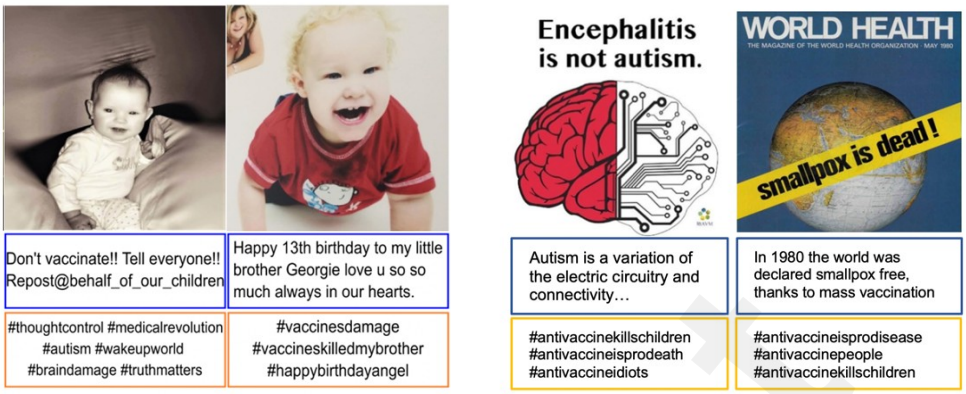


Figure 1. Examples of Vaccine-Skeptical versus Advocating Content on Instagram

Several researchers have recently compared the behaviors of pro- and anti-vaccine activists who engage with the formation and evolution of those respective communities on social media and how these individuals diffuse their views and exert influence on one another [16–19]. These prior researchers have concluded that individuals' existing views about vaccines lead to selective acquisition and consumption of social media content and subsequent reinforcement of their existing views about vaccines [16,18,23]. Especially, Schmidt et al. (2020) observed Facebook members of one anti-vaccine and one pro-vaccine groups, and found echo-chamber effects in regard to the members' content consumption and the evolution of each community.

Despite the seminal work done by these prior researchers on polarization, directly applying the findings from pro- and anti-vaccine clusters on social media to adolescents' mothers should be cautioned. It is unknown whether adolescents' mothers have clearly established consistent views

about HPV vaccines as pro- and anti-vaccine activists have [20]. Johnson et al. (2020) and Guess et al. (2020)'s studies showed that the majority of social media users are rather "undecided," and only small fractions constitute pro- and anti-vaccine activists. As such, it is unclear whether or not adolescents' mothers will demonstrate the polarized patterns of content acquisition and consumption similar to those of anti- and pro-vaccine activists' [20]. Therefore, it is important to compare between adolescents' mothers' engagement with vaccine-skeptical and advocating social media content in terms of mothers' vaccine hesitancy or their children's HPV vaccination rates. The lack of empirical studies is a barrier to our understanding of how vaccine-advocating and skeptical content indeed relates to the stagnant HPV vaccination rates among US adolescents [20]. We aim to close this gap in the current literature as shown in **Figure 2**.

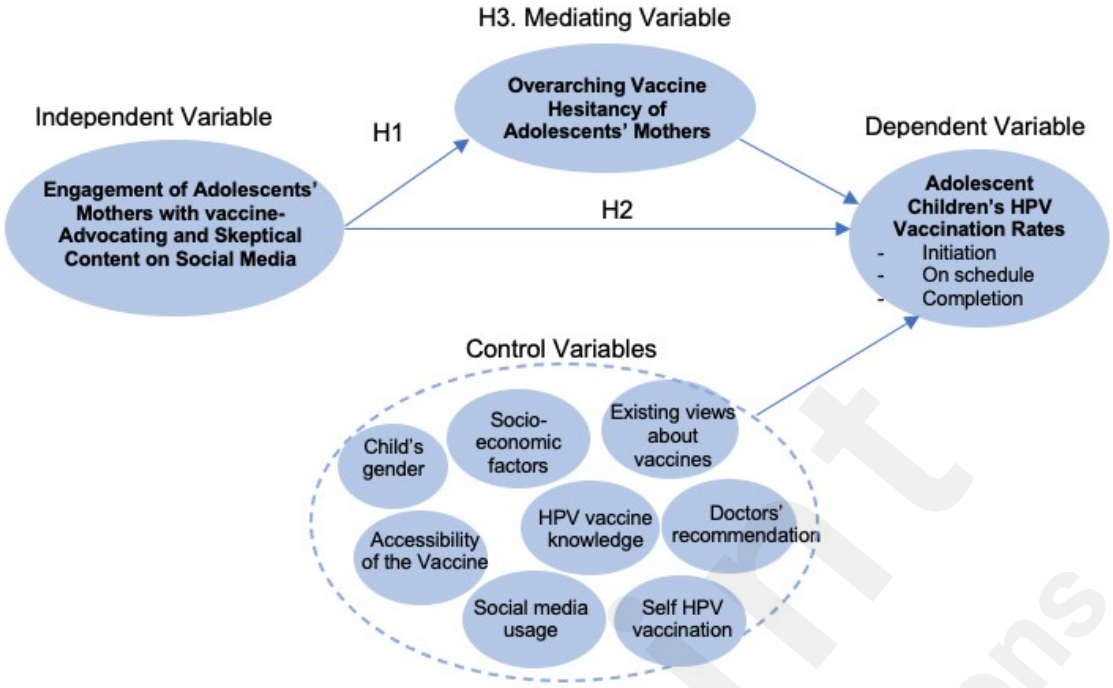


Figure 2. Research Model and Hypotheses

Maternal Engagement with Vaccine-Skeptical vis-à-vis Advocating Content and Overarching Vaccine Hesitancy

The predominant cause of vaccine hesitancy is the individual risk–benefit assessments of vaccination [32]. Anti-vaccine activists affect these assessments by questioning the safety of vaccines, thereby exacerbating parents' concerns about injuries [33] and by fostering the false belief that maintaining a healthy lifestyle can supplant the need for vaccinations [34]. As a consequence, mothers who engage with vaccine-skeptical content are likely to perceive the safety risks to be greater than the benefits. This disproportionate assessment of the risks to the benefits increases their overarching vaccine hesitancy [7].

However, this explanation does not extend to why engagement with vaccine-advocating content does *not* decrease mothers' overall vaccine hesitancy; vaccine-advocating content highlights the benefits, just as vaccine-skeptical content emphasizes the risks. The concept of framing in terms of loss versus gain is useful for explaining the discrepant outcomes from vaccine-advocating content [35,36]. A gain-framed message presents the benefits of performing a behavior, while a loss-framed message emphasizes the costs of doing so. Prior research indicates that loss-framed messages are

more effective for promoting risk-detection behaviors in comparison to gain-framed messages [37]. Vaccine-skeptical content is framed in terms of risks (e.g., dramatized anecdotes about vaccine injuries) to attract audiences' attention to the risks before the benefits [38]. Dixon [39] conducted an online experiment, albeit not on social media, and found that vaccine content mentioning an adverse consequence from vaccination led individuals to assume that the harm from vaccination was permanent, thus generating negative emotions.

Furthermore, in uncertain, emotionally difficult situations, individuals' tendency to avoid losses increases, while their tendency to seek gains decreases [35,40,41]. For an emotion-laden decision concerning their children's welfare, mothers' loss aversion increases disproportionately to their gain seeking [42]. Given an emotionally challenging task in a controlled experiment, such as making decisions about their children's health, participants' tendency to choose a status-quo option (wherein they refuse to take any action) increased disproportionately with regard to their choices of options that increased the benefits [43]. Based on this experiment result, we argue that, as a result of the loss aversion intensified by emotional vaccination decisions, mothers are likely to become more receptive to the risks of vaccines portrayed in vaccine-skeptical content than to the benefits described in vaccine-advocating content. As such, we expect the following:

Hypothesis 1.1: Mothers' engagement with vaccine-skeptical content is positively associated with their overarching vaccine hesitancy.

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

Vaccine-Skeptical vis-à-vis Advocating Content and HPV Vaccine Uptake Rates

Gain-and-loss message framing again provides a valuable lens through which we can identify a relationship between maternal engagement and adolescents' HPV vaccination rates. In particular, parents respond differently to message frames based on whether they focus on the distant or immediate future [44]. Individuals react more positively to gain-framed content than to loss-framed

content when they are focused on the distant future [45]. In contrast, they react more to loss-framed content when they are focused on the immediate future than to gain-framed content [44,45]. This shift has important implications on parents' HPV vaccination decisions. Immediate goals for HPV vaccines include avoiding a fear of needles and pain at the injection site [46,47] and presumably the inconvenience of visiting a healthcare facility for "well-visits" (e.g., regular checkups for children without an immediate or urgent medical need). When mothers pay more attention to these immediate costs and inconvenience, they are less likely to focus on the benefits of long-term prevention.

Furthermore, as shown in **Figure 1** above, vaccine-skeptical content is framed in terms of "personalized" dramatizations of injuries, while vaccine-advocating content is framed in terms of benefits for the broader society, such as creating herd immunity [38]. 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 [45]. 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 vaccine-skeptical content is negatively associated with their adolescent children's HPV vaccination rates.

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

Overarching Vaccine Hesitancy as a Mediator between Engagement with Vaccine-Skeptical Content and HPV Vaccination Rates

We assert that overarching vaccine hesitancy mediates the relationship between mothers' engagement with vaccine-skeptical posts and their children's HPV vaccination rates. We do not argue for an equivalent role of vaccine hesitancy for vaccine-advocating posts, given that we have posited that no association exists between vaccine-advocating content and overall vaccine hesitancy (H1.2) or HPV vaccination rates (H2.2). As we argue in H1.1 and H2.1, vaccine-skeptical content frames vaccines as being harmful in the immediate personal future, thus distorting maternal assessments of

the risks and benefits. As such, maternal engagement with vaccine-skeptical content is associated with increases in overarching vaccine hesitancy and with decreases in adolescent children's HPV vaccination rates. As a consequence, we propose that overarching vaccine hesitancy is a mediator between mothers' engagement with vaccine-skeptical content and their children's HPV vaccination rates.

Although prior studies have not yet identified the mediating role of overarching vaccine hesitancy in the HPV vaccination context, vaccine hesitancy has been often inferred as an interference with immunization in general [48–51]. Prislin et al. [52] demonstrate that safety concerns expressed in vaccine-skeptical content increase negative attitudes toward vaccines, which in turn result in less up-to-date immunizations. In Prislin et al.'s study [52], 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 in the prior studies [48–51], we argue that mothers' engagement with vaccine-skeptical social media content has a negative association with their children's HPV vaccination rates through overarching vaccine hesitancy.

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

METHODS

From late December 2019 to mid-January 2020, we conducted a web- and mobile-based survey among 426 mothers of US adolescents. An *a priori* power analysis requires 395 respondents to reach a power of 0.94 at the .05 significance level, with a medium effect size (0.50) [53]. Accordingly, our sample included 426 mothers of US adolescents aged 13–18. We hired an online panel service provider, Qualtrics, that maintains respondent pools across diverse US population accounts. The vendor contacted their respondent pools to identify a sample that met our selection criteria; Qualtrics incentivized the survey respondents based on their agreements. An 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; a consent was obtained from each respondent before they proceeded to the questionnaire. Qualtrics prevented multiple entries from the same individuals by checking their panel ID, which remains 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, using US census data. These selection criteria included wide ranges in education, household income, insurance, ethnicity, and region of residence. **Table 1** includes the factors pertinent to HPV vaccination among our respondents: the gender of the eldest child about whom they answered the questions (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 justified our choice of mothers as the survey's respondents. In regard to social media use, over 91% of respondents stated that they use social media, which aligns with the 2019 report from Edison Research (288/436, 91.1%). On average, they spend 166.1 minutes per day on their preferred social media sites (Standard Deviation (SD)=176 minutes). Therefore, our sample represents our target population in the US, allowing us to generalize the findings from our survey to this population.

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%
	Master's degree or higher	55	13%

Ethnicity/race	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 minutes	148	34.7%
	1–3 hours	115	27.0%
	3–6 hours	60	14%
	6 hours 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	8%
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 (8.9%) and those who said that they did not use any social media (8.5%). 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.

Furthermore, we chose mothers of adolescents aged 13–18 because we operationalized three levels of HPV vaccination delivery: initiation (whether children have begun the vaccination series),

on schedule (whether children are receiving the series in a timely manner, following recommendations from the CDC), and completion (whether children have completed the series). The 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; however, 13-year-olds should have started the series. 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 legally under parental care.

As shown in **Table 2,** we conceptualized mothers' engagement with vaccine-skeptical and advocating content in terms of endorsing, promoting, conversing, and composing. We developed a new scale for engagement and distinguished it from "passive exposure," which has often been used in prior studies [27]. In the contexts of social media vaccine debate, Johnson et al. (2020) and Guess et al. (2020) have shown that undecided individuals actively search for vaccine-related information, in contrast to the common notion that they would be passively exposed to and persuaded by such content. Following these studies, we developed a new instrument for active engagement distinguished from passive exposure.

To measure vaccine hesitancy, we revised Opel and colleagues' pre-validated instrument [54]. Using the age of the respondent's child, the number of doses received, and the year of the latest dose received (all of which were reported in the questionnaire), we operationalized HPV vaccination rates at three progressive levels of vaccine delivery, as shown in Table 2.

Table 2. Operationalization of the Variables and Scales Used

Engagement with Vaccine-Skeptical Content on social media (developed based on Schivinski et al. [55])
The respondent was asked to answer the following survey items on a five-point scale (1 = Never, 2 = once/month or less, 3 = a few times/month, 4 = a few times/week, and 5 = once/day or more).
[AV1] How often do you REACT (like, thumbs up or down, love, laugh, angry, wow, cry) to posts that contain CONCERNS about vaccines on SM sites? [AV2] How often do you COMMENT on others' social media posts that contain CONCERNS about vaccines? [AV3] How often do you SHARE content that contains CONCERNS about vaccine safety on SM sites? [AV4] How often do you POST content that contains CONCERNS about vaccine safety on SM sites?
Engagement with Vaccine-Advocating Content on social media (developed based on Schivinski et al. [55])
The respondent was asked to answer the following survey items on a five-point scale (1 = Never, 2 = once/month

or less, 3 = a few times/month, 4 = a few times/week, and 5 = once/day or more).			
[PV1] How often do you REACT (like, thumbs up or down, love, laugh, angry, wow, cry) to posts that advocate the BENEFITS of vaccines on SM sites? [PV2] How often do you COMMENT on others' social media posts that advocate the BENEFITS of vaccines on SM sites? [PV3] How often do you SHARE content that advocates the BENEFITS of vaccines on SM sites? [PV4] How often do you POST content that advocates the BENEFITS of vaccines on SM sites?			
Vaccine Hesitancy: Revised from Opel et al. [54]			
The revised instrument for vaccine hesitancy has three questions on a five-point scale (1 = strongly disagree, 3 = neutral, and 5 = strongly agree).			
[VH1] I have hesitated or felt reluctant to get a vaccination for my child. [VH2] I have delayed having my child get a vaccine for reasons other than illness or allergy. [VH3] I have refused having my child get a shot for reasons other than illness or allergy.			
Three Levels of HPV Vaccination Rates			
1. Initiation: 0 (no) versus 1 (Yes)—those who have begun the series. 2. Completion: 0 (no) versus 1 (Yes)—those who answered that they have completed the series. 3. On schedule: 1 (no dose received), 2 (Out of schedule), or 3 (On schedule) defined as:			
Age	On schedule (Assigned a value of 3)	Out of schedule (Assigned a value of 2)	None (Assigned a value of 1)
13	Received at least one dose in total and received one in the past 12 months	Received at least one, but did not receive any in the past 12 months	Received none
14	Received at least two doses in total and received one in the past 12 months	Received at least one, but did not receive any in the past 12 months	Received none
15 or above	Completed the series (3 doses)	Received at least one, but did not complete the series	Received none

We added 13 *control variables* that could negatively or positively affect HPV vaccination rates, including socioeconomic statuses, accessibility, HPV vaccine knowledge, child's gender, mothers' own HPV vaccination statuses, healthcare providers' recommendations, social media usage behaviors, and mothers' existing views about vaccines (**Table 3**).

Table 3. Control Variables

Area	Variable	Definition
HPV Vaccine	Accessibility	We measured the extent to which the respondent agrees or disagrees with the following statements about HPV vaccine availability on a five-point scale (1=strongly disagree, …, 5=strongly agree)[56]. [AC1] Access to the HPV vaccine is conveniently located for me. [AC2] The process of becoming immunized against HPV is welcoming. [AC3] I feel confident that the health clinic or doctor's office will have the HPV vaccine I need when I need it. [AC4] HPV vaccines are difficult to get because of the schedule [reverse]. [AC5] The cost of an HPV vaccine would prevent me from getting it, even if I felt I or my child needed it [reverse]. This instrument covers five dimensions of vaccine accessibility with respect to location, pleasantness of the processes, vaccine availability, schedule convenience, and price. We therefore created five separate control variables.
	Knowledge about HPV vaccine	Respondents' perceived knowledge about HPV vaccines (1 = not at all, …, 5 = extremely knowledgeable) [28].
	HPV vaccine self-received	Whether the respondent herself (i.e., mother) received the HPV vaccine (1=Yes, 0 =No).

		We controlled this factor because those who vaccinated themselves against the HPV may already have positive views about the vaccine [57].
	Doctor's recommendation	Whether the child's primary healthcare provider (doctor, nurse practitioner, or doctor's assistant) ever recommended the HPV vaccine for the child (1=Yes, 0 =No) [58]. The primary healthcare provider's recommendations have been found as a significant predictor of HPV vaccination rates [59], thus controlled.
Demographics	Age (Child)	The age of the respondent's child.
	Gender (Child)	The gender of the respondent's child (1 = Female, 0 = Male)
	Race/ethnicity	The race of the respondent. We used the US Census classifications.
	Region	The region of the US where the respondent currently resides. Geographical pockets of low HPV vaccine coverage were reported [27]; thus, controlled.
Socio-Economic Status	Education Level	The highest level of education that the respondent completed (1=Less than high school, 2=Completed high school, 3= Some College or associate degree, 4= Bachelor's degree, 5= Master's degree or above), following the US Census classifications.
	Health Insurance	The respondent's current health coverage (0=Uninsured, 1= Medicaid/Medicare/Military-provided, 2=Private).
	Household Income	The respondent's annual household income from all sources (1=Less than $50,000, 2=$50,000 - $99,999, 3=$100,000 - $149,999, 4=$150,000 - $199,999, 5=$200,000 or more), following the US census.
SM Usage Patterns (SM)	Subscription to vaccine-skeptical accounts	Whether the respondent has ever subscribed to any social media group or account that has concerns about vaccines (1=Yes, 0 =No). This factor was used as a control variable because subscribing to vaccine-skeptical content suggests potentially preestablished negative views about the vaccine. Given strong echo-chamber effects reported [16–19], this variable was controlled [60].
	Subscription to vaccine-advocating accounts	Whether the respondent has ever subscribed to any social media group or account that advocates the benefits of vaccines (1=Yes, 0 =No). This factor was controlled for the same reason as above.
	Daily SM Use time	The number of minutes the respondent spends PER DAY on the social media site that he/she uses most often (1=1 hour or less than 1 hour, 2=1-3 hours, 3=3-6 hours, 4=above 6 hours). This factor was used as a control due to substantial variance in the usage time (mean=166, SD=172 minutes) among users.

Throughout the survey, we implemented several techniques to alleviate the common limitations of survey methodology, such as social desirability, recall, and common method biases [61]. First of all, we clearly defined vaccine-skeptical and advocating content before the respondents were presented with any questions about them, and repeated these definitions in each question as shown in Table 2. Second, we included quality checks to prevent the common method bias whereby respondents do not pay attention to the survey instructions and instead choose a neutral option (e.g., three on the five-point scale). In particular, our quality check question was "I am paying attention while filling in this questionnaire," on a five-point Likert scale with 1 being "I strongly disagree to this statement," 3 being "neither agree or disagree," and 5 being "strongly agree to this statement." Those who chose 3, 2, and 1 were not allowed to proceed to the next questions. Third, we included a

warning about the inclusion of these quality check questions in the survey to encourage our respondents to answer the questions conscientiously. These instructions functioned as warnings rather than screeners because only a few of our respondents failed to pass these questions.

RESULTS

Reliability and Validity

The descriptive statistics of the key variables including correlations are reported in **Appendix A**. We measured and tested the reliability and the discriminant and convergent validity of our scales —i.e., engagement with vaccine-skeptical/advocating content, and vaccine hesitancy. Our testing results indicate that all three instruments are reliable and valid (**Table 4**).

Table 4. 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 Vaccine-Skeptical 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-Advocating 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***

For the statistical analysis, we used Hayes' PROCESS tool (Model 4), which is an ordinary least squares and logistic regression path analysis tool for estimating direct and indirect effects in mediation models [62]. 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 [63]. An exception is the correlation between engagement with vaccine-skeptical and advocating content (0.84). This high correlation suggests that mothers consider both sides of views about vaccine. These results are in alignment with the prior studies, such as Johnson et al. (2020) and Guess et al. (2020). Undecided

individuals actively search for vaccine-related information [19]. 84% of Guess et al.'s (2020) participants visit vaccine-related websites annually. Table 5 shows the patterns of information search by adolescents' mothers on social media. 302 out of 426 mothers (71% of our sample) have been engaged with either side of vaccine debate. 176 out of these 302 mothers (58%) engaged with both sides of the debate. 126 out of these 302 (42%) engage disproportionally with one side of the debate: 61 out of these 126 mothers (52%) were more engaged with vaccine-advocating content, while 65 of them (48%) more with vaccine-skeptical content.

Table 5. Mothers' Engagement with Vaccine-Skeptical and Advocating social media Content

Engagement with vaccine-skeptical content[a]	Engagement with vaccine-advocating content[b]						
	0	1	2	3	4	Total
0[a]	124	20[c]	0	0	0	144
1	33[d]	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 Table 2 for the four questions about engagement.
[c] Dark-shaded cells: Those who engage more with vaccine-advocating content
[d] None-shaded cells: Those who engage more with vaccine-skeptical content

This high correlation between the two, 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 vaccine-skeptical content and the other for vaccine-advocating content.

Hypothesis Testing Results

Hypotheses 1.1 and 1.2 concern the association between maternal engagement with vaccine skeptical (H1.1) versus advocating (H1.2) posts and overarching vaccine hesitancy. **Table 6** presents our H1 testing results. Model 1 shows our testing result of H1.1; Model 2 shows that of H1.2. Model 1 illustrates that the coefficient for engagement with vaccine-skeptical content is significant and positive (0.23, p = .002); Model 2 demonstrates that the coefficient for engagement with vaccine-advocating content is *not* significant at the 0.05 significance level (0.07, p = .39). Thus, these results support Hypotheses 1.1 and 1.2.

Table 6. Results of Regression on Vaccine Hesitancy

	M1: Vaccine Hesitancy (Engagement with vaccine-skeptical content)			M2: Vaccine Hesitancy (Engagement with vaccine-advocating content)		
	Coefficient	SE[c]	*P* value	Coefficient	SE	*P* value
Constant	4.11	0.63	<.001	4.52	0.66	<.001
Accessibility: Location	-0.08	0.09	.37	-0.12	0.10	.22
Accessibility: Welcoming	-0.21	0.06	<.001	-0.22	0.06	.001
Accessibility: Availability	-0.10	0.09	.27	-0.08	0.10	.40
Accessibility: Schedule	-0.16	0.06	.01	-0.16	0.06	.02
Accessibility: Price	-0.02	0.06	.75	0.00	0.06	.99
Knowledge about HPV Vaccine	0.15	0.05	.006	0.17	0.06	.003
HPV Vaccine Self-received	-0.21	0.13	.12	-0.10	0.14	.47
Doctor Recommended	-0.14	0.15	.34	-0.19	0.15	.21
Child's Age	-0.06	0.03	.08	-0.08	0.03	.02
Child's Gender	0.10	0.10	.33	0.06	0.11	.58
Education Level	0.09	0.07	.20	0.08	0.07	.27
Health Coverage	0.00	0.13	.98	0.01	0.13	.96
Household Income	-0.04	0.05	.44	-0.04	0.06	.49
Race: Asian[a]	-0.22	0.22	.31	-0.43	0.24	.08
Race: White	-0.03	0.14	.82	-0.03	0.15	.84
Race: African American	0.10	0.17	.57	0.07	0.19	.70
Race: Multiracial	0.27	0.28	.33	0.24	0.28	.39
Race: Other	-0.10	0.45	.82	-0.10	0.45	.83
Region: Northeast[b]	-0.04	0.15	.82	-0.01	0.16	.94
Region: Midwest	0.21	0.14	.13	0.15	0.14	.30
Region: West	0.21	0.15	.15	0.33	0.16	.04
Subscription to vaccine-skeptical accounts	0.58	0.26	.03	0.80	0.26	.003
Subscription to vaccine-advocating accounts	-0.65	0.23	.005	-0.62	0.25	.01
Daily Social Media Use Time	0.03	0.05	.58	0.06	0.06	.28
Engagement with Vaccine-Skeptical Content	**0.23**	**0.07**	**.002**			
Engagement with Vaccine-Advocating Content				**0.07**	**0.08**	**.39**
R-squared	0.1932			0.1870		
MSE	1.0334			1.0393		

[a] Race reference group = Hispanic or Latino; [b] Region group reference = South; [c] SE = Standard Error

Hypotheses 2.1 and 2.2 concern associations between maternal engagement with vaccine-skeptical (H2.1) / advocating (H2.2) posts and HPV vaccination rates. We ran OLS regressions instead of PROCESS because PROCESS does not report the direct effects of the independent variables when the dependent variable is binary, as in the case of our vaccine initiation and completion. **Table 7** reports the regression results for initiation, on schedule, and completion in Models 1, 2, and 3, respectively. The coefficient for engagement with vaccine-skeptical posts is significant for initiation (-0.49, p = .04 in Model 1) and completion (-0.46, p = .03 in Model 3) at the significance level (α) of 95%, and marginally significant for staying on schedule (-0.10, p = .051 in Model 2) at the significance level (α) of 90%.

Table 7. Results of Regression on Vaccination Rates (Engagement with vaccine-skeptical content)

	M1: Initiation			M2: On Schedule			M3: Completion		
	Coef[c]	SE[d]	*P* value	Coef	SE	*P* value	Coef	SE	*P* value
Constant	-10.10	2.15	<.001	-1.16	0.44	.008	-11.79	1.88	<.001
Accessibility: Location	0.16	0.26	.55	0.01	0.07	.83	0.08	0.23	.73
Accessibility: Welcoming	0.99	0.19	<.001	0.22	0.04	<.001	0.64	0.16	<.001
Accessibility: Availability	0.52	0.25	.04	0.11	0.06	.09	0.29	0.23	.21
Accessibility: Schedule	0.08	0.19	.69	0.04	0.04	.32	0.31	0.16	.05
Accessibility: Price	0.09	0.19	.63	0.02	0.04	.62	0.06	0.15	.72
Knowledge about HPV Vaccine	-0.06	0.18	.72	0.01	0.04	.69	0.15	0.14	.30
HPV Vaccine Self-received	2.05	0.59	.001	0.36	0.09	<.001	1.42	0.40	<.001
Doctor Recommended	2.25	0.41	<.001	0.60	0.10	<.001	1.33	0.38	<.001
Child's Age	0.27	0.10	.009	0.10	0.02	<.001	0.35	0.09	<.001
Child's Gender	-0.01	0.32	.98	0.05	0.07	.53	0.37	0.27	.17
Education Level	-0.26	0.20	.19	-0.04	0.05	.42	-0.33	0.17	.05
Health Coverage	-0.12	0.40	.77	-0.11	0.09	.21	-0.14	0.32	.67
Household Income	-0.15	0.16	.34	0.02	0.04	.60	0.10	0.14	.46
Race: Asian[a]	2.07	0.93	.03	0.47	0.16	.004	1.16	0.57	.04
Race: White	-0.24	0.41	.55	-0.03	0.10	.73	-0.02	0.35	.96
Race: African American	0.74	0.57	.19	0.23	0.13	.07	0.63	0.48	.19
Race: Multiracial	0.42	0.86	.63	-0.07	0.19	.73	-0.35	0.72	.63
Race: Other	0.47	1.63	.77	0.23	0.30	.44	1.85	1.32	.16
Region: Northeast[b]	1.49	0.57	.009	0.17	0.11	.11	0.56	0.41	.17
Region: Midwest	-0.28	0.41	.49	0.00	0.09	.97	0.08	0.35	.81
Region: West	-0.28	0.43	.52	-0.08	0.10	.42	0.15	0.39	.70
Subscription to vaccine-skeptical accounts	-0.68	0.88	.44	-0.19	0.18	.28	-0.86	0.78	.27
Subscription to vaccine-advocating accounts	3.28	1.05	.002	0.48	0.16	.002	2.32	0.77	.003
Daily Social Media Use Time	-0.21	0.16	.21	-0.04	0.04	.28	-0.14	0.15	.34
Engagement with vaccine-skeptical Content	**-0.49**	**0.24**	**.04**	**-0.10**	**0.05**	**.051**	**-0.46**	**0.21**	**.03**
R-Squared	0.4043			0.3656			0.2972		

[a] Race reference group = Hispanic or Latino; [b] Region group reference = South; [c] Coef = Co-efficient; [d] SE = Standard Error

Table 8 reports the results of engagement with vaccine-advocating posts (Models 1, 2, and 3). The coefficient for engagement with vaccine-advocating content is not significant in any of the three HPV vaccination rates: initiation (-0.22, p = .38 in Model 1), on schedule (-0.04, p = .41 in Model 2), or completion (-0.05, p =.79 in Model 3). Taken together, the results provide strong evidence for Hypothesis 2.1 and 2.2.

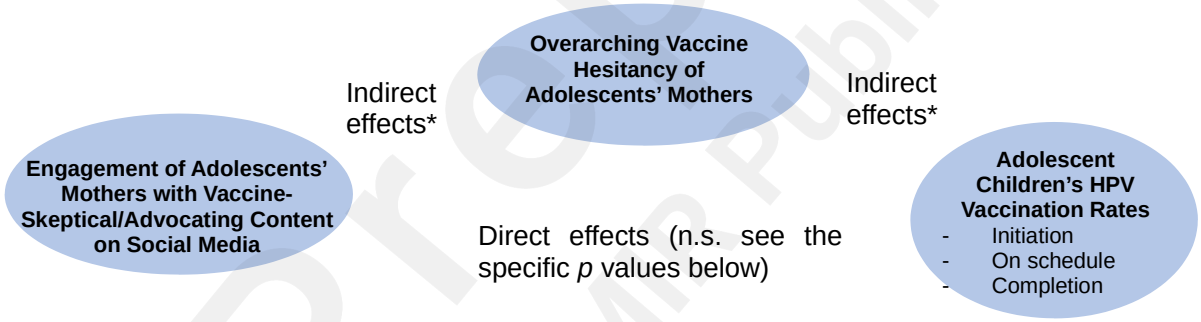
Table 8. Results of Regression on Vaccination Rates (Engagement with vaccine-advocating content)

	M1: Initiation			M2: On Schedule			M3: Completion		
	Coef[c]	SE[d]	*P* value	Coef	SE	*P* value	Coef	SE	*P* value
Constant	-10.35	2.14	<.001	-1.14	0.42	.007	-10.87	1.68	<.001

Accessibility: Location	0.14	0.26	.59	0.01	0.06	.85	0.08	0.21	.71
Accessibility: Welcoming	0.97	0.19	<.001	0.23	0.04	<.001	0.57	0.15	<.001
Accessibility: Availability	0.50	0.25	.047	0.11	0.06	.07	0.27	0.22	.21
Accessibility: Schedule	0.11	0.19	.57	0.04	0.04	.34	0.29	0.14	.04
Accessibility: Price	0.09	0.19	.63	0.01	0.04	.70	0.07	0.14	.59
Knowledge about HPV Vaccine	-0.07	0.18	.68	0.01	0.04	.84	0.09	0.13	.47
HPV Vaccine Self-received	1.97	0.59	.001	0.27	0.09	.003	0.79	0.34	.02
Doctor Recommended	2.25	0.41	<.001	0.58	0.10	<.001	1.26	0.35	<.001
Child's Age	0.29	0.10	.006	0.09	0.02	<.001	0.30	0.08	<.001
Child's Gender	0.01	0.33	.98	0.05	0.07	.44	0.32	0.25	.19
Education Level	-0.24	0.20	.23	-0.01	0.04	.74	-0.23	0.16	.15
Health Coverage	-0.20	0.40	.61	-0.12	0.08	.14	-0.18	0.30	.55
Household Income	-0.14	0.16	.39	0.02	0.04	.60	0.12	0.13	.34
Race: Asian[a]	2.11	0.93	.02	0.44	0.15	.003	1.14	0.50	.02
Race: White	-0.23	0.41	.58	-0.04	0.09	.65	-0.02	0.33	.96
Race: African American	0.72	0.56	.20	0.11	0.12	.35	0.31	0.41	.45
Race: Multiracial	0.38	0.85	.65	-0.05	0.19	.80	-0.22	0.69	.75
Race: Other	0.44	1.62	.79	0.20	0.30	.50	1.77	1.28	.17
Region: Northeast[b]	1.43	0.56	.01	0.11	0.10	.30	0.11	0.37	.76
Region: Midwest	-0.26	0.41	.53	-0.03	0.09	.77	0.05	0.33	.88
Region: West	-0.32	0.43	.45	-0.10	0.10	.29	-0.12	0.35	.74
Subscription to vaccine-skeptical accounts	-0.99	0.86	.25	-0.28	0.17	.10	-1.47	0.74	.049
Subscription to vaccine-advocating accounts	3.18	1.06	.003	0.47	0.16	.004	1.96	0.73	.008
Daily Social Media Use Time	-0.24	0.17	.15	-0.02	0.03	.47	0.00	0.12	.98
Engagement with vaccine advocating Content	**-0.22**	**0.25**	**.38**	**-0.04**	**0.05**	**.41**	**-0.05**	**0.18**	**.79**
R-Squared	0.3973			0.3416			0.2469		

[a] Race reference group = Hispanic or Latino; [b] Region group reference = South; [c] Coef = Co-efficient; [d] SE = Standard Error

H3 states that global vaccine hesitancy mediates the association between maternal engagement with vaccine-skeptical content and the children's HPV vaccination rates. We tested whether the mediating effect of vaccine hesitancy is significant using Hayes' PROCESS Model. **Figure 3** reports that the indirect effect of engagement with vaccine-skeptical content on initiation (–0.09), as mediated by vaccine hesitancy, is statistically significant at a 95% confidence interval (CI) (–0.18, –0.01). The indirect effect is also significant in the cases of on schedule (–0.02, 95% CI –0.05, –0.01) and completion (–0.08, 95% CI –0.19, –0.02). In contrast, the direct effect of engagement with vaccine-skeptical content is nonsignificant on initiation (–0.28, $p = .14$), on schedule (–0.03, $p = .41$), and completion (–0.00, $p = .98$). The results of the indirect and direct effects suggest that vaccine hesitancy fully mediates the relationship between engagement with vaccine-skeptical content and HPV vaccination rates. Taken together, the results support Hypothesis 3.



Effects[a]	Initiation		On Schedule		Completion	
	Coef.(SE)	95% CI[b]	Coef.(SE)	95% CI	Coef.(SE)	95% CI
Indirect Effect (Engagement with vaccine-skeptical content à Vaccine hesitancy à HPV Vaccination Rates)	-0.09 (0.06), *Sig*[2]	(-0.25, -0.01)	-0.03 (0.01) *Sig*[2]	(-0.06, -0.01)	-0.10 (0.05), *Sig*[2]	(-0.23, -0.02)
Direct Effect (Engagement with vaccine-skeptical content à HPV Vaccination Rates)	-0.39 (0.24), $p = .11$ (n.s.)[c]	(-0.87, 0.08)	-0.06 (0.05), $p = .21$ (n.s.)	(-0.16, 0.04)	-0.16 (0.19), $p = .39$ (n.s.)	(-0.54, 0.21)

[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 [62].

[c] n.s. = not significant

Figure 3. Mediation Test Results

Robustness Checks to Account for Echo-Chamber Effects and Platform Effects

We undertook three robustness tests to rule out alternative explanations. First, one may raise the concern that parents have chosen not to vaccinate their children because they already hold strongly negative views about HPV vaccines, and not because they are engaged with vaccine-skeptical social media posts. To resolve this concern about echo-chamber effects or polarization, we excluded respondents who had subscribed to vaccine-skeptical and advocating accounts on social media. Subscriptions to pro- or anti-vaccination accounts mean that respondents opted to receive updates for any new one-sided posts regarding the vaccine debate by an account on social media (**Appendix B**). The hypothesis testing results remain unchanged, which alleviated potential concerns about echo-chamber effects.

Second, the ways in which mothers engage with vaccine-skeptical content may vary across social media platforms and may affect respondents' HPV vaccination decisions. We tested whether the results hold, irrespective of the type of social media in use (**Appendix C**). 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 = Yes if Facebook was chosen; 0 = No), and included it in the model. Controlling for Facebook did not affect the results, indicating that our results were not subject to the type of SM in use.

DISCUSSION

Summary and Discussion of the Findings

The results from our population-based survey among 426 mothers of adolescents supported all of our hypotheses that mothers' engagement with vaccine-skeptical content is significantly associated with increases in their overarching vaccine hesitancy (H1.1) and decreases in their children's HPV vaccination rates (H2.1). In contrast, maternal engagement with vaccine-advocating social media content is not associated with either overarching vaccine hesitancy (H1.2) or HPV vaccine vaccination rates (H2.2). Overarching vaccine hesitancy plays a mediating role (H3) such

that mothers' engagement with vaccine-skeptical content is negatively associated with their children's HPV vaccination rates *via their increased overarching vaccine hesitancy*. These results remained significant after controlling for socioeconomic, demographic, and accessibility factors, suggesting that mothers' engagement with vaccine-skeptical content on social media explains above and beyond what other known factors explain. Moreover, these results remained significant after controlling for factors relevant to echo-chamber effects [16]. That is, the elimination of those respondents who subscribe to vaccine-skeptical and advocating accounts on social media did not change our hypothesis testing results. We interpreted these contrasts between vaccine-skeptical and advocating social media posts by recognizing the notion of loss aversion.

It is important to note that the majority of demographic, socioeconomic, and accessibility factors were *not* significantly associated with either overarching vaccine hesitancy or HPV vaccination rates. In particular, most of the factors related to access barriers such as convenience of the location, availability of the vaccine, and price were not significantly associated with either vaccine hesitancy or HPV vaccination rates in any of the models. One exception was "whether the vaccination processes are welcoming," which was significant in all three hypothesis tests (p = or < .001). The significance of the welcomeness of a vaccination process suggests that increasing trust in healthcare providers is critical for a socially sensitive topic like HPV vaccinations as shown in prior studies [22]. In a study conducted on mothers of 11- and 12-year-old girls, interactions with healthcare providers became a prevalent theme in mothers' decision to move forward with the HPV vaccination [65]. In another study, open-ended interviews with new mothers postpartum and when their infant was 3 to 6 months of age found that trust or lack of trust and the relationship they perceived with their pediatrician influenced their choice to vaccinate their child [66]. The mistrust in medical authorities and their vested interests in the medical industry play significant roles in patients' vaccination decisions [22]. The significant effects of the welcomeness of a vaccination process demonstrates the importance of fostering trust between healthcare providers and patients in

increasing HPV vaccination rates.

Contributions and Public Health Implications

Our study provides empirical evidence on the mediating role of overarching vaccine hesitancy that catalyzes an association between mothers' engagement with vaccine-skeptical and advocating content and their children's HPV vaccination rates. In alignment with prior studies on loss aversion [43], our results show that mothers' overarching vaccine hesitancy plays a critical "bridging" role between their engagement with vaccine content and their decisions to vaccinate their children against HPV.

The significant role of mothers' overarching vaccine hesitancy aid in the developments of future interventions. Granted, prior studies have shown clear patterns of polarization and echo-chambers among anti- and pro-vaccine activists such that they selectively consume content congruent with their existing views [16–18]. For this reason, future intervention efforts must consider "backlash" that can occur when individuals are presented with information incongruent with their existing views [67]. In addition to debiasing those individuals with strong views against vaccines, public health officials and researchers alike can consider targeting mothers who have not yet firmly established vaccine hesitancy and are actively looking for information to make vaccination decisions for their children. Interventions for mothers should center around increasing their digital health literacy [20], by providing them with inoculation [68], education [69], and fact-checkers [70,71]. These methods can "inoculate" them against vaccine misinformation that fosters vaccine hesitancy, and enable adolescents' mothers to acquire and consume balanced, credible content about vaccines.

Limitations

Like any other research, this study has several limitations. First and foremost, the well-known limitations of survey methodology must be noted. Self-reported methods, such as surveys, suffer from social desirability, recall, and common method biases [61]. As our chosen method is a survey,

our study is not free from these well-known limitations. Nonetheless, surveys can compensate potential weaknesses of direct observations of social media user behaviors. In particular, surveys can capture respondents' perceptions (such as vaccine hesitancy) and collect socioeconomic and demographic factors, and respondents' children's HPV vaccination statuses (collections of which are banned by the stringent social media privacy settings). Thus, we tried to minimize the limitations of surveys by avoiding potentially judgmental terms (e.g., anti-vaxxers) that could invoke social desirability, repeating the definitions of important terms, and including quality checks to prevent common method biases. Second, online surveys may be limited in reflecting underserved populations that lack access to broadband Internet. However, in recent years, smart mobile device ownership has increased among individuals from low-income households due to the greater affordability of such devices [72]. Also, our online survey could be completed on either desktop or mobile devices, and thus did not exclude mobile device users. Lastly, we should note that our cross-sectional study may involve endogeneity issues. Nonetheless, we included 13 control variables and conducted two robustness checks to alleviate these limitations.

Suggestions for Future Research and Conclusion

Our limitations summarized above suggest directions for future researchers. Future researchers may consider a multi-method approach wherein both a self-report method and a direct observation from social media sites are employed in such a way that one can compensate the other's potential weaknesses. For instance, direct observations from social media can lessen the concerns about social desirability, recall, and common bias problems associated with survey methodologies, while surveys can capture broader ranges of respondents' characteristics that cannot be collected from direct observations Also, future researchers are recommended to conduct longitudinal studies and/or in vivo experiments to strengthen the causal relationships between mothers' engagement with vaccine-skeptical social media content and their children's HPV vaccination rates over time. Researchers may expand their investigations to other crucial vaccines (Covid-19 and flu) to avert

vaccine-preventable epidemics.

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Supplementary Files

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