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A Protocol of a Pilot Experimental Study Using Social Network Interventions to Examine the Social Contagion of Attitudes Towards Childhood Vaccination in Parental Social Networks

PRE-REGISTRATION

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ABSTRACT

Increasing vaccination hesitancy that burdens global health and safety can be attributed to multiple reasons. Individuals' social environment seems to be the catalyst for vaccination hesitancy perpetuation, thus it is important to examine the influence of different social network mechanisms in vaccination attitudes' contagion. The proposed pilot experiment will examine the social contagion of childhood vaccination attitudes within a parental community using social network interventions. By identifying centrally-located people or groups of like-minded individuals from a parents' community, we will examine whether the position of a person within a social group can have a greater impact in spreading positive vaccination messages to other community members. Parents will be recruited from social media and will be randomly assigned into three groups. Firstly, each group will participate in an online game to map their social networks and identify members with certain network position, who will then receive a short training about valid vaccination information provisions. All groups' members will participate in daily vaccination discussion groups for one week, where the selected members will spread positive vaccination attitudes to others. We hypothesize that centrally located individuals and like-minded group of people will more likely cause a change on the childhood-vaccination attitudes and will sustain a long-term change at 3 months follow-up, compared to randomly located people.

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INTRODUCTION

Vaccinating an infant or a child is an important decision for parents and caregivers worldwide. From the first two months of a child's life, parents are advised to vaccinate their children against more than 20 infectious diseases, like tetanus, measles, diphtheria and other life-threatening diseases (European Centre for Disease Control and Prevention, 2022; World Health Organization, 2020). Despite the availability of vaccinating services almost worldwide and the national vaccination recommendations by health care providers and professional associations, there is a proportion of parents who refuse to comply with these guidelines resulting in diseases outbreaks (Salmon, Dudley, Glanz & Omer, 2015). A notable example is the measles outbreak in 2017 that had affected more than 21.000 people and led to 35 deaths worldwide (World Health Organization, 2018). This measles outbreak happened despite the availability of a vaccine to prevent the risk of getting infected or spreading it to other people and as a result of non-vaccinated children. Therefore, it is of great importance to identify the reasons underlying vaccine hesitancy of parents to childhood vaccination.

Vaccine hesitancy is widely examined but remains a complicated and insufficiently understood concept. The SAGE Working Group on Vaccine Hesitancy suggested that vaccine hesitancy occurs when parents for various reasons delay or deny vaccinations even if there is vaccine availability (SAGE, 2014; MacDonald & SAGE, 2015). They also categorized vaccine hesitancy reasons into three distinct clusters: 1) *Contextual Influences* (i.e., historic, socio-cultural, environmental, health system, political factors), *2) Individual/ Group Influences* (i.e., individual, social, peer factors), and *3) Vaccine Specific Issues* (i.e., vaccine or vaccination factors). Several studies and theories have further explored factors that might influence parents' attitudes towards childhood vaccination including vaccines' side effects, mistrust towards doctors, perceived lack of vaccines' necessity, and vaccines' ineffectiveness (Dyda, et al., 2020; Gidengil, et al., 2019).

The Health Belief Model (HBM; Glanz & Bishop, 2010; Jones, Jensen, Scherr, Brown, Christy, & Weaver, 2015), presupposes that perceived vulnerability, benefits, efficacy, and obstacles can explain parents' actions to immunize their children (Cheung et al., 2015; Gargano et al., 2013; Gilkey et al., 2016; Radisic et al., 2017; Reiter et al., 2009; Smith et al., 2011). It is also suggested that parents' attitudes and behaviors can be affected by their social environment as well, like family, friends, or other social groups (Brewer et al., 2017; Christakis & Fowler, 2013; Jones et al., 2015; Gargano et al., 2013; Radisic et al., 2017).

Diffusion of ideas, thoughts, behaviors, and attitudes in social networks has been the core of the *Social Contagion Theory* (Christakis & Fowler, 2013). This approach, primarily originating from a social network perspective, presumes that social contagion takes place between at least two people from the same social group (e.g., family, friends, or other social contacts): the *ego*, that is a person with certain attitudes, and the *alter*, another person with different attitudes. After frequent and close contact and communication it is anticipated that the ego will take on the alter's opinion, or vice versa (Burt, 1987; Scherer & Cho, 2003; Smith & Christakis, 2008). This hypothesis was tested in several studies that aimed to understand the role of social networks in the contagion of attitudes towards various health-related issues, like vaccinations (Brunson, 2013; Christakis & Fowler, 2010; Nyhan et al., 2012), depression (Bastiampillai et al., 2013; Rosenquist et al. 2011), drug use (Ali et al., 2011; Mednick et al., 2010), smoking (Campbell et al., 2008; Christakis & Fowler, 2008; Cobb et al., 2010), obesity (Christakis & Fowler, 2007; Cohen-Cole & Fletcher, 2008), happiness (Fowler & Christakis, 2008), and loneliness (Cacioppo et al., 2009).

There is also a growing research interest to identify and explore the specific processes or mechanisms of a social network that might influence the contagion of positive attitudes within a community (Valente, 2012; Latkin & Knowlton, 2015). By using network intervention programs, researchers aim to manipulate different features of a social network and examine to what extent they can cause changes in attitudes, or behaviors (Badham, Kee, & Hunter, 2018; 2021; Campbell et al., 2008; Centola, 2010; Kim et al., 2015; Shirado et al., 2013). One approach used to model change in members' connections and at the same time change in individual behaviours is the Stochastic Actor-Oriented Models (SAOMs) estimated using the SIENA (Simulation Investigation for Empirical Network Analysis) software (Snijders, 2001; Snijders et al., 2010). Studies using this approach have indicated the salience of social networks in delinquent behaviour (McMillan et al., 2018), marijuana use (Barnett et al., 2022), internalizing behaviour and victimization (Neal & Veenstra, 2021), obesity (Smith et al., 2020) among others allowing to determine co-evolution of behaviours and relationships over time.

Valente (2012) proposes four perspectives (i.e., individual, segmentation, induction, alteration) that can be used to design social network interventions to influence a behavior change, although only two of them will be utilized in the present pilot study*: the individual and the segmentation approach.* In the *Individual* approach, the goal is to detect important people based on their *structural position* within a network. Those key individuals are then used in a network intervention to transmit a desired belief or behavior to their social contacts by applying various processes of behavior modification. It is proposed that *centrally* located people might more easily and quickly pass on their attitudes across a social

network (Campbell et al., 2008; Christakis & Fowler, 2008; 2013; Perkins et al., 2015; Rosenquist et al., 2011; Valente et al., 2004). In the *Segmentation* approach, clusters of individuals are detected within a social network as a starting group to implement an intervention and achieve behavior change at a group level (Badham et al., 2021; Valente, 2012). People perceive themselves as part of a community that has certain beliefs and attitudes and when a change happens at a group level is more likely to transfer to the individual (Pagkas-Bather et al., 2020; Valente, 2012).

These two approaches will be utilized in the study since they can be more easily translated into strategies used for public health interventions. Also, two recent review studies supported the effectiveness of using these social network interventions for promoting and changing several health-related behaviors (Hunter et al., 2019; Shelton et al., 2019). The most effective intervention technique was the individual approach since it has successfully allowed the spread of positive health behaviors through the influence of central members in a social network (Hunter et al., 2019). As for the segmentation approach which is the least examined (Hunter et al., 2019; Shelton et al., 2019), it was found to be efficient in spreading positive health behaviors by engaging group interaction and enhancing social learning (Pagkas-Bather et al., 2020).

The majority of these aforementioned studies focus on promoting healthy sexual behaviors and substance use cessation, but none have examined vaccination attitudes and uptake. Taking into consideration the great influence of social contacts on spreading vaccination attitudes to others (Brewer et al., 2017; Christakis & Fowler, 2013; Gargano et al., 2013; Jones et al., 2015; Konstantinou et al., 2021; Radisic et al., 2017), the application of different social network interventions might facilitate the examination of how they might affect the contagion of ideas and beliefs within a social community.

RESEARCH OBJECTIVES AND HYPOTHESES

The general purpose of the present pilot study is to experimentally examine the contagion of positive attitudes towards childhood vaccination within a parental community using social network interventions. Network intervention programs focus on manipulating different features of a social network (e.g., centrality, clusters) and examine to what extent they can affect the contagion of attitudes or behaviors in a social network (Badham, Kee, & Hunter, 2018; 2021; Centola, 2010; Kim et al., 2015; Shirado et al., 2013). In order to achieve this, the present study will evaluate how different mechanisms of social networks (i.e., centrality, clusters) influence the social contagion of positive childhood vaccination attitudes.

The research objective will be to examine whether the position of a person within a social community (i.e., centrally-located, clusters) will have an impact on how efficiently positive attitudes toward childhood vaccinations are transmitted. The *first hypothesis* is that members of the individual group (i.e., centrally-located people) will more likely contribute to a change upon other members' attitudes about childhood vaccines, in relation to the segmentation (i.e., group of connected people) and the control group (i.e., randomly selected members). *The second hypothesis is* that members of the segmentation group will more likely cause a change on others' attitudes toward childhood vaccination, in relation to the control group. *The third hypothesis* is that members of the individual and segmentation group will more likely sustain a change at 3 months follow-up, in relation to the control group.

METHODS

STUDY DESIGN AND PROCEDURES

The present pilot study is part of the "SAFEST: Tackling anti-vaccination: mapping the Social contagion of beliefs and attitudes" research project. It is funded by the Cyprus Research and Innovation Foundation (RIF) and approved by the Cyprus National Bioethics Committee (#EEBK EH 2019.01.131) and investigates with novel methodologies the social spread of vaccination beliefs and attitudes. This study will be conducted in two steps: network building and randomized-controlled laboratory experiment. All materials for this study are available at https://osf.io/vyt74.

Step 1: Network building

This step will include participants' recruitment, screening, random assignment to three groups, observation of each group's interaction and social network building.

Participants' recruitment, screening, and randomization. Participants will be approached using multiple recruitment methods. Initially, different parenthood-related Facebook groups (e.g., mamadescy, attachment parenting) will be used and people will be informed through a post to participate in an awareness session about childhood vaccines (Appendix A). At the end of the awareness session, they will be informed about this study's goals and procedures and asked to participate by completing the online screening questionnaire (see measures section). Additionally, the research team will be distributing flyers (Appendix A) to parent in pediatricians and gynecologists offices, administrative and academic stuff of Cypriot universities, private and public hospitals, playgrounds and parks, private kindergartens and parents associations of pre-primary and primary education. The flyers will include information about the study's purpose and procedures and a link (or QR code) to complete the online screening set of scales.

A sample size calculation revealed using the R 4.3.1 statistical software was performed. Specifically, an

approximated sample size on an average effect size was calculated based on other effect sizes reported from previous studies. A systematic review and meta-analysis (Hunter et al., 2019) that collated evidence on social network interventions for health behaviours and outcomes was used to extract the odd ratios (OR) reported for each health-related behavior for all the interventions in order to calculate the Cohen's d from each OR using the computation of effect sizes (Lenhard & Lenhard, 2016). The larger OR was 3.97 indicating a Cohen's d estimate equal to 0.7602 and the smaller OR was 1.31 indicating a Cohen's d estimate equal to 0.1489. Therefore, the range of the reported effect sizes was from 0.1489 to 0.7602. We calculated the average effect size which was equal to 0.45455. The required sample size for linear mixed effects model with 3 groups, a power equal to 0.80 and a medium effect size (Cohen's d) of 0.45455 was 51 individuals per group and hence a total sample size of 153 participants is needed for all three groups.

The recruitment process will be terminated when each of the three groups consists of 51 members. Each group will purposively consist of equivalent number of members who are positive, hesitant and negative towards vaccination, based on their PACV score (Opel et al., 2011). Thus, the research team will aim to balance the attitudes in each group to avoid one group for example consisting of a majority of positive members and compromising the effect of the network intervention tested. Dropout rates in previous longitudinal randomized controlled trials was estimated to be around 20% (Bell et al., 2013; Cramer et al., 2016; Linardon et al., 2017). Thus, it is expected that at least 10 people from each group might dropout at any arm of the study. In order to remedy that, participants will receive different incentives for joining the online game (e.g., person with the higher participation rate will receive 1 euro per day of joining the game) and for completing all parts of the study (e.g., people will enter in an online draw for several gifts).

After the screening, a minimum of 153 people will be selected who meet five inclusion criteria: 1) Are at least 18 years old, 2) Have at least one child aged from one month to 12 years old, 3) Own a computer or smartphone with internet access, 4) Are Greek-speakers, and 5) Provide informed consent and commitment to complete all parts of the study. After recruitment and screening, by using the Random Allocation Software (Saghaei, 2004), participants will be randomly assigned into three groups based on their vaccination attitudes level (i.e., positive believers, hesitant, or negative believers), which will be measured through the PACV scale (see measures section). The three groups are: a) *Individual group:* Centrally-located members will be identified, receive the short training = and transmit information and messages to their group's members, b) *Segmentation group:* Cluster of like-minded members will be identified, trained and transmit information and messages to their group's members, and c) *Random group*: Random members will be identified, trained and transmit information and messages to their group's members.

Participants' observation and network building. After formulating the groups, participants will interact daily for one week through the Breadboard Software Platform (McKnight & Christakis, 2016), which is used to build and run experiments on social networks of people by using domain specific language. Specifically, each group of participants will join in daily 15–20 minute online interaction games, with the aim of making as many friends (connections) as possible. Participants of each group will be assigned to a random position into the network and will be instructed to: 1) Create a personal profile (name, age, interests, children's age and gender), 2) Review other users profile, 3) Decide to connect (or disconnect) with other users based on a friendship criterion "Whether they would want to be friends with them in real life". As an additional plan, at the end of every interaction game, participants will answer two friendship nomination questions (see measures section). In addition, participants will be able to interact and communicate daily with their group's members through closed Facebook groups throughout the online game.

By the end of the week, a pre-analysis will be performed to map the social network of each group and related network characteristics. In the individual group, centrally-located members will be detected by using centrality measures (e.g., in-degree, betweenness), in the segmentation group, a cluster of like-minded members will be identified by through k-cliques, k-scores and k-plexes algorithms and for the random group, random members from each group will be identified. All selected members must have positive vaccination attitudes, which will be determined based on their vaccination hesitancy score (PACV; Opel et al. 2011) in the screening session.

Breadboard Pilot Testing: The online game was pilot tested using 50 undergraduate students who received an extra class credit as an incentive in a single session (game). Students were asked to enter breadboard through a link, to create their online profile (e.g., name, age, interests, etc.) and to connect with other users after reviewing their profile. Preliminary results showed that five members were identified as central (Figure 1a), a group of five members as cluster (Figure 1b), and five as random members (Figure 1c).

Step 2: Randomized-controlled laboratory experiment

The second step will last for one week. At the beginning of the week, the selected members of each group will join a 50-minute online group meeting through the Microsoft Teams ® app, in which they will receive the training. During the week, all members of each group will be requested to join in closed Facebook group to discuss about their worries, fears and opinions on childhood

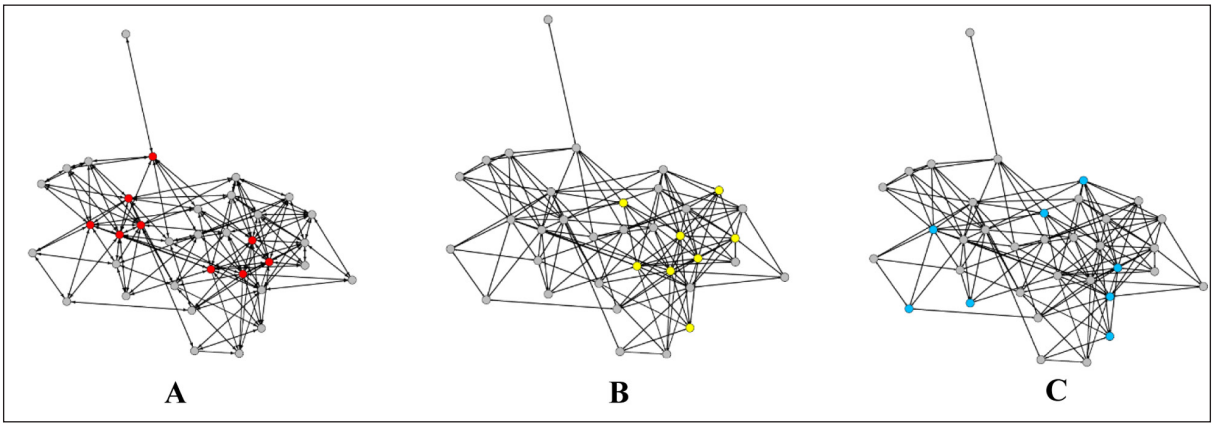

Figure 1 Preliminary results on breadboard pilot testing revealed: Central members **(A)**, Cluster of members **(B)**, and Random members **(C)**. *Note*: Dots = People; Lines = Connections; Colors = Selected individuals.

vaccinations. All participants will be requested to complete a package of questionnaires in the end of the intervention and in one follow-up session 3 months after the intervention ends.

Training session. The training will be delivered separately for the three group's selected members (i.e., individual, segmentation, and random) in a single-session. It will aim to train people to deliver values-based messages and valid vaccination-related information to others. During the session, at first participants will be educated on different childhood vaccination topics (e.g., childhood vaccination safety, effectiveness, importance and side-effects) and provided with valid and reliable knowledge about general childhood vaccines (like diphtheria-tetanus-pertussis, poliomyelitis, measles-mumps-rubella, etc.) so as to help them in the discussion groups to persuade others to change their beliefs. The material will be developed by two healthcare professionals from the Cyprus Medical Association. At the end of session, trained participants will also receive values-based messages about childhood vaccines to promote them to their groups. The messages will be developed based on the Values core component of the Acceptance and Commitment Therapy model (Hayes, Strosahl, & Wilson, 1999). Based on participants' answers on the values clarification exercise at the screening session, the five most important values will be chosen to create the messages.

Discussion groups. Each group's members will participate in discussion and interaction meetings through closed Facebook groups daily for one week. Researchers will create three different closed Facebook groups and invite members of each group to join. Everyday researchers will post general vaccine- and health-related information and participants will have to join the group daily and discuss their worries, fears, ideas, beliefs and attitudes. All discussion will be performed based on GDPR guidelines (i.e., participants' consent, rules of communication, and no personal data). Selected trained members will be instructed to deliver the values-based messages and vaccine related information through the daily discussion groups in order to influence and persuade their group's members to adopt positive attitudes toward vaccinations. All discussion sessions of each group will be monitored by members of the research team.

Expert, patient, and public involvement. The research team, throughout the development of the intervention, will consult an advisory panel of health care professionals,parents, researchers, academics, and other members of the community. The purpose of this advisory panel is to provide constructive feedback and contribute to the experiment's design and delivery based on their experiences and knowledge.

MEASURES

Two different sets of scales (one for the screening session and another for the other time-points) will be uploaded on an online survey platform (i.e., RedCap) and the link will be given to the participants to complete the questionnaires (see Table 1 for more information).

Socio-demographics

Information will be collected at the screening phase regarding age, gender, ethnicity, level of education, marital status, place of residence, and number and age of children.

Vaccine Hesitancy Scale (VHS; English version by Larson et al. 2015)

The VHS is a 26-item measure evaluating parental beliefs, attitudes and actions towards pediatric vaccinations. It consists of three parts: 1) Close-ended questions about reasons for vaccination hesitancy (Items 1–11), 2) Beliefs and attitudes about vaccinations (Items 12–21), and 3) Open ended questions about reasons for vaccination hesitancy (Items 22–26). Only the first part of the scale will be used in order to collect descriptive information about the reasons for vaccination hesitancy. The VHS is rated on different scales: 2-point (i.e., yes-no), 5-point (i.e., 1: strongly agree to 5: strongly disagree), and open-ended questions.

MEASURES	PURPOSE	COLLECTION TIME-POINTS		
		SCREENING SESSION	POST SESSION	3 MONTHS FU
Socio-demographics	Collect demographic information (e.g., age, gender, etc.)	X		
Vaccine Hesitancy Scale (Larson et al. 2015)	Only the first part of the scale will be used in order to evaluate the reasons for vaccination hesitancy or refusal.	X		
List of Parental Values	Created to evaluate participants' most important values and tailor the values-based messages.	X		
Parent Attitudes about Childhood Vaccines (Opel et al. 2011)	Identify participant's vaccination attitude level (positive, hesitant, negative). Evaluate change on vaccination attitudes at different time-points and groups.	X	X	X
Friendship nomination questions	Collect information to identify central people and cluster of like-minded people.	After each breadboard game session		

Table 1 List of measures.

Parent Attitudes about Childhood Vaccines (PACV; English version by Opel et al. 2011; Greek version by Fostiropoulou, 2018)

The PACV is a 15-item questionnaire identifying parents who have concerns about childhood vaccinations or are hesitant to vaccinate their children. It comprises three domains: Immunization behavior (Items 1–5), Beliefs about vaccine safety and efficacy (Items 6–12), and Trust (Items 13–15). It is rated on different scales: 3-point (i.e., yes-not sure-no), 5-point (i.e., 1: strongly disagree to 5: strongly agree) and 11-point (i.e., 0: not sure at all to 10: completely sure). Higher composite scores indicate more positive attitudes towards childhood vaccination. At the screening session, participants' composite PACV score will be utilized to identify participants' vaccination attitude level based on selected cut-off scores: 0–50 for negative, 51–70 for hesitant, and 71–100 for positive (Strelitz et al., 2015). It will be also used to evaluate a change on vaccination attitudes based on participants' composite scores. If the vaccination hesitancy level of the sample is low, the inter-quartile range of the median will be used to determine negative (lower quartile), positive (higher quartile), and hesitant (25% above and below the median) participants.

List of Parental Values

This list was created by the SAFEST research team to evaluate people's most important values as parents. Researchers created a pool of parenthood-related values by choosing values from previous research work by Stapleton and colleagues (2020) and Nicolaou and colleagues (2022). It consists of 24 different values (e.g., hope, faireness, accomplishment, kindness, creativity, etc.) that are related to parenthood and participants will have to choose five of the most important values as parents. The top five most important values of all participants will be used to tailor the vaccine-related messages, since there is evidence which shows that tailoring vaccine-related information on parents' parental values makes them less hesitant towards childhood vaccinations (Politi et al., 2017; Witteman et al., 2015; 2020).

Friendship nomination questions

Two friendship nomination questions were created by the research team as an additional measure to identify central members ("Name one person from your group that you would like to be friends with in real life") and clusters of like-minded members ("Name a group of people from your group that you would like to be friends with in real life").

STATISTICAL PLAN

DEALING WITH MISSING DATA

For evaluating the extent of missing data we will present the comparison of participants with and without full data on socio-demographic characteristics and experimental group membership (differential attrition). Assuming that missing data will be Missing-At-Random, we will use linear mixed models for the analysis, which along with the inclusion of good covariates minimizes bias (Little & Rubin, 2002). For the Stochastic Actor-Oriented Models, missing data are imputed by the mode for the simulations stage to allow for meaningful simulations. These values, however, are excluded at the parameter estimation stage, in line with Ripley et al. (2022).

STATISTICAL ANALYSES FOR NETWORK MAPPING

The analyses will rely on social network methodology. For each condition, we select N members, in which N is going to be determined the following way: (1) we take 15% of

the number of participating individuals in the largest of the networks at the data collection before the treatment, and (2) we round it up to the closest whole number. With 51 individuals in the largest network, this would be 6 people. We opt for selecting 15% following the suggestion of Kelly and Stevenson (1997) and Campbell et al. (2008) that 15% of the target group should be treated to achieve a critical mass for peer influence.

For selecting group members with central positions, we will select participants high in *in-degree centrality* and individuals high in *betweenness centrality*. In-degree centrality is the total number of nominations someone receives from others and is thus a good measure of someone's potential direct impact on the group (those with high in-degree centrality may influence many people directly because many consider them as a social contact). Betweenness centrality is based on the number of times someone is in a "bridge" position on the shortest path between two other individuals and is thus a good measure for the control of information flowing in the network (those with high betweenness centrality may influence many people because information from one person to another will often travel through them). Relying on in-degree centrality and betweenness centrality is a useful approach, as in-degree centrality expresses a more direct ability to influence others (many connections) and betweenness centrality expresses a more indirect influence (many shortest paths involve the person). This way, we can balance between these two types of centrality.

The procedure of selecting individuals will be as follows: The procedure will be as follows: (1) In the first step, we determine the number of treated individuals (N), see details in the first paragraph of this session. (2) Based on each centrality measure, we will rank all individuals separately. (3) We will take the sums of centrality scores for each individual and take the individuals with the N highest scores. (4) If there are people with equal scores for N^{th} place, we randomly select among them.

For selecting clusters of connected individuals, we aim at identifying groups of participants who have a large number of social ties between them, compared to the rest of the network. We identify a group through the following steps: (1) As we are looking for clusters of like-minded individuals, we first exclude those who do not have positive attitudes about vaccination. (2) We list largest group of fully connected individuals. If there are multiple groups with the same size, we randomly select one. If this group is larger in size than N, we randomly select N people from the group. If this equals N, we select all N people. In both cases, our procedure is complete. (3) If the largest group of fully connected people is smaller than N, we first start from this group. (4) We then add the person to group who has the largest number of ties with the current members of group. If there are multiple such people, we randomly select one. (5) We repeat Step 4 until we reach N. (6) In case our initial group was smaller than N, we repeat steps 2–5 1000 times due to the probable need for random selection in the process. We assess all 1000 outcomes and calculate how many ties the members of each of the 1000 potential groups share. We select the group that has the largest number of internal ties. If there are multiple groups with the largest number of ties, we randomly select one.

STATISTICAL ANALYSES FOR THE MAIN HYPOTHESES

We will use a linear mixed effects model to examine H1a, H1b & H1c to identify an effective change on others' attitudes toward vaccination, that segmentation group will more likely cause a change on others' attitudes toward childhood vaccination, in relation to the control group and that the members of the individual and segmentation group will more likely maintain a change at 3 months follow-up, in relation to the control group using the hesitancy score. Graphs will be used to present the change at 3 months follow-up, in relation to the control group.

Additionally, Social Network Analysis will be performed. First we will report densities and Jaccard indices. Densities show the proportion of social ties realized in a network compared to all possible ties. We compute this for each wave of each network and present it together with the average attitudes in the given wave and network. We also compute the Jaccard index, which expresses how much the network changes from one observation to another (by presenting the proportion of ties that exist in both data waves, compared to all ties that exist in at least one of the waves). We present the Jaccard index for each pair of consecutive data waves for each network.

Then, Stochastic Actor-Oriented Models (SAOMs) will be applied to model the co-evolution of social networks and attitudes towards vaccination. This way, 1) the effect of social ties on attitudes (i.e., social influence) will be tested, and 2) this effect will be substantively compared between the different experimental conditions. Whereas we may not have sufficient power to estimate significant social influence parameters in the social network model (based on Stadtfeld et al., 2020, the probability to successfully identify social influence should be higher than 29%), we will most likely be able to capture changes in the network structure based on changes in attitudes over time and based on the treatment itself, which will help us interpret our results on social influence (based on Stadtfeld et al. 2020, the probability to successfully identify social selection effects is higher than 97.5%). For instance, if members selected for treatment become more popular over time in the random condition, that could explain relatively small differences between the random and the central-members conditions.

Our SAOMs will have the following model specification:

Selection (Dependent variable: friendship nomination questions)

Independent variables:

1. Outdegree (density)
2. Reciprocity (recip)
3. Transitive triplets (transTrip)
4. Transitive reciprocated triplets (transRecTrip)
5. Indegree popularity (inPop)
6. Outdegree popularity (outPop)
7. Outdegree activity (outact)
8. Treated ego, alter, same
9. Vaccination attitudes ego, alter, similarity (egoX, altX, simX)
10. Age similarity (simX)
11. Same marital status (sameX)
12. Same place of residence (sameX)
13. Similarity in number of children (simX)

Influence (Dependent variable: attitude)
Independent variables:

14. Linear shape (linear)
15. Quadratic shape (quad)
16. Degrees (indeg, outdeg)
17. Own treatment status
18. Having treated friends (totSimW)
19. Average similarity (avSim)
20. Own age (effFrom)
21. Own marital status (effFrom)
22. Own number of children (effFrom)

We will also conduct Goodness of fit checks in line with Ripley et al (2022, pp. 59–60) for distributions of indegrees, outdegrees, triad census, and the behavioural variable (that is, attitudes) We will make appropriate changes in the model specification if our model does not show satisfying fit. In addition, we will perform Siena time tests (Ripley et al, 2022, pp. 202–203) to check whether there are significant variations between the modelled time periods. In case we see significant variations, we will use dummy variables to account for the differences. If the use of these so-called time dummies (and their interactions with other variables) proves insufficient to capture heterogeneity, we will model the time periods separately.

STUDY RISKS AND CONTINGENCY PLAN

For participants dropping out we will examine all decisions before drop out. Several measures will be undertaken to overcome risks (see Table 2 for more information).

STUDY IMPLICATIONS

Evidence from this study will inform on new approaches of delivering public health interventions. Individual interventions rarely reach population-level changes and thus there is an international challenge in achieving large-scale behaviour change which considers contextual and social factors (Davis et al., 2015). Social contagion evidence is crucial because the cumulative impact of health behaviour changes and interventions can be measured not only for the individual but also in combination with impact in other individuals of their social network (Christakis, 2004). Social contagion data can therefore inform on the cumulative impact of health behaviour changes, maximise population-level behaviour change efficacy, enhance intervention diffusion (impact to non-participants) and achieve larger scalability through network targeting (Kim et al., 2015; Shakya et al., 2017). Diffusion is defined as influence that occurs when non-participants of an intervention are indirectly exposed through friendships with intervention participants (Rulison et al., 2015).

RISK	POTENTIAL PROBLEM	CONTINGENCY PLAN
Experiment's complexity	Compromising participants' recruitment and engagement	Using incentives, multiple recruitment procedures (social media, awareness sessions, pediatricians, health clinics, etc.) and a simplified intervention (i.e., short with fewer and simpler tasks and requirements).
Short online game for mapping connections	Might be difficult to create meaningful connections.	Adding nomination questions and daily interaction through closed social media groups.
Software game limitations	Unable to map a real and meaningful social network.	Running a pilot to evaluate strengths and weaknesses, and make the appropriate adjustments.
Unable to recruit participants with negative vaccination attitudes.	Might be difficult to detect significant impact in vaccination hesitancy after the intervention.	Multiple recruitment methods (hospitals, social media, schools, playground, parks etc.) to reach a more heterogeneous and representative sample of people. Incentives to motivate people that are hesitant to participate.

Table 2 Risks and Contingency Plan.

Monitoring if and how health promoting and harmful behaviours are diffused within networks can inform major challenges in preventing serious conditions such as achieving large-scale behaviour change and tackling prevention in a holistic way.

ADDITIONAL FILE

The additional file for this article can be found as follows:

- **Appendix A.** Awareness session's invitation. DOI: https://doi.org/10.5334/hpb.37.s1

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AUTHORS NOTE

The researchers recognize that they stem from a positive stance towards vaccinations and they support their benefits for the society and public health. The study was conducted during the COVID-19 pandemic where the use and distribution of vaccines has been discussed extensively in the society with polarizing views.

COMPETING INTERESTS

The authors have no competing interests to declare.

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